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SEASONAL EVALUATION OF THE EFFECTS OF CHEMICAL EFFLUENTS ON SELECTED WATER BODIES IN RIVERS STATE, NIGERIA:
A CASE STUDY OF CHOKOCHO AND OKULU RIVERS

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Abstract

This study evaluated the effects of chemical effluents discharge on selected water bodies (Okulu and Chokocho Rivers) in Rivers State, Nigeria. The sampling was conducted in the rainy and dry seasons. The water samples collected were analyzed for physicochemical parameters and heavy metal content. The results revealed that the rivers were neither acidic nor too alkaline in nature, with no significant seasonal variation in pH and dissolved oxygen levels of the rivers. Rainy season mean electrical conductivity levels were 61.90 and 1548.63 µs/cm for Chokocho and Okulu rivers respectively; dry season mean conductivity levels were 62.47 and 1933.49 µs/cm for Chokocho and Okulu rivers respectively. Rainy season mean chloride levels were 48.51 and 438.85 mg/l for Chokocho and Okulu rivers respectively; dry season mean chloride levels were 50.46 and 491.87 mg/l for Chokocho and Okulu rivers respectively. Rainy season mean Total PAHs were 3.55 and 601.57 mg/l for Chokocho and Okulu rivers respectively; dry season mean Total PAHs were 4.07 and 385.95mg/l for Chokocho and Okulu rivers respectively. Rainy season mean NO_3^- levels were 10.53 and 74.06 mg/l for Chokocho and Okulu rivers respectively; dry season mean NO_3^- were 10.64 and 69.27 mg/l for Chokocho and Okulu rivers respectively. Rainy season mean TDS levels were 52.11 and 618.88 mg/l for Chokocho and Okulu rivers respectively; dry season mean TDS were 50.52 and 1160.09mg/l for Chokocho and Okulu rivers respectively. Rainy season mean Oil and Grease levels were 5.10 and 288.01mg/l for Chokocho and Okulu rivers respectively; dry season mean Oil and Grease were 5.10 and 288.01mg/l for Chokocho and Okulu rivers respectively. Rainy season mean BOD levels were 4.05 and 9.25mg/l for Chokocho and Okulu rivers respectively; dry season mean BOD were 4.10 and 9.3mg/l for Chokocho and Okulu rivers respectively. Rainy season mean COD levels were 78.35 and 678.44 mg/l for Chokocho and Okulu rivers respectively; dry season mean COD were 77.74 and 616.62mg/l for Chokocho and Okulu rivers respectively. It was observed that approximately 85% of physicochemical components of Okulu River exceeded limits; 100% of heavy metals in Okulu River surpassed limit. About 20% of physicochemical components of Chokocho River exceeded limits; about 30% of heavy metals in Chokocho River surpassed limit. The study showed that the Okulu River is more polluted than Chokocho River which underscored the need for urgent government interventions to safeguard waterbodies in Rivers State from further deterioration.

Keywords:

Chemical Effluents, physicochemical components, heavy metals, rainy season, dry season.

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1.0 Introduction

The Niger Delta region is faced with significant environmental challenges due to extensive oil and gas and industrial related activities, leading to the discharge of treated and untreated effluents into surrounding water bodies (Aa *et al.*, 2022). Industrial effluents, generated from oil and gas production life cycle, continue to impact ecosystems and water resources despite technological advancements and regulatory frameworks (Singh & Shikha, 2019). Understanding the composition, sources, and environmental impacts of industrial effluents is crucial for effective pollution control and sustainable resource management in the Niger Delta region (Igbiri *et al.,* 2017).

Industrial wastewater effluents generated by chemical plants including petrochemical plants and petroleum refinery are often characterized by high concentrations of pollutants, which usually comprise of organic and inorganic compounds. The organic compounds contain in wastewater are mainly aliphatic and aromatic petroleum hydrocarbons, while the inorganic compounds are mostly heavy metals like mercury, lead, manganese, Nickel and other substances like Sulphur and phosphorus ((Srivastava *et al.,* 2019; Wei *et al*., 2020). Whenever an excess amount of heavy metals is discharged into a water source, the quality of the water decreases due to their chemical reactions and transformations (Wei *et al*., 2020). Consequently, heavy metals exposure to human may pose health risk. These substances usually have detrimental effects on plant and aquatic life as well as surface and ground water sources. Therefore, it become imperative to ascertain the effects of industrial wastewater discharges on the pollution level of receiving waterbodies. The daily discharge of high-volume effluents produced from industrial plants and the amount of hazardous substances contain in the effluents, even after treatment poses tremendous risk to the environment (Igbiri *et al.,* 2017).

When industrial wastewater effluents are discharged into a surface water body, pollutant constituents form a waterproof film on the surface water which prevents the exchange of oxygen between the environment and water causing damages to aquatic plant and animals as well as humans (Ray *et al.,* 2020). Some pollutants contain in industrial wastewater effluents effluent have been identified to be of concern to the environments and they include polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and heavy metals (Alshemmari, 2021).

Environmental pollution through industrial discharge of petroleum hydrocarbon-based effluents has been recently identified as one of the most significant problems in the world (Ifelebuegu *et al*., 2017). There is also increased health risk of exposure to people living around the industrial chemical effluents discharge into water bodies resulting in adverse health effects (Johnston *et al*., 2019). As a results disposal of industrial effluents, abattoir wastewater and sand mining activities in in water bodies in Rivers, there has been reports of water pollution in Okulu river Eleme LGA as well as Chokocho River in Etche LGA all in Rivers State resulting to fish kills, destruction of aquatic life such as loss of flora and fauna, eutrophication as well as making the water bodies unfit for both domestic and industrial purposes. Therefore, this study was carried out to assess and evaluate the extent of the impact of chemical effluents on the receiving water bodies in Rivers State, Nigeria.

2. Materials and Methods

2.1 Research Design

This study adopted quantitative experimental research design. This design is considered suitable for this study because the research investigated the impact of discharge of industrial chemical effluent on the pollution level of the surface waterbodies. The research design involves carrying out experimental procedures that comprise of sampling water from the rivers, laboratory analysis of collected samples for physicochemical parameters, and heavy metals. It also involves statistical analysis of data to obtain seasonal variations of the pollution levels.

2.2 Study Area

This study is carried out on two surface waterbodies of Okulu and Chokocho Rivers in Eleme and Etche Local Govern Areas (LGAs) respectively. This study was carried out on the Okulu and Chokocho Rivers, which stream are fresh water bodies in Aleto Community in Eleme and Chokocho community in Etche Local Government Area, Rivers State. The Okulu river is situated between latitude 4°48’32.7” North and Longitude 7°6’2” East; while the Chokocho River is located between latitude 4°59’37.3” North and Longitude 7°3’49.1”. Several anthropogenic activities that are potential wastes sources are found along the shore of the rivers. These anthropogenic activities include sand mining (Mechanical and manual dredging), cattle feed lot, vegetable gardening/Agriculture. The study area could be classified as industrial area, with scattered residential areas, because different types of industries.

The map of Nigeria showing the location of Rivers State and the study area is shown in Figure 3.1.

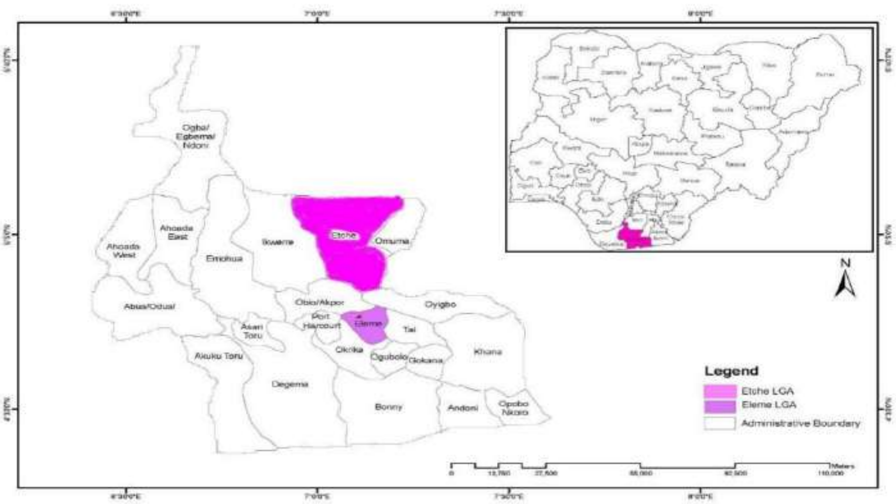

Figure 1: Maps of Nigeria and Rivers State showing the study area

2.3 Sample and Sampling Techniques

Sampling points were established and properly geo-referenced during the preliminary survey. In order to minimize errors during the sampling process, a standard operating procedure (SOP) was prepared for the sampling team. The SOP was strictly adhered to by the sampling personnel to ensure that samplings were carried out in accordance with recommended standard procedures for surface water sampling (Bartram & Ballance (1996). The field sampling was planned such that the current natural characteristics of the rivers' environment adequately captured and described to produce reliable data. These sampling techniques were employed in order to obtain data that are reliable and fit for the intended purpose and achieve the set objectives. Water samples were collected from the ten (10) points within the Okulu river and five (5) points within the Chokocho river. The number of sampling points on the Okulu river was more than that of Chokocho river because of the multiple activities taking place within the Okulu river. The sampling points within the Okulu River were located at distances 0 meters upstream of effluent discharge point and at distances of 50 meters to 500 meters downstream of effluent discharge point. The five sampling points within the Chokocho river were located at distances 100 meters apart. The samples were collected in triplets (three samples from each collection distance). The map showing the locations of the sampling points for Okulu River is shown in Figure 2; while the map showing the sampling points for Chokocho river is shown in Figure 3.

Figure 2: Map of Okulu River showing sampling points

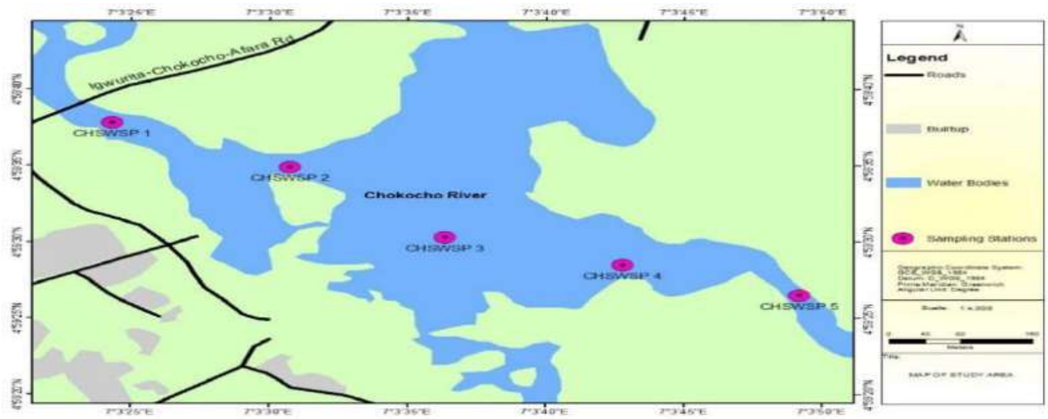

Figure 3: Map of Chokocho River showing sampling points

2.4 Methods of Data Collection/Instrumentation

Water samples were collected using clean, sterilized plastic sample bottles (500 mL to 1 L). the collected samples were preserved and stabilize using chemicals such as nitric acid (for heavy metal analysis) and sulfuric acid (for nutrient preservation). On-site measurements of pH, temperature, dissolved oxygen (DO), electrical conductivity, and turbidity were carried out with the aid of a multi-parameter instruments fitted with a probes. A bucket fitted with a rope was used to collect water from deeper sections of the river.

The surface water samples for the study were collected at each established sampling point along the river. Samples were collected at ten (10) points spaced at distances of 50m, 100m, 150m, 200m, 250m, 300m, 350m, 400m 450m and 500m. The sampling containers were properly washed, dried, corked with covers, well labeled and stored in ice packed cooler box under laboratory condition a day before the sampling date. Samples for PAHs were contained in glass bottles. This was to avoid contamination of containers. All sample containers were rinsed three times with the river water at each sampling point before samples are collected (APHA, 2012). The water samples were collected by hand lowering the sample containers below the water surface at the depth of 15-30 cm. The containers were completely submerged and allowed to fill to the bream with no air bubbles stroked inside and the covers were stoppered while under water. Each sample were treated accordingly as stated by standard procedure (APHA, 2012).

Samples collected from each point was thoroughly stored in a clean plastic container and well labeled prior to the analysis. Plastic containers were used to collect water for trace heavy metals analysis; while physicochemical analyses were placed in a 2-litre plastic container which was previously rinsed three times with the water sample to be analysed and sealed appropriately. The samples for polycyclic aromatic hydrocarbons (PAHs) and total organic carbon (TOC) measurements were placed in 1-liter glass containers concentrated hydrochloric acid (HCl) added and sealed with aluminum foil. While the samples for the heavy metal analyses were placed in 150ml plastic container concentrated nitric acid ($HN0_3$) added to adjust the pH to 2. Biochemical oxygen demand (BOD) samples were collected in 250ml brown reagent bottles, sealed to exclude air bubble; while the dissolved oxygen (DO) samples were fixed immediately with Winkler's I and II reagents. Thereafter, all the samples were stored in the ice packed cooler box and subsequently be transported to Laboratory for analysis.

2.5 Methods of Data Analysis

The analysis was carried out to determine the physicochemical components of the water bodies. This provides an understanding of the quality status of the rivers and the potential effects of anthropogenic activities such as effluent discharge on the water quality of the rivers. The exploratory assessment was performed by analyzing and comparing the measured parameters in water samples and sediment samples of the rivers with Federal Ministry of Environment (FMEnv) and World health organization (WHO) recommended permissible standards for the water quality parameters.

2.5.1 Determination of Physicochemical properties

The water samples were transported to the Laboratory for analysis. The physicochemical properties of water samples that were analyzed are Temperature, pH, total dissolved solids (TDS), Turbidity, and electrical conductivity (EC) were estimated using a water multimeter of HACH, USA (model: HQ-40D, CDC-401). Dissolved oxygen (DO) was estimated using a bench top Hanna Instruments meter (model: HI 5421). Subsequently, the water samples were acidified to pH between 2 and 3 using nitric acid (HNO3) in polypropylene bottles and stored at 4^oC for further analysis in the laboratory. Temperature of water samples was measured in degree Celsius (°C) with the aid of a scaled digital thermometer.

2.5.2 Determination of Polycyclic Aromatic Hydrocarbons (PAHs) Content

PAHs in water samples were determined by method of Gas Chromatograph - Flame Ionization Detector (GC-FID). The samples were treated and analysed for concentration of polycyclic aromatic hydrocarbon according to the US EPA method 8100. The Gas Chromatography (6890 series and plus) coupled FID-ECD as reported by Daka, and Ugbomeh (2013). The separation and detection of compounds in the samples were carried out using Agilent 6890N Gas Chromatograph - Flame Ionization Detector (GC-FID) instrument. 3 µl of concentrated sample eluted from column was injected into GC vial. The blank DCM was injected into micro-syringe of GC to clean the syringe (3 times) before taking the sample for analysis. The micro-syringe was further rinsed with the sample. Then the sample was injected into the column for separation of compounds in the sample. After separation the compounds were passed through a flame ionization detector. FID detects the compounds in the sample. The number of PAHs was resolved at a particular chromatogram in milligram per kilogram of sample (mg/kg).

2.5.3 Determination of Heavy metal Content

The concentration of heavy metals (Ni, Pb, Cd, Cu, Cr, Fe and Zn) in water samples were determined using atomic absorption spectrophotometry (Varian AA 240 AAS) (American Public Health Association (APHA) and American water works Association (ALPHA, 2012).

$$\text{Total metal concentration} = \frac{(\text{D x R x V})}{\text{W}} \quad (3.10)$$

Where, D = Serial dilution, R = Concentration reading (from the AAS), V = final volume of acid digestion (makeup volume) and W = Dry weight of sample (Ama *et al*, 2017; Chris *et al*. 2023).

2.6 Statistical analysis

The results of the laboratory analysis, namely the physicochemical properties and heavy metals were analyzed using descriptive statistic to determine the means and standard deviation, percentages and coefficient of variations. The descriptive statistics was carried out using XL-STAT and Statistical Product for Service Solution (SPSS).

3 Results and Discussions

A summary results of the physical and chemical parameters of the water samples for both the rainy and dry seasons are presented in Table 1; while, a summary results of heavy metal parameters of the water samples for both the rainy and dry seasons are presented in Table 2. The assessment of the water quality of the water bodies was carried out by comparing the water quality parameters of the Rivers with both FMEnv and WHO guidelines and standards.

The result in Table 1 indicates that the rainy and dry seasons mean pH values fall within both FMEnv and WHO recommended ranges for surface water bodies. Mean concentration level of conductivity in the Okulu River surpasses WHO permissible limit by 416.2% and 544.5% in the rainy and dry seasons respectively. Mean turbidity level surpasses FMEnv limit by 301% and 306% in both the rainy and dry seasons respectively, but falls below WHO limit by 19.8% and 18.8% respectively in both seasons. Mean chloride concentration in the river exceeds FMEnv limit by 46.3% 64.0% respectively in the rainy and dry seasons, and exceeds WHO limit by 75.5% and 96.7% in the rainy and dry seasons respectively. Rainy and dry seasons mean dissolved oxygen (DO) values are above both FMEnv and WHO recommended value of 6 mg/l for surface water bodies. The computed mean concentration of total alkalinity surpasses WHO permissible limit by 43.6% and 54.4% in the rainy and dry seasons respectively.

Computed average nitrate concentration exceeds FMEnv and WHO limits in the rainy season by 713.8% and 640.6% respectively, and surpasses both limits in the dry season by 661.2% and 592.7% respectively.

Likewise, average sulphate level surpasses the permissible limits in the rainy season by 255.6% and 77.8% respectively, and also exceeds both limits in the dry season by 289.5% and 94.7% respectively. Mean phosphate level falls below FMEnv limit in the rainy season by -79.7% but surpasses WHO limit by 42.0%. It also falls below FMEnv limit in the dry season by 74.3% and exceeds WHO limit by 80.0%. Average TDS concentration surpasses the permissible limits in the rainy season by 23.8%, and also exceeds both limits in the dry season by 132.0%. Computed mean oil and grease levels surpasses both permissible limits by more than 1.5 million percent in both the rainy and dry seasons. Mean BOD concentration level exceeds FMEnv and WHO limits in the rainy season by 259.3% and 169.5% respectively. It also surpasses both limits in the dry season by 208.3% and 131.3% respectively. The mean concentration level of COD in the Okulu River surpasses FMEnv permissible limit by 2161.5 % and 1955.4 % in the rainy and dry seasons respectively.

The computed mean pH levels for Chokocho River in the rainy and dry seasons fall within both FMEnv and WHO recommended ranges for surface water bodies. The mean conductivity level of in the Chokocho River falls below WHO permissible limit by 79.4% and 79.2% in the rainy and dry seasons respectively. Computed mean turbidity level falls below both FMEnv and WHO limits by 92.0% and 98.4% respectively in the rainy season. It also falls below both limits by 93.0% and 98.6% respectively in the dry season. The mean concentration of chloride in the Chokocho falls below both FMEnv and WHO limits by 83.8% 80.3% respectively in the rainy season. It also falls below both limits in the dry season by 83.2% and 79.8% respectively. Mean dissolved oxygen (DO) levels for Chokocho river in both seasons are above both FMEnv and WHO recommended value of 6 mg/l for surface water bodies. The computed mean concentration of total alkalinity falls below WHO permissible limit by 64.5% and 64.1% in the rainy and dry seasons respectively. Computed average nitrate concentration exceeds FMEnv and WHO limits in the rainy season by 15.7% and 5.3% respectively, and surpasses both limits in the dry season by 16.9% and 6.4% respectively. The mean concentration level of sulphate falls below the permissible limits in the rainy season by 74.3% and 87.1% respectively, and also falls below both limits in the dry season by 74.3% and 87.2% respectively. Mean phosphate level falls below both FMEnv and WHO limits in the rainy season by 99.7% and 98.0% respectively. It is also far below both limits in the dry season by 99.6% and 99.4% respectively.

Similarly, computed mean TDS concentration falls below both permissible limits in the rainy season by 89.6% each, it also falls below both limits in the dry season by 89.9% each. The mean level of oil and grease exceeds both FMEnv and WHO permissible limits by more than 50 thousand percent in both the rainy and dry seasons. Mean BOD concentration level surpasses FMEnv and WHO limits in the rainy season by 53.0% and 14.8% respectively. It also surpasses both limits in the dry season by 35.0% and 1.3% respectively. The mean concentration level of COD in the Chokocho River surpasses FMEnv permissible limit by 161.2 % and 159.1 % in the rainy and dry seasons respectively.

Similarly, mean concentration levels of cadmium, iron, zinc, lead, nickel, copper, and chromium in Okulu River all far exceed both FMEnv and WHO permissible limit in the rainy and dry seasons see Table 2. Likewise, Table 2 showed that the mean concentration levels of cadmium, iron, lead, and nickel in the Chokocho River all fall below both FMEnv and WHO permissible limit in the rainy and dry seasons. Mean concentration of zinc in the rainy season exceeds FMEnv limit by 6840.0%, but falls below WHO permissible limit by 30.6%. It also surpasses FMEnv limit by 5980.0% in the dry season, but falls below WHO limit by 39.2% in the same season. Mean concentration of copper in the rainy season exceeds FMEnv limit by 120.0%, but falls below WHO permissible limit by 78.0%. It also surpasses FMEnv limit by 220.0%, but falls below WHO limit by 68.0% in the same season. Mean chromium concentration level exceeds FMEnv and WHO limits in the rainy season by 12900.0 % and 160.0% respectively. It also surpasses both limits in the dry season by 2900.0 %, but falls below FMEnv limit 40.0% in the dry season see Table 2.

Table 1: Comparative seasonal analysis of physical, and chemical constituents of Okulu and Chokocho River

	Rainy season		Dry season			
Statistics/ Parameter	**Chokocho**	**Okulu**	**Chokocho**	**Okulu**	**FMEnv limit**	**WHO limit**
pH	6.76	8.09	7.81	7.44	6.5-8.5	6.0-9.0
Cond. (µs/cm)	61.90	1548.63	62.47	1933.49		300
Temp. (°C)	25.65	28.04	26.54	27.66		
Turbidity (NTU)	0.08	4.01	0.07	4.06	1	5
Chloride, Cl^- (mg/l)	48.51	438.85	50.46	491.87	300	250
DO (mg/l)	14.17	9.42	14.73	7.99	> 6.0	6
Total PAHs (mg/l)	3.55	601.57	4.07	385.95		
Total Alkalinity (mg/l)	71.00	287.29	71.76	310.83		200
NO_3^- (mg/l)	10.53	74.06	10.64	69.27	9.1	10
SO_4^{2-} (mg/l)	25.73	355.59	25.70	389.49	100	200
PO_4^{2-} (mg/l)	0.01	0.71	0.013	0.90	3.5	0.5
TDS (mg/l)	52.11	618.88	50.52	1160.09	500	500
Oil and Grease (mg/l)	5.10	288.01	5.10	288.01	0.01	0.01
BOD (mg/l)	4.05	9.25	4.10	9.30	3	4
COD (mg/l)	78.35	678.44	77.74	616.62	30	

Table 2: Comparative seasonal analysis of heavy metals constituents of Okulu and Chokocho River

	Rainy season		Dry season			
Statistics/ Parameter	**Chokocho**	**Okulu**	**Chokocho**	**Okulu**	**FMEnv limit**	**WHO limit**
Cadmium, Cd (mg/l)	0.001	0.42	0.001	0.60	0.005	0.005
Iron, Fe (mg/l)	0.02	6.17	0.022	8.73	0.050	0.300
Zinc, Zn (mg/l)	3.47	11.04	3.040	11.76	0.050	5.000
Lead, Pb (mg/l)	0.02	7.44	0.014	7.76	0.500	0.050
Nickel, Ni (mg/l)	0.00	0.72	0.0012	1.07	0.010	0.100
Copper, Cu (mg/l)	0.22	13.12	0.32	16.31	0.100	1.000
Chromium, Cr (mg/l)	0.13	12.56	0.030	15.84	0.001	0.050

3.1.2 Statistical comparison of the physicochemical constituents of the selected water bodies

The summary of analyses of variance (ANOVA) test of significance between the water quality parameters of Okulu River and Chokocho River in both the rainy and dry seasons are presented in Tables 3 to 4. The statistical summaries of the levels of significant difference between the two water bodies in the rainy and dry seasons are shown in Tables 3 and 4 respectively. These results generally show that the Okulu River is highly polluted compared to the Chokocho River and thus requires further investigation.

Table 3: Summary of comparison between Okulu River and Chokocho River in the rainy season

Statistics/ Parameter	*F-stat*	*P-value*	*F crit*	Remark
Comparison of physical constituents				
Conductivity	78.73557	< 0.0001	5.317655	Significant
Temperature	17.40529	0.003114	5.317655	Significant
Turbidity	43.33498	< 0.0001	4.964603	Significant
Comparison of chemical constituents				
Chloride	280.1701	< 0.0001	5.317655	Significant
Total PAHs	57.75676	< 0.0001	5.317655	Significant
Total Alkalinity	33.85566	0.000397	5.317655	Significant
NO_3^-	145.0948	< 0.0001	5.317655	Significant
SO_4^{2-}	175.8641	< 0.0001	5.317655	Significant
TDS	88.1507	< 0.0001	5.317655	Significant
Oil and Grease	9.201117	0.016227	5.317655	Significant
BOD	51.78166	< 0.0001	5.317655	Significant
COD	224.1894	< 0.0001	5.317655	Significant
Comparison of heavy metals				
Cadmium	6.081334088	0.038950431	11.25862414	Significant
Iron	30.93332907	0.000533559	11.25862414	Significant
Zinc	29.99043242	0.000589997	11.25862414	Significant
Lead	42.5183063	0.000184068	11.25862414	Significant
Nickel	10.91847551	0.010789279	11.25862414	Significant
Copper	63.39264318	< 0.0001	11.25862414	Significant
Chromium	50.53739175	0.000101094	11.25862414	Significant

Table 4: Summary comparison between Okulu River and Chokocho River in the dry season

Statistics/ Parameter	*F-stat*	*P-value*	*F crit*	Remark
Comparison of physical constituents				
Conductivity	203.8294	< 0.0001	5.317655	Significant
Temperature	8.823529	0.017859	5.317655	Significant
Turbidity	68.55373	< 0.0001	5.317655	Significant
Comparison of chemical constituents				
Chloride	464.9476	< 0.0001	5.317655	Significant
Total PAHs	30.81432	0.00054	5.317655	Significant
Total Alkalinity	92.0709	< 0.0001	5.317655	Significant
NO_3^-	70.56284	< 0.0001	5.317655	Significant
SO_4^{2-}	234.8939	< 0.0001	5.317655	Significant
TDS	198.8131	< 0.0001	5.317655	Significant
Oil and Grease	7.93357	0.02261	5.317655	Significant
BOD	48.20372	0.000119	5.317655	Significant
COD	104.4178	< 0.0001	5.317655	Significant
Comparison of heavy metals				
Cadmium	6.715432143	0.032042	5.317655072	Significant
Iron	74.94804034	< 0.0001	11.25862414	Significant
Zinc	37.38977	0.000285	11.25862	Significant
Lead	65.93753948	< 0.0001	11.25862414	Significant
Nickel	14.69979444	0.0049893	11.25862414	Significant
Copper	68.71607208	< 0.0001	11.25862414	Significant
Chromium	74.02299738	< 0.0001	11.25862414	Significant

4. Discussions

4.1 Physicochemical parameters of Okulu River

Findings from the indicate that the rainy and dry seasons mean pH values for Okulu Rivers meet FMEnv and WHO recommended ranges for surface water bodies. This implies that the Okulu river is neither acidic nor alkaline in nature. This finding is slightly different from that reported by Rim-Rukeh (2013) who reported acidic to neutral pH in some surface water bodies in Niger Delta. Seasonal concentration levels of conductivity and turbidity in the Okulu River surpasses permissible limits. Seasonal mean concentration of chloride in the Okulu river were found to exceed permissible standards. The Okulu river was found to be saturated with dissolved oxygen (mean DO > 6 mg/l) in both the rainy and dry seasons. Seasonal mean concentrations of total alkalinity surpass permissible limit. The mean concentration of Total PAHs was observed to be more than 600mg/l in the rainy season and 300mg/l in the dry season. Seasonal average concentration levels of nitrate and sulphate were ob served to exceed permissible standards. The levels of Total PAHs measured in the Okulu River is far higher than that reported in Woji River by Iyama *et al.* (2020). However, mean concentration of phosphate was observed to be below FMEnv limit in the rainy season, but was above WHO limit in the dry season. Average TDS concentration was found to surpass the permissible standards in the rainy and dry seasons. The study found that mean levels of oil and grease in the Okulu river far exceeded both permissible standards in both the rainy and dry seasons by more than 1.5 million percent. This could be attributed to oil spillages from dredging activities. Mean concentration levels of BOD and COD were found to exceed permissible standards in both the rainy and dry seasons. Mean concentration levels of all the heavy metals (cadmium, iron, zinc, lead, nickel, copper, and chromium) in Okulu River were found to far exceed permissible standards in both the rainy and dry seasons. Major sources of heavy metal pollution of the Okulu river can be attributed to petrochemical effluent discharge, sand mining activities such as maintenance of sand mining equipment, and barges among others. These findings strongly affirmed the findings by Tamunobereton-ari & Omubo-Pepple (2011), Onyeugbo *et al.* (2021), and Ahuchaogu *et al.* (2025).

4.2. Physicochemical parameters of Chokocho River

It was found that the rainy and dry seasons mean pH values for Chokocho Rivers satisfy FMEnv and WHO recommended ranges for surface water bodies. This suggests that the Chokocho river is neither acidic nor alkaline in nature. Also, this finding is slightly different from that reported by Rim-Rukeh (2013) in the study of surface water bodies in Niger Delta. The mean concentration of conductivity in the Chokocho River falls below permissible standards. Mean concentration levels turbidity and chloride in the Chokocho River in the rainy and dry seasons were found to be low, below permissible standards. The Chokocho river is saturated with dissolved oxygen (mean DO > 6 mg/l) in both the rainy and dry seasons. Mean concentration of total alkalinity falls below permissible standards. Average nitrate concentration slightly exceeds permissible standards in the rainy season. This can be attributed to the presence of organic waste in some parts of the river. Mean concentration levels of sulphate, phosphate and TDS fall below the permissible standards in the rainy and dry seasons. Mean level of oil and grease was observed to exceed permissible standards by more than 50 thousand percent in both the rainy and dry seasons. Oil spillages and discharges from dredging machines in the Chokocho River could be responsible for the high level of oil and grease in the river. Mean concentration levels of BOD and COD in the Chokocho were found to higher than permissible standards in both the rainy and dry seasons. Again, this can be attributed to the presence of organic waste in some parts of the river. The study found that mean concentration levels of cadmium, iron, lead, and nickel in the Chokocho River are below permissible standards in the rainy and dry seasons. However, mean concentration of zinc, copper and chromium slightly exceed FMEnv permissible standards in the rainy and dry season. The levels of physicochemical parameters and heavy metals obtained in the Chokocho River are consistent with similar studies carried out on some water bodies in River state (Kalagbor *et al.,* 2021: Kalagbor *et al.,* 2023: Ntembaba *et al*. 2023; Olopade & Dieyne, 2023; Ubaka *et al*., 2025).

4.3 Statistical analysis and assessment of the physicochemical water quality constituents of the selected water bodies

Statistical analysis and assessment of the water bodies indicate that more than 85% of the physicochemical components of the Okulu River exceed permissible standards in the rainy and dry seasons. All (100%) the heavy metals measured in the Okulu River surpass the stipulated permissible standards in both the rainy and dry seasons. On the other hand, it was found that less than 20% of the physicochemical components of the Chokocho River exceed stipulated permissible standards in the rainy and dry seasons. All (100%) the heavy metals measured in the Chokocho River the dry season fall below both FMEnv and WHO permissible standards, while less than 30% exceed FMEnv permissible standards in the rainy season. Statistical comparison of the two water bodies indicates that the difference between the water quality of Okulu River and Chokocho River in both the rainy and dry seasons is highly significance ($P < 0.05$, 95% CI). These results suggest that the Okulu River is more polluted than Chokocho River. These results compromise the study by Onyeugbo et al. (2021), and Ahuchaogu et al. (2025) on the Okulu River. The results also corroborated similar studies carried out on some water bodies in River state (Kalagbor et al., 2021: Kalagbor et al., 2023: Ntembaba et al. 2023; Olopade & Dieyne, 2023; Ubaka et al., 2025).

The temperature levels of the two water bodies are within the ranges obtained in some rivers in Rivers State by Onyeugbo et al. (2021), Olopade and Dieyne (2023) and Ahuchaogu et al. (2025). Temperature of a water bodies is influenced by the condition of the weather, ambient atmosphere and temperature of runoff and effluent discharge into them. The temperature profile of the Okulu river was found to be higher than that of Chokocho river. The increase in the temperature of the Okulu river could be attributed to effluent discharge into it from the adjacent chemical industry (Ahuchaogu et al., 2025). The water bodies are freshwater with pH within permissible standards, there is no significant change in the pH of the two water bodies, implying those anthropogenic activities (effluent discharge, sand mining, etc.,) have not significantly altered the pH of the water bodies. This finding corroborated the studied by Onyeugbo et al. (2021) and Ahuchaogu et al. (2025), but contradicts the study by Kalagbor et al. (2023) who reported low pH (acidic) in Eweh river in Khana Local Government Area of Rivers State. Turbidity of the Okulu river was very much higher than that of Chokocho river, as a result of shallow depth of the eroding banks and high velocity of water stirring suspended sediments. Effluent discharge at high velocity and volume, and manual sand mining activity could also cause a stirring of the sediments, thereby increasing the turbidity and particulate matter along the river channel (Tamunobereton-ari & Omubo-Pepple, 2011; Onyeugbo et al., 2021).

Comparing the physicochemical and heavy metals results of the water bodies with FMEnv and WHO standards, suggests that the Okulu stream far exceeded permissible limits compared to the Chokocho river. The TDS values of the Okulu river were very high (>500 mg/l) compared to that of Chokocho river. Manual and mechanical sand mining are the major activities altering the physical water quality of the two water bodies, especially the Okulu river. This is evident in the physical collapse of the river banks at several points (see plate 4.1 in Appendix 4.3). This finding agrees with the study by Onyeugbo et al. (2021) who obtained a TDS as high as 2603.00 mg/l in the Okulu River. However, it is inconsistent with the highest TDS value of 445.55mg/l reported by a Ahuchaogu et al. (2025) in the same River. The BOD and COD levels of the Okulu river were also found to be extremely high above permissible standards compared to the Chokocho river. The high level of organic matter in the Okulu river may be caused by animal wastes from slaughter activities and human faeces from open defecation taking place at the bank of the river. In a similar study, Ahuchaogu et al. (2025) also reported high levels of BOD and COD levels in the Okulu river. Heavy metals were determined to be extremely high in the Okulu river compared to the Chokocho. Surface water in the Niger Delta has been reported to contain high concentration metals such as iron, which are bound to the soil and sediment matrix (Rim-Rukeh (2013; Iyama et al., 2018; Onyeugbo et al., 2021: Ahuchaogu et al., 2025). The intense manual sand mining observed during study is a confirmed contributing factor for the high heavy metal concentration observed in the water bodies, especially in the Okulu river (Onyeugbo et al., 2021: Ahuchaogu et al., 2025).

Heavy metals, PAH, nitrate, and phosphate were found to be high in the sediment samples of Okulu river compared to Chokocho river. Percentages of total organic carbon (TOC) in sediment of Okulu river were also found to be higher than that of Chokocho river. This finding further attest to the fact that the Okulu river is highly chemically contaminated compared to the Chokocho river. The high level of TOC in sediment samples of Okulu river is an indication of excessive organic matter which could be injurious to aquatic life (flora and fauna).

5. Conclusions

This study evaluated the effects of industrial chemical effluents on a selected water bodies in River State. The study quantitatively demonstrated scientific prove that anthropogenic activities affect the physicochemical characteristics of the water bodies. The following conclusions are therefore drawn from the results and findings of this study. The study established evidences that industrial effluent discharge and sand mining are the major anthropogenic activities affecting the physical water quality of the two water bodies, especially the Okulu river. This study showed evidences of high levels of physicochemical and heavy metal parameters in the Okulu river that exceeded permissible standards compared to the Chokocho river. The intense sand mining was shown to the main contributing factor for the high heavy metals' pollution of the water bodies, particularly the Okulu river. The study showed that dissolved minerals from sand mining, runoff from farm land, and wastewater effluent significantly contribute to the concentrations of nitrate, phosphate and sulphate in the rivers. It is therefore advocated that concerned authorities take urgent actions necessary to safeguard waterbodies in the Rivers State from further deterioration.

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