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Impacts of Industrial Wastewater Effluent on Ekerekana Creek and Policy Recommendations for Mitigation

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Abstract
This study investigated the impact of industrial wastewater originating from the Port-Harcourt Refinery Company Limited on Ekerekana Creek in Rivers State, serving as a primary fishing source for various communities. Water samples were collected and tested using established laboratory techniques, focusing on parameters such as heavy metals, pH levels, Phosphate, Nitrate, Temperature, Dissolved Oxygen, and BOD5**.** The findings revealed varying concentrations of heavy metals and other parameters in the water samples, with the highest concentrations observed at the discharge point (station 2), negatively affecting the flora population. The values of most parameters analyzed were below NESREA/WHO standards; however, the results underscore the importance of proper wastewater treatment and management from industrial sources to protect the environment and ensure the health and well-being of communities that rely on the creek.Based on the study's findings and best practices from the UK, US, and France, a set of comprehensive policy directions and community social responsibility measures are proposed. These recommendations include proper

treatment of effluent by the Port-Harcourt Refinery Company Limited before discharge, active regulatory agency involvement, the adoption of an efficient and modern wastewater treatment facility, and the initiation of a clean-up procedure to reduce heavy metal concentrations and mitigate environmental hazards. Additionally, we advocate for the establishment of collaborative partnerships, community engagement, integrated watershed management, enforcement and compliance, research and innovation, and climate change adaptation and resilience measures. Implementing these recommendations will contribute to lasting improvements in water quality and the overall health of Ekerekana Creek and its surrounding communities.
Keywords: Industrial wastewater. Port-Harcourt Refinery Company Limited. Ekerekana Creek. Heavy metals. PH. Dissolved oxygen. BOD5. Turbidity. Spatial inequality. Industrial effluents. Water quality.

1. Introduction

Nigeria, the most populous country in Africa, has a population exceeding 206 million people (Abubakar *et al.*, 2022). The nation is endowed with abundant water resources that are essential for various activities, such as fisheries, transportation, irrigation, recreation, and domestic use (Ekiye & Zejiao, 2010). However, the rapid industrialization and urbanization in Nigeria have raised significant concerns about the quality and sustainability of these water resources, particularly in terms of pollution from industrial effluents (Adelegan, 2004; Eniola, Chukwu, & Olaide, 2010; Onanuga, Eludoyin, & Ofoezie, 2022). Ekerekana Creek, located in Rivers State, Nigeria, has been receiving industrial wastewater effluent from the Port-Harcourt Refinery Company Limited (PHRC), which has fueled concerns about potential environmental pollution and its impacts on the creek's water quality, aquatic life, and the health of surrounding communities (Diya'uddeen, Daud, & Aziz, 2011; Kanu & Achi, 2011; Nwaichi & Osuoha, 2021). This study aims to investigate the effects of industrial wastewater effluent on Ekerekana Creek, focusing on heavy metal concentrations, physicochemical parameters, and impacts on flora populations.

In recent years, several studies have highlighted the implications of industrial effluents on water resources in Nigeria (Ajibade *et al.*, 2021). These effluents, which contain various pollutants such as heavy metals, chlorides, phosphates, oil and grease, and nitrates, pose a significant threat to the environment and human health if not properly managed and treated (Ekiye & Zejiao, 2010; Osibanjo, Daso, & Gbadebo, 2011). Consequently, there is a growing need for robust research on the effects of industrial effluents on water bodies like Ekerekana Creek to understand the extent of pollution better and inform effective management strategies for water resources in Nigeria.

Understanding the impacts of industrial wastewater effluent on Ekerekana Creek and other water bodies in Nigeria is essential for several reasons. First, it can help identify the main sources and types of pollution affecting water quality, which is crucial for developing targeted mitigation measures (Nwaichi & Osuoha, 2021). Second, it can support the establishment and enforcement of more effective environmental regulations and guidelines, such as those published by the National Environmental Standards and Regulations Enforcement Agency (NESREA). Finally, the findings can raise public awareness about the importance of protecting water resources and promoting sustainable water management practices in Nigeria (Abubakar *et al*., 2022; Ajibade *et al*., 2021). Industrial activities generate vast amounts of wastewater containing various pollutants, such as heavy metals, chlorides, phosphates, oil and grease, and nitrates (Ekiye & Zejiao, 2010; Osibanjo *et al*., 2011). Industries worldwide are responsible for dumping 300-400 million tons of heavy metals, solvents, toxic sludge, and other waste into waters each year (Oyelaran, Balogun, Ambali, & Abidoye, 2017). If not properly treated and managed, industrial effluents can contaminate surface and groundwater resources, negatively impacting aquatic ecosystems and human health (Chowdhary, Bharagava, Mishra, & Khan, 2020; Edokpayi, Odiyo, & Durowoju, 2017).

In Nigeria, numerous regulations have been enacted to protect the marine environment and other water bodies, but their effectiveness in controlling the indiscriminate dumping of effluents remains limited (Ekiye & Zejiao, 2010). The National Environmental Standards and Regulations Enforcement Agency (NESREA) published the "National Guidelines and Standards for Environmental Pollution," focusing primarily on industrial pollution, to improve environmental management and control. Despite these efforts, water pollution due to industrial effluents continues to be a significant concern in Nigeria (Ighalo & Adeniyi, 2020).

The discharge of industrial wastewater effluent can have severe consequences on the physical, chemical, and biological properties of receiving water bodies (Kanu & Achi, 2011). For instance, heavy metals, such as Lead, copper, Chromium, and Cadmium, can accumulate in the tissues of aquatic organisms, leading to bioaccumulation and biomagnification through the food chain (Diya'uddeen *et al*., 2011). These heavy metals can also cause adverse effects on the growth, reproduction, and survival of aquatic plants and animals (Emenike, Iwuozor, & Anidiobi, 2021). Furthermore, industrial effluents containing high concentrations of nutrients, such as nitrates and phosphates, can lead to eutrophication, a process characterized by excessive algal growth, reduced dissolved oxygen levels, and the subsequent decline of aquatic life (Eniola *et al*., 2010; Sonone, Jadhav, Sankhla, & Kumar, 2020). These alterations in water quality can negatively impact the biodiversity, structure, and functioning of aquatic ecosystems (Kanu & Achi, 2011).

Water pollution due to industrial effluents can have severe consequences on human health, particularly for communities that rely on contaminated water sources for domestic use, including drinking, cooking, and sanitation (Aboyeji, 2013). Heavy metals and other toxic substances present in industrial effluents can accumulate in the human body, leading to various health problems such as gastrointestinal disorders, kidney damage, neurological disorders, and even cancer (Osibanjo *et al*., 2011). Moreover, the contamination of water resources can also lead to the proliferation of waterborne diseases, such as cholera, dysentery, and typhoid, especially in areas with inadequate water treatment and sanitation facilities (Ekiye & Zejiao, 2010). The World Health Organization (WHO) has established guidelines for safe drinking water quality to protect public health. However, the widespread pollution of water resources in Nigeria remains a significant challenge to achieving these standards (Edition, 2011).

The effective management and treatment of industrial wastewater effluent are crucial in mitigating its impacts on aquatic ecosystems and human health. Various treatment technologies, such as physical, chemical, and biological processes, can be employed to remove pollutants from industrial effluents before discharge (Diya'uddeen *et al*., 2011). However, the effectiveness of these treatment methods depends on several factors, including the type and concentration of pollutants, the availability of resources and infrastructure, and the enforcement of environmental regulations (Osibanjo *et al*., 2011). In Nigeria, the enforcement of environmental regulations, such as the NESREA guidelines, is critical in ensuring the proper treatment and management of industrial wastewater effluent. However, challenges such as inadequate infrastructure, insufficient funding, and weak enforcement mechanisms have hindered the successful implementation of these regulations (Ekiye & Zejiao, 2010; Eniola *et al*., 2010). Consequently, there is a need for continued research and investment in the development and implementation of effective wastewater treatment technologies, as well as the strengthening of regulatory frameworks to protect Nigeria's water resources from the adverse effects of industrial effluents (Adelegan, 2004; Osibanjo *et al*., 2011).

The impact of industrial wastewater discharge on Ekerekana Creek in Rivers State, Nigeria, is a pressing concern that demands further exploration, particularly considering its potential consequences on aquatic ecosystems, human health, and nearby communities. While Balogun *et al*. (2019) conducted a similar study, it lacked policy recommendations. The present study seeks to enhance our understanding of the effects of industrial effluent release on the creek's water quality, heavy metal concentrations, physicochemical parameters, and plant populations. By offering valuable data on the current condition of Ekerekana Creek and evaluating the efficacy of existing regulations and wastewater treatment practices, this research can guide future endeavors to strengthen the management and control of industrial effluents in Nigeria, thereby contributing to the preservation of the nation's crucial water resources. Confirming the findings of Balogun *et al*. (2019) and other studies, this research not only corroborates the pollution in the creek but also provides policy recommendations for mitigation.

2. Methods

2.1. Description of Study Area

2.1.1 Location

Okrika, also spelled as Okirika, is a town and local government area in Rivers State, Nigeria. It is situated along the eastern bank of the Bonny River, which is part of the Niger Delta region. Okrika serves as a significant hub for trade and commerce due to its strategic location near the confluence of the Bonny River and the Atlantic Ocean. The town's population is predominantly comprised of the Okrika people, who belong to the Ijaw ethnic group and speak the Okrika language. The region is known for its rich cultural heritage, vibrant festivals, and traditional arts, including masquerades, dances, and crafts. Fishing and farming are the primary occupations of the local inhabitants, though some residents are also involved in the oil industry, as the Niger Delta is home to vast oil and gas reserves. However, the area faces several challenges, such as environmental degradation, pollution, and socio-economic issues, primarily due to the oil industry's activities. Oil spills, gas flaring, and other industrial activities have negatively impacted the environment and the livelihoods of the local communities, leading to a decline in fishing and agricultural productivity. Efforts to address these issues have been made in recent years through government regulations, corporate social responsibility initiatives, and local community involvement. However, there is still much work to be done to mitigate the adverse effects of the oil industry on Okrika's environment and people.

2.1.2 Population and Human Activities

Rivers State, home to a population of around three million people, is a culturally diverse region in Nigeria (World Bank, 2021). This region comprises various ethnic groups such as Kalabari, Ikwere, Okrika, Ibani (Bonny & Opobo), Ekpeye, Ogba, Etche, Khana, Gokana, Eleme, Ndoni, Abua, and Odual (Naanen, 2012). While the area is primarily known for its oil exploration activities, its residents are also engaged in various other sectors including commerce, administration, banking and finance, information, transportation, marine transportation, academia, manufacturing, mining of river and upland sand, exploration and exploitation of crude oil, fishing, and farming (Onu, Surendran, & Price, 2014).The population distribution and settlement patterns in the Niger Delta are largely determined by the availability of dry land (Onokerhoraye, 1999). This is especially true for the mangrove swamp zone, characterized by extensive swamps interspersed with dry land islands. It is common for larger settlements to be established on these islands, making them the primary residential areas in the region (Onokerhoraye, 1999).

2.1.3 Climate and Geo-Characteristics

Located in South-South Nigeria, Rivers State has a climate typical of a tropical wet-and-dry region (as per Koppen's AW Climate) due to its proximity to the equator. The rainy season is marked by abundant cloud cover and frequent rainfall, with annual precipitation levels reaching between 300-450 cm. The extended wet season lasts from March to September, with average monthly temperatures ranging from 24 to 27°C and humidity levels around 80% (Balogun, Owuama, & Onukogu, 2019). The area's geology consists primarily of marine sediments from the Lower and Upper Cretaceous age, which form the essential structures where petroleum was generated and deposited. The soil in the region can be characterized as coarse, loamy, highly weathered, and moderately acidic, with low soluble salt content (Zipper, Burger, Barton, & Skousen, 2013).

2.1.4 Topography and Drainage

The Niger Delta, one of Nigeria's seven relief regions, encompasses approximately 95% wetland, characterized by a network of channels and small waterways that lead to rapid coastal rivers. Prominent drainage systems in the Niger Delta include those of the Niger, Ase, Ethiope, Warri, Orashi, Sombreiro, New Calabar, and Imo rivers (Balogun *et al*., 2019). Discharge generally increases from July to October, peaking in October. The Atlantic Ocean, which borders the Niger Delta's southern coastline, contributes high-salinity and high-conductivity waters. Throughout the Niger Delta, the ocean water exhibits a regular inland and seaward shift. The region's waters remain warm year-round, with temperatures between 22 and 30°C (Elenwo & Akankali, 2016; Obuah & Keke, 2022).

2.1.5 Vegetation and Land Use

Urban and industrial development has significantly impacted this area, leaving only a few untouched zones of natural, lush vegetation. Most regions now feature secondary growths rather than pristine landscapes. The original vegetation consists mainly of dense red mangrove forests.

2.2 Sampling & Sampling Points

Three primary sample points were chosen along the Ekerekana creek in Okirika. These sampling points were established 500 meters apart during a preliminary survey using a boat traversing the creek. Each primary sample point was further divided into three sub-points. The coordinates of each station were recorded using a geographical positioning system (GPS) (Garmin 12) to accurately identify the sampling locations.

2.2.1 Sampling Point 1

Sampling Point 1, which serves as the upstream of the river, is located at 7^{0}5'33.68" E and 4^{0}45'35.84"N. It is situated 500 m away from the point source of the creek.

2.2.2 Sampling Point 2

This represents the point of discharge into the river. It is located at 7^{0}5'39.95"E and 4^{0}45'19.86"N.

2.2.3 Sampling Point 3

Representing the downstream of the river. It is located at 7^{0}5'41.24"E and 4^{0}45'02.94"N.

2.3 Sample Collection

The samples were collected at low tide at about 30cm deep for physico-chemical properties. The bottles and containers were rinsed, dried and labelled accordingly prior to the sampling day. Samples for BOD were collected in 250ml brown bottles; water samples for heavy metals were collected in 30ml plastic containers and fixed with concentrated HNO_3 in a ratio of 2:500. All samples were transported in an ice-packed cooler to the Laboratory Institute of pollution studies, Rivers State University of Science and Technology, Port Harcourt laboratory.

2.4 Sources of Data

The required data collected and analyzed in this study were collected from different sources. The sources of data are primary and secondary data.

2.4.1 Primary Data

Primary data are usually the first-hand data collected or observed directly from sources. In this study, the primary data were obtained through random sampling.

1.4.2 Secondary Data

These secondary data were collected based on existing records kept by different agencies, such as Port Harcourt Refinery Company Limited, Federal Ministry of Environment, Department of Environmental Technology FUTO, Government of Rivers state, the Federal University of Technology Library, Owerri and E-books and Journals.

2.5 Sample Analysis

2.5.1 pH

The pH levels were assessed on-site at both the effluent discharge point and the river using a Mettler Toledo 320 pH meter, following the guidelines outlined by the American Public Health Association (APHA, 1998). According to the standard method, the pH meter was calibrated using two pH 7.0 - 4.0 buffer solutions. After calibration, the electrodes were rinsed with distilled water and gently dried using a soft tissue before being immersed into the sample for 120 seconds (2 minutes) to obtain a reading.

2.5.2 Conductivity

Conductivity measurements were taken on-site using a PHA (2510B) conductivity meter. The meters were calibrated with 0.001N and 0.1N KCl solutions for low conductivity samples and 0.39N KCl solutions for high conductivity samples**.**

2.5.3 Temperature

Sample temperatures were determined on-site using a 0-100 °C mercury-in-glass thermometer. The thermometer was placed into the sample, allowing sufficient time for equilibration before recording the temperature in deg. Celsius (°C**).**

2.5.4 Turbidity

Turbidity levels were quantified in Nephelometric units (NTUs) using a HACH 2100A turbidity meter.

2.5.5 Phosphate

Phosphate levels in the water samples were measured using a multi-parameter photometer (Hanna Instrument H183200). Following the procedure, 10ml of the sample was added to the photometer cuvette to zero the instrument. Then, a H193713-0 phosphate reagent packet was added to the cuvette, gently shaken for one minute, and allowed to react for five minutes before taking a reading.

2.5.6 Salinity

Salinity measurements were obtained using a salinity meter, with results reported in parts per thousand (‰).

2.5.7 Dissolved Oxygen

Dissolved oxygen (DO) levels were directly measured in the river using a DO meter.

2.5.8 Nitrate Ions

Nitrate levels in the water samples were determined using the cadmium reduction method (APHA, 1998). A cadmium-based reagent pillow was added to a 25ml water sample in a cuvette, shaken for one minute, and allowed to stand for an additional five minutes for the reaction to complete. The absorbance and concentration (in mg/L) were read at a 500nm wavelength using a HACH DR 2010 UV-visible spectrometer.

2.5.9 Biological Oxygen Demand

The biological oxygen demand (BOD) was assessed following conventional methods outlined by the Association of Official Analytical Chemists (AOAC, 2002). A 50ml sample was placed in a 500ml BOD bottle, which was then filled with prepared dilution water. A blank solution of dilution water was prepared similarly and placed in two BOD bottles. The bottles were sealed and incubated for two days at room temperature. BOD was calculated using the following relationship**:**

$$BOD = \frac{D_1 - D_2}{P} \quad (1)$$

Where D_1 is the dissolved oxygen of the dilution sample 15 minutes after preparation. D_2 = dissolved oxygen in the diluted sample after an incubation period of 5 days. P = the decimal fraction of the sample used.

2.5.10 Chlorophyll

The analysis of the samples employed the spectrophotometric method 10200H (Apha, 1998), which utilizes the red fluorescence of chlorophyll when excited by blue light. This characteristic helps in measuring chlorophyll levels, indicating algal biomass. To obtain direct and continuous measurements of chlorophyll fluorescence, a fluorimeter was used either in situ by circulating water through it or by submerging it into the water using specifically designed instruments. For laboratory chlorophyll analysis, samples were collected in polyethylene containers, with an addition of 0.1 to 0.2 ml of magnesium carbonate suspension as a preservative. These samples could be stored in a cool, dark place for up to 8 hours before being filtered. After filtration using a glass fiber (GF/C grade) filter, the filtrate could be kept frozen for a short duration prior to examination. Chlorophyll pigments are extracted using solvents and measured using spectrophotometry. It is essential to account for the interference of chlorophyll degradation products, like phaeophytin, which can affect the estimation of chlorophyll concentrations in the solvent extract. This issue can be resolved by determining the optical density before and after acidifying the extract.

2.5.11 Total Hydrocarbon

The hydrocarbon content of the water samples was determined by mixing 10 ml of the sample with 20 ml of toluene. The samples were determined with the use of the spectrometer (Spectronic 20).

2.5.12 Heavy Metals

Calcium, Lead, copper and Cadmium were determined using an atomic absorption spectrometer (model AA6800 – SHIMADZU) according to Apha (1998).

3. Result

3.1 Statistical Analysis

SPSS(C) Statistical Package for Social Scientists and Excel was used in this study. Data obtained were subjected to analysis of variance (ANOVA) to determine significant differences between groups of means at $P < 0.05$.

3.2 Analysis of Results among the Stations (Rainy Season)

During the rainy season, as presented in Tables 1-3, variations were observed in all the parameters analyzed between stations. The temperature was highest in stations 2 and 3 (discharge point and downstream). This may be due to the release of wastewater with slightly increased Temperature into the receiving water body or due to the actions of microorganisms involved in the degradation of biogenic waste.

The value for pH was close to neutral in station 1 (upstream) and slightly acidic in station 2. The acidity will encourage the mineralization of heavy metals in the solution, hence their detection in station 2. The effluent discharged from the refinery is susceptible to ionization and remobilizing the acidic radicals, hence the slightly acidic condition in station 2. Dissolved Oxygen (DO) has the lowest value at station 2, and this is an indication of pollution and a direct effect of waste released into the water body at station 2.

Biochemical Oxygen Demand (BOD_5) was highest in station 2, an indication of water pollution due to the activities of the refinery, hence an affinity for oxygen by microbes involved in degradation. Although the value of BOD_5 was slightly high in station 1, it may be due to the synergistic effect from other sources. Turbidity was highest at station 2; this was due to disturbance of the hydrologic regime by the inflow of effluent and its constituents, upsetting the state of the river.

Salinity was slightly higher at station 2, an indication of an increase in the concentration of saline ions/ compounds. This may be due to the use and release of a saline compound by the refinery company, slightly increasing the saline state of the river. Conductivity is linked with the ionic concentration of the solution. Conductivity was highest at station 2 as a result of a corresponding increase in the salinity of station 2. Phosphate concentration was very low and almost uniform across the stations. Its presence may be due to the synergistic effect rather than the effect of the activities from the refinery.

Nitrate was found to be highest at station 2, compared to stations 1 and 3; the increase was due to effluent discharged at station 2 by the activities of the refinery. Total Hydrocarbon content found at station 2 was more than twice the content at station 1. This has a direct correlation with the activities of the refinery. Chlorophyll" a" was found to be low at station 2 and high in stations 1 and 3. Effluent from the refinery may be directly responsible for the failure of flora to produce Chlorophyll "a".

For heavy metals concentrations, Cadmium, Lead, Chromium and Copper were detected, and all had their highest concentrations at station 2. They were mineralized out due to the slightly acidic pH at station 2 and their presence in the effluent discharged at this station. Although, their presence and low quantity detected in stations 1 and 3 may be a result of synergistic effects from other human and natural activities.

Table 1 - Physicochemical Parameters Analyzed in Station 1 (Rainy Season).

S/N	Parameters	Station 1			
		1 A	**1B**	**1C**	**Ẍ1**
1	Temp °C	26.5	27.0	26.9	26.8
2	pH	6.5	6.8	6.6	6.6
3	DO (mg/L)	6.40	6.40	6.30	6.37
4	BOD_5 (mg/L)	6.40	6.70	6.20	6.43
5	Turbidity (NTU)	10.20	10.60	10.40	10.40
6	Salinity ‰	6.50	6.10	6.20	6.27
7	Conductivity (μ_s/cm)	10000	10500	10500	10333
8	Phosphate (mg/L)	0.03	0.03	0.02	0.03
9	Nitrate (mg/L)	0.68	0.50	0.60	0.60
10	THC (mg/L)	1.10	1.20	1.20	1.17
11	Chlorophyll ‘a’ (mg/L)	1.50	1.30	1.40	1.40
12	Cadmium (mg/L)	0.03	0.06	0.07	0.05
13	Lead (mg/L)	0.09	0.10	0.11	0.10
14	Chromium (mg/L)	0.04	0.05	0.07	0.05
15	Copper (mg/L)	0.15	0.10	0.13	0.13

Table 2 - Physicochemical Parameters Analyzed in Station 2 (Rainy Season).

S/N	Parameters	Station 2			
		2 A	**2B**	**2C**	**Ẍ2**
1	Temp °C	27.3	27.7	27.2	27.4
2	pH	5.8	5.9	5.7	5.8
3	DO (mg/L)	4.20	4.00	4.10	4.10
4	BOD_5 (mg/L)	8.30	8.40	8.10	8.27
5	Turbidity (NTU)	11.20	10.90	11.10	11.07
6	Salinity ‰	8.80	8.60	8.40	8.60
7	Conductivity (μ_s/cm)	12000	12700	12600	12433
8	Phosphate (mg/L)	0.05	0.07	0.06	0.06
9	Nitrate (mg/L)	0.90	0.93	0.96	0.93
10	THC (mg/L)	2.50	2.40	2.40	2.43
11	Chlorophyll ‘a’ (mg/L)	0.60	0.50	0.20	0.43
12	Cadmium (mg/L)	0.60	0.65	0.59	0.61
13	Lead (mg/L)	0.36	0.38	0.32	0.35
14	Chromium (mg/L)	0.30	0.33	0.36	0.33
15	Copper (mg/L)	0.60	0.65	0.63	0.63

Table 3 - Physicochemical Parameters Analyzed in Station 3 (Rainy Season).

S/N	Parameters	Station 3			
		3 A	**3B**	**3C**	**Ẍ3**
1	Temp °C	27.3	27.4	27.6	27.4
2	pH	6.4	6.3	6.2	6.3
3	DO (mg/L)	5.00	5.20	5.30	5.16
4	BOD_5 (mg/L)	7.90	7.50	7.30	7.57
5	Turbidity (NTU)	10.30	10.40	10.40	10.37
6	Salinity ‰	7.60	7.40	7.30	7.43
7	Conductivity (μ_s/cm)	10500	10000	10500	10333
8	Phosphate (mg/L)	0.05	0.04	0.05	0.05
9	Nitrate (mg/L)	0.66	0.60	0.79	0.68
10	THC (mg/L)	2.00	1.90	1.96	1.95
11	Chlorophyll 'a' (mg/L)	0.90	0.80	0.80	0.83
12	Cadmium (mg/L)	0.48	0.42	0.44	0.45
13	Lead (mg/L)	0.24	0.20	0.22	0.22
14	Chromium (mg/L)	0.20	0.28	0.25	0.24
15	Copper (mg/L)	0.55	0.50	0.54	0.53

3.3 Analysis of Results among the Stations (Dry Season)

During the dry season, as presented in Tables 4-6, variations were observed in all the parameters analyzed between stations. Apart from pH, Dissolved Oxygen and Chlorophyll "a" which had low values at station 2, other parameters analyzed had high values at station 2. Increased values observed were directly related to the activities of the refinery.

Table 4 - Physicochemical Parameters Analyzed in Station 1 (Dry Season).

S/N	Parameters	Station 1			
		1 A	**1B**	**1C**	**Ẍ1**
1	Temp ° C	29.0	28.8	28.9	28.9
2	pH	6.2	6.3	6.4	6.3
3	DO (mg/L)	5.00	5.20	5.10	5.10
4	BOD_5 (mg/L)	6.20	6.30	6.20	6.23
5	Turbidity (NTU)	8.60	8.90	8.95	8.82
6	Salinity ‰	8.70	8.90	8.80	8.80
7	Conductivity (μ_s/cm)	11800	12000	11900	11900
8	Phosphate (mg/L)	0.02	0.02	0.03	0.02
9	Nitrate (mg/L)	0.90	0.89	0.94	0.91
10	THC (mg/L)	2.50	2.64	2.45	2.53
11	Chlorophyll 'a' (mg/L)	0.96	1.22	1.30	1.16
12	Cadmium (mg/L)	0.04	0.08	0.06	0.06
13	Lead (mg/L)	0.10	0.12	0.09	0.10
14	Chromium (mg/L)	0.09	0.10	0.07	0.09
15	Copper (mg/L)	0.15	0.12	0.10	0.12

Table 5 - Physicochemical Parameters Analyzed in Station 2 (Dry Season).

S/N	Parameters	Station 2			
		2_A	**2_B**	**2_C**	**$\ddot{X}_2$**
1	Temp ^oC	29.1	29.0	29.1	29.0
2	pH	5.8	5.9	5.9	5.8
3	DO (mg/L)	3.40	3.60	3.50	3.50
4	BOD_5 (mg/L)	9.50	9.80	9.90	9.73
5	Turbidity (NTU)	9.20	9.00	9.20	9.13
6	Salinity ‰	9.80	9.60	9.40	9.60
7	Conductivity (μ_s/cm)	15000	14500	14500	14666
8	Phosphate (mg/L)	0.08	0.08	0.08	0.08
9	Nitrate (mg/L)	1.50	1.48	1.45	1.48
10	THC (mg/L)	4.50	4.00	4.25	4.25
11	Chlorophyll ‘a’ (mg/L)	0.45	0.40	0.39	0.41
12	Cadmium (mg/L)	0.70	0.68	0.66	0.68
13	Lead (mg/L)	0.65	0.60	0.55	0.60
14	Chromium (mg/L)	0.50	0.46	0.44	0.47
15	Copper (mg/L)	0.90	0.75	0.82	0.82

Table 6 - Physicochemical Parameters Analyzed in Station 3 (Dry Season).

S/N	Parameters	Station 3			
		3_A	**3_B**	**3_C**	**$\ddot{X}_3$**
1	Temp ^oC	28.9	29.0	29.0	28.9
2	pH	6.0	6.1	6.0	6.0
3	DO (mg/L)	4.00	4.50	4.30	4.27
4	BOD_5 (mg/L)	8.40	8.30	8.60	8.43
5	Turbidity (NTU)	9.00	9.10	9.00	9.03
6	Salinity ‰	9.40	9.30	9.20	9.30
7	Conductivity (μ_s/cm)	14000	14000	13900	14000
8	Phosphate (mg/L)	0.07	0.07	0.08	0.07
9	Nitrate (mg/L)	1.29	1.30	1.34	1.31
10	THC (mg/L)	3.96	3.90	3.94	3.93
11	Chlorophyll ‘a’ (mg/L)	0.78	0.80	0.85	0.81
12	Cadmium (mg/L)	0.50	0.52	0.49	0.50
13	Lead (mg/L)	0.44	0.40	0.39	0.41
14	Chromium (mg/L)	0.39	0.34	0.33	0.35
15	Copper (mg/L)	0.44	0.50	0.55	0.50

3.4 Analysis of Results between the Seasons

General results indicated that values obtained during the dry season were higher than values recorded during the rainy season (Table 7 and 8). Loss of fluid in the river may have increased the concentration of parameters under investigation during the dry season.

Table 7 - Comparative Table in the Means of Parameters across the Stations (Rainy Season)

Parameters	Mean (X_1)	Mean (X_2)	Mean (X_3)	NESREA STD	WHO STD
Temp ^{0}C	26.8	27.4	27.4	40.0	20 – 32
pH	6.6	5.8	6.3	6.5 – 8.5	6.5-8.5
DO (mg/L)	6.37	4.10	5.16	-	-
BOD_5 (mg/L)	6.43	8.27	7.57	6.0	2.0
Turbidity NTU	10.40	11.07	10.37	5.0	
Salinity ‰	6.27	8.60	7.43		
Conductivity µs/cm	10333	12433	10333		900
Phosphate mg/l)	0.03	0.06	0.05	3.5	
Nitrate (mg/L)	0.60	0.93	0.68	10	10
THC (mg/L)	1.17	2.43	1.95	10	
Chlorophyll 'a’ mg/L	1.40	0.43	0.83		
Cadmium (mg/L)	0.05	0.61	0.45	<0.01	0.003
Lead (mg/L)	0.10	0.35	0.22	0.05	0.01
Chromium (mg/L)	0.05	0.33	0.24	<0.05	0.005
Copper (mg/L)	0.13	0.63	0.53	<0.01	2.0

Table 8 - Comparative Table in the Means of Parameters across the Stations (Dry Season)

Parameters	Mean (X_1)	Mean (X_2)	Mean (X_3)	NESREA STD	WHO STD
Temp ^{0}C	28.9	29.0	28.9	40.0	20 – 32
pH	6.3	5.8	6.0	6.5 – 8.5	6.5-8.5
DO (mg/L)	5.10	3.50	4.27	-	-
BOD_5 (mg/L)	6.23	9.73	8.43	6.0	2.0
Turbidity NTU	8.82	9.13	9.03	5.0	
Salinity ‰	8.80	9.60	9.30		
Conductivity µs/cm	11900	14666	14000		900
Phosphate mg/l)	0.02	0.08	0.07	3.5	
Nitrate (mg/L)	0.91	1.48	1.31	10	10
THC (mg/L)	2.53	4.25	3.93	10	
Chlorophyll ‘a’ mg/L	1.16	0.41	0.81		
Cadmium (mg/L)	0.06	0.68	0.50	<0.01	0.003
Lead (mg/L)	0.10	0.60	0.41	0.05	0.01
Chromium (mg/L)	0.09	0.47	0.35	<0.05	0.005
Copper (mg/L)	0.12	0.82	0.50	<0.01	2.0

4. Discussion

Temperature plays a vital role in influencing chemical reaction rates and biological activities in aquatic systems, ultimately determining their assimilation capacity. Fish can survive up to a maximum temperature of 36°C. In this study, the temperatures at all stations during rainy and dry seasons were within acceptable ranges according to NESREA and WHO standards (Tables 7-8). Marcus and Ekpete (2014) observed an average annual temperature of 27°C in a comparable study. Adefemi and Awokunmi (2010) and Ogunlaja and Ogunlaja (2007) noted that higher water temperatures could promote microorganism growth, potentially increasing issues with taste, odor, color, and corrosion. On the other hand, Arimoro and Ikomi (2008) found no significant seasonal variations in water temperature, which somewhat aligns with the current study. Their study attributes the lack of seasonal variation to water's high specific heat capacity, which prevents significant daily fluctuations due to radiation exposure. This finding is in contrast with the present study. The effects of cloud cover and river flow on ambient and water temperature should be considered (Imoobe & Oboh, 2003). The response to major ambient temperature changes is slow, as water must absorb significant amounts of heat to alter its temperature by 10°C. The low temperatures in this study could be due to the prevalence of overhanging macrophytes in the study area, which block sunlight from reaching the water (Balogun *et al*., 2019; King, Egwali, & Nkanta, 1991).

The pH values within the stations and between the seasons were generally below both NESREA and WHO standard boundaries, except for station 1 during the rainy season, which was slightly above the lower boundary (Tables 7-8). Low pH values below the lower boundary indicate acidity, promoting heavy metal mineralization in rivers and subsequent movement along the food chain to humans. In contrast, higher pH levels encourage heavy metal immobilization, leading to sedimentation. Kanu and Achi (2011) and Singh and Gupta (2016) reported that industrial effluents released into streams and direct groundwater seepage might contribute to water source acidity in the area. Streams receiving effluents from petrochemical areas are more acidic (Ogunlaja & Ogunlaja, 2007). Arimoro and Ikomi (2008) reported a pH range of 6.60-8.22, indicating slightly acidic water with occasional slight alkalinity. The range in this study closely resembles those recorded in various Nigerian and African water bodies (Egborge & Benka-Coker, 1986; Jonnalagadda & Mhere, 2001; Ogbeibu & Victor, 1995; Onwudinjo, 1990). Contrary to Egborge and Benka-Coker (1986) and Odum (1992), there was a minor seasonal pH pattern change. A pH below 6.5 can cause metal pipe corrosion and bedrock inorganic material dissolution, releasing toxic metals such as Pb, Cd, and Fe into the water, posing significant health risks.

Dissolved oxygen (DO) is essential for chemical reactions and biological activities that determine the assimilative capacity of aquatic systems. Although NESREA and WHO have not specified DO values, in the worst conditions, such as warm water environments, DO concentrations range from 4-1 mg/L. In this study, average DO concentrations across stations and seasons ranged from 3.50-6.37 mg/L, suggesting pollution. Fish require a minimum DO concentration of 2 mg/L for survival (Carlson, Blocher, & Herman, 1980).

5. Comprehensive Policy Directions

Based on this observations, this paper proposes a set of comprehensive policy directions and community social responsibility measures inspired by best practices from the United Kingdom, United States, and France to address water pollution in the region.

Stricter regulations on industrial effluent discharge

To minimize the impact of industrial wastewater on aquatic ecosystems and human health, it is crucial to establish and enforce stringent limits on heavy metals, pH, temperature, and other pollutants in industrial effluents. In the United States, the Environmental Protection Agency (EPA) enforces the Clean Water Act, which sets pollutant-specific limits on industrial discharges.

Similarly, the European Union's Water Framework Directive, implemented in the UK and France, provides a regulatory framework to protect and improve the water environment. The Niger Delta region can adopt a similar approach by strengthening and enforcing its own regulations, such as the National Environmental Standards and Regulations Enforcement Agency (NESREA) standards.

Comprehensive monitoring programs

Developing and implementing regular monitoring programs to evaluate water quality in the Niger Delta region is essential for assessing the effectiveness of implemented policies and measures. In the UK, the Environment Agency monitors water quality to ensure compliance with established standards. In the US, the EPA oversees the National Aquatic Resource Surveys, which assess the condition of the nation's water resources. France also has a robust water monitoring system managed by the French Agency for Biodiversity. Adopting a similar monitoring system in the Niger Delta region would enable authorities to identify pollution hotspots, track progress, and determine the need for corrective actions.

Improved wastewater treatment infrastructure

Investing in upgrading and expanding wastewater treatment facilities is necessary to ensure that industrial effluents are treated to acceptable standards before discharge into water bodies. The US has made significant progress in improving wastewater treatment through the Clean Water State Revolving Fund, which provides low-interest loans for water quality projects. In the UK, the government has invested in advanced wastewater treatment technologies to meet the requirements of the EU Urban Waste Water Treatment Directive. France has also prioritized wastewater treatment infrastructure, with significant investments in recent years. The Niger Delta region can learn from these countries by allocating resources to improve wastewater treatment infrastructure and adopt advanced technologies to reduce pollution.

Promoting sustainable industrial practices

Encouraging industries in the Niger Delta region to adopt sustainable practices can significantly reduce water pollution. In the UK, the Industrial Emissions Directive aims to prevent and control pollution from industrial activities by promoting the use of Best Available Techniques (BATs). The US EPA has a similar program called the National Pollutant Discharge Elimination System (NPDES), which requires industries to implement pollution prevention measures. France has also adopted BATs to minimize industrial pollution. The Niger Delta region could establish similar programs to incentivize the adoption of cleaner production technologies and practices.

Strengthening public-private partnerships

Collaboration between the public and private sectors can accelerate progress in addressing water pollution. In the UK, the Catchment-Based Approach (CaBA) brings together various stakeholders, including industries, to develop and implement collaborative solutions to water quality issues. In the US, the EPA's Water Quality Trading program fosters collaboration between point sources (e.g., industries) and non-point sources (e.g., agriculture) to improve water quality. France has also implemented successful public-private partnerships to address water pollution. Developing similar partnerships in the Niger Delta region could help mobilize resources, share knowledge, and foster a sense of shared responsibility for water quality.

Community engagement and education

Involving local communities in the efforts to address water pollution is essential for success. Community engagement can take various forms, such as public awareness campaigns, educational programs, and citizen science initiatives. In the UK, the Rivers Trust engages communities in river restoration and conservation projects. The US EPA's Adopt-a-Stream program encourages community involvement in monitoring and protecting local water resources. In France, local water agencies collaborate with communities to promote water stewardship. The Niger Delta region could establish similar initiatives to empower communities, promote environmental stewardship, and raise awareness about the importance of clean water.

Integrated watershed management

Addressing water pollution requires a holistic approach that considers the entire watershed. Integrated watershed management, as practiced in the UK, US, and France, brings together various stakeholders to manage land and water resources in a coordinated manner. In the UK, the Catchment Management Plans provide a framework for collaborative action to improve water quality. The US EPA's Healthy Watersheds Program supports integrated watershed management through planning, assessment, and implementation. In France, watershed management is coordinated by river basin committees and local water agencies. Implementing an integrated watershed management approach in the Niger Delta region would facilitate the development of comprehensive strategies to address water pollution and its root causes.

Enforcement and compliance

Effective enforcement of environmental regulations is critical to ensure that industries comply with established standards. In the UK, the Environment Agency is responsible for enforcing water quality regulations and prosecuting non-compliant entities. The US EPA plays a similar role, with authority to issue fines and penalties for non-compliance. France's Ministry of Ecological Transition oversees the enforcement of environmental regulations. Strengthening enforcement capacity in the Niger Delta region, along with the implementation of effective penalties for non-compliance, would deter industries from violating regulations and encourage adherence to established standards.

Research and innovation

Investing in research and innovation can lead to the development of new technologies and strategies for addressing water pollution. In the UK, the government supports research and innovation through initiatives such as the Water Innovation Competitions. The US EPA's Science to Achieve Results (STAR) program funds research to inform environmental policy and decision-making. France also invests in water research and innovation through its National Research Agency. The Niger Delta region could support research and innovation by funding projects, fostering collaboration between academia and industry, and promoting the adoption of new technologies and practices.

Climate change adaptation and resilience

Climate change can exacerbate water pollution challenges by affecting precipitation patterns, water temperatures, and the frequency of extreme events. Developing strategies to adapt to climate change and build resilience is essential for long-term water quality management. In the UK, the National Adaptation Program includes measures to protect water resources from the impacts of climate change. In the US, the EPA's Climate Resilience Evaluation and Awareness Tool (CREAT) helps water utilities assess climate change risks and implement adaptation measures. France has integrated climate change adaptation into its water policies and plans. The Niger Delta region should similarly prioritize climate change adaptation and resilience in its efforts to address water pollution.

By adopting these comprehensive policy directions and community social responsibility measures, inspired by best practices from the UK, US, and France, the Niger Delta region can make significant progress in addressing water pollution and its impacts on the environment and human health. This approach will require collaboration among government agencies, industries, communities, and other stakeholders, as well as the commitment of resources and the implementation of effective strategies to achieve lasting improvements in water quality.

6. Conclusions

In summary, this study investigated the presence of heavy metals and other pollutants in Ekerekana Creek, which receives waste from industrial, agricultural, and domestic sources and serves as a primary fishing source for various communities along its banks and catchment area. The research revealed that the Port-Harcourt Refinery Company Limited discharges a significant amount of pollutants into the creek without proper treatment, leading to increased pollution and potential risks to public health. The pollution was more concentrated at the discharge point than upstream, indicating the need for constant monitoring.

The study found substantial heavy metal concentrations at the discharge point during both the rainy and dry seasons, as well as elevated values of temperature, pH, BOD5, THC, turbidity, salinity, and conductivity. Phosphate and nitrate concentrations were also highest at the discharge point during both seasons, negatively affecting the flora population. The values of most parameters analyzed were below NESREA/WHO standards, but the findings underscore the importance of proper wastewater treatment and management from industrial sources to protect the environment and ensure the health and well-being of communities that rely on the creek.

To address these issues, we propose a set of comprehensive policy directions and community social responsibility measures based on best practices from the UK, US, and France. These recommendations include proper treatment of effluent by the Port-Harcourt Refinery Company Limited before discharge, active regulatory agency involvement, the adoption of an efficient and modern wastewater treatment facility, and the initiation of a clean-up procedure to reduce heavy metal concentrations and mitigate environmental hazards. Additionally, we advocate for the establishment of collaborative partnerships, community engagement, integrated watershed management, enforcement and compliance, research and innovation, and climate change adaptation and resilience measures.

By adopting these comprehensive policy directions and community social responsibility measures, inspired by best practices from the UK, US, and France, the Niger Delta region can make significant progress in addressing water pollution and its impacts on the environment and human health. This approach will require collaboration among government agencies, industries, communities, and other stakeholders, as well as the commitment of resources and the implementation of effective strategies to achieve lasting improvements in water quality.

References

Aboyeji, O. O. (2013). Freshwater pollution in some Nigerian local communities, causes, consequences and probable solutions. Academic Journal of Interdisciplinary Studies, 2(13), 111.

Abubakar, I., Dalglish, S. L., Angell, B., Sanuade, O., Abimbola, S., Adamu, A. L., . . . Onwujekwe, O. (2022). The Lancet Nigeria Commission: investing in health and the future of the nation. The Lancet, 399(10330), 1155-1200.

Adefemi, S., & Awokunmi, E. (2010). Determination of physico-chemical parameters and heavy metals in water samples from Itaogbolu area of Ondo-State, Nigeria. African Journal of Environmental Science and Technology, 4(3).

Adelegan, J. A. (2004). The history of environmental policy and pollution of water sources in Nigeria (1960-2004): The way forward. Invited paper, 2004, 16p.

Ajibade, F. O., Adelodun, B., Lasisi, K. H., Fadare, O. O., Ajibade, T. F., Nwogwu, N. A., . . . Wang, A. (2021). Environmental pollution and their socioeconomic impacts. In Microbe mediated remediation of environmental contaminants (pp. 321-354): Elsevier.

Akintoye, O. A., Obi, C. N., Etim, O. A., Olorundami, T., Ukata, S. U., & Harrison, U. (2014). Seasonal variation in the physicochemical characteristics of surface water in Etche River, Niger Delta Area of Nigeria. Journal of Environmental Science, Toxicology and Food Technology, 8(7), 01-07.

Apha, A. (1998). Standard methods for the examination of water and wastewater. American Public Health Association. Inc., Washington, DC.

Arimoro, F. O., & Ikomi, R. B. (2008). Response of macroinvertebrate communities to abattoir wastes and other anthropogenic activities in a municipal stream in the Niger Delta, Nigeria. Environment Systems & Decisions, 28(2), 85.

Balogun, B. A., Owuama, C., & Onukogu, O. A. (2019). The Effects of an Industrial Wastewater Effluent on the Seasonal Variations of Ekerekana Creek, Rivers State Nigeria. International Journal of Environment and Climate Change [Online], 9(11), 671-681.

Carlson, A. R., Blocher, J., & Herman, L. J. (1980). Growth and survival of channel catfish and yellow perch exposed to lowered constant and diurnally fluctuating dissolved oxygen concentrations. The Progressive Fish-Culturist, 42(2), 73-78.

Chowdhary, P., Bharagava, R. N., Mishra, S., & Khan, N. (2020). Role of industries in water scarcity and its adverse effects on environment and human health. Environmental Concerns and Sustainable Development: Volume 1: Air, Water and Energy Resources, 235-256.

Dahlin, J., Hess, S., Duncan, P., & Powell, C. (1985). Composition of the Phytoplankton and zooplankton communities of the Niger Delta. Paper presented at the Proc. International Seminar on the petroleum industry and the Nigerian environment, Kaduna, Nigeria.

Diya'uddeen, B. H., Daud, W. M. A. W., & Aziz, A. A. (2011). Treatment technologies for petroleum refinery effluents: A review. Process safety and environmental protection, 89(2), 95-105.

Edition, F. (2011). Guidelines for drinking-water quality. WHO chronicle, 38(4), 104-108.

Edokpayi, J. N., Odiyo, J. O., & Durowoju, O. S. (2017). Impact of wastewater on surface water quality in developing countries: a case study of South Africa. Water quality, 10, 66561.

Egborge, A. B., & Benka-Coker, J. (1986). Water quality index: application in the Warri River, Nigeria. Environmental Pollution Series B, Chemical and Physical, 12(1), 27-40.

Ekiye, E., & Zejiao, L. (2010). Water quality monitoring in Nigeria; Case Study of Nigeria's industrial cities. Journal of American Science, 6(4), 22-28.

Elenwo, E., & Akankali, J. (2016). The estimation of potential yield of water hyacinth: a tool for environmental management and an economic resource for the Niger Delta region. Journal of Sustainable Development Studies, 9(2).

Emenike, E. C., Iwuozor, K. O., & Anidiobi, S. U. (2021). Heavy metal pollution in aquaculture: sources, impacts and mitigation techniques. Biological Trace Element Research, 1-17.

Eniola, E., Chukwu, L., & Olaide, B. (2010). Hydro-chemistry, macroinvertebrate fauna and fish production of acdja fishing sites in a Tropical Lagoonal Ecosystem. J. Am. Sci, 6(1), 22-28.

Förstner, U., & Wittmann, G. T. (2012). Metal pollution in the aquatic environment: Springer Science & Business Media.

Ibiebele, D. (1983). Effective solid waste disposal in Port Harcourt. Need for Sanitary Landfill. Paper presented at the National Conference on Development and the Environment, NISER, University of Ibadan, Nigeria.

Ighalo, J. O., & Adeniyi, A. G. (2020). A comprehensive review of water quality monitoring and assessment in Nigeria. Chemosphere, 260, 127569.

Imoobe, T., & Oboh, I. (2003). Physical and chemical hydrology of river Jamieson, Niger Delta, Nigeria. Benin Science Digest, 1, 105-119.

Jonnalagadda, S., & Mhere, G. (2001). Water quality of the Odzi River in the eastern highlands of Zimbabwe. Water research, 35(10), 2371-2376.

Juntunen, P., Liukkonen, M., Lehtola, M. J., & Hiltunen, Y. (2013). Dynamic soft sensors for detecting factors affecting turbidity in drinking water. Journal of Hydroinformatics, 15(2), 416-426.

Kanu, I., & Achi, O. (2011). Industrial effluents and their impact on water quality of receiving rivers in Nigeria. Journal of applied technology in environmental sanitation, 1(1), 75-86.

King, R., Egwali, E., & Nkanta, N. (1991). Population dynamics of the freshwater clam Galatea paradoxa (Donacidae) in the cross River, Nigeria.

Makinde, O., Edun, O., & Akinrotimi, O. (2015). Comparative assessment of physical and chemical characteristics of water in Ekerekana and Buguma Creeks, Niger Delta Nigeria. Journal of Environment Protection and Sustainable Development, 1(3), 126-133.

Marcus, A., & Ekpete, O. (2014). Impact of discharged process wastewater from an oil refinery on the physicochemical quality of a receiving waterbody in Rivers State, Nigeria. J. Appl. Chem, 7, 01-08.

Naanen, B. (2012). The Nigerian state, multinational oil corporations, and the indigenous communities of the Niger Delta. The Politics of Resource Extraction: Indigenous Peoples, Multinational Corporations and the State, 153-179.

Nwadiaro, C., & Umeham, S. (1989). The chemical hydrology of Oguta Lake, Imo State Southern Nigeria. Archiv für Hydrobiologie, 251-269.

Nwaichi, E. O., & Osuoha, J. O. (2021). Has the National policy on environmental pollution control in Nigeria been neglected in the Niger Delta region? An update. Environment, Development and Sustainability, 1-24.

Obuah, E. E., & Keke, R. C. (2022). Mitigating the Negative Externalities of Oil Drilling Activities in the Niger Delta, Nigeria. Open Access Library Journal, 9(5), 1-21.

Odum, O. (1992). The ecology and biology of the fishes of Ethiope River, Nigeria. Doctor of Philosophy), University of Benin, Benin City, Nigeria.

Ogbeibu, A., & Victor, R. (1995). Hydrobiological studies of water bodies in the Okomu Forest Reserve(Sanctuary) in southern Nigeria. 2. Physical and chemical hydrology. Tropical freshwater biology. Benin City, 4, 83-100.

Ogunlaja, A., & Ogunlaja, O. (2007). Physico-chemical analysis of water sources in ubeji community and their histological impact on organs of albino mice.

Olaleye, V., & Adedeji, A. (2005). Water and planktonic quality of a palm oil effluent impacted river in Ondo state, Nigeria. International Journal of Zoological Research, 1(1), 15-20.

Onanuga, M. Y., Eludoyin, A. O., & Ofoezie, I. E. (2022). Urbanization and its effects on land and water resources in Ijebuland, southwestern Nigeria. Environment, Development and Sustainability, 24(1), 592-616.

Onokerhoraye, A. G. (1999). Access and utilization of modern health care facilities in the petroleum-producing region of Nigeria: The case of Bayelsa State. Research paper, 162.

Onu, B., Surendran, S. S., & Price, T. (2014). Impact of inadequate urban planning on municipal solid waste management in the Niger Delta Region of Nigeria. Journal of sustainable Development, 7(6), 27.

Onwudinjo, C. (1990). The hydrology and plankton of Benin River, Nigeria. Unpublished Ph. D. thesis, University of Benin, Benin City. 355pp.

Osibanjo, O., Daso, A. P., & Gbadebo, A. M. (2011). The impact of industries on surface water quality of River Ona and River Alaro in Oluyole Industrial Estate, Ibadan, Nigeria. African Journal of Biotechnology, 10(4), 696-702.

Otokunefor, T., & Obiukwu, C. (2005). Impact of refinery effluent on the physicochemical properties of a water body in the Niger delta. Applied ecology and environmental research, 3(1), 61-72.

Oyelaran, O. A., Balogun, O., Ambali, A. O., & Abidoye, J. K. (2017). Characterization of briquette produced from tannery solid waste. Journal of Materials and Engineering Structures «JMES», 4(2), 79-86.

Singh, M. R., & Gupta, A. (2016). Water pollution-sources, effects and control. Centre for Biodiversity, Department of Botany, Nagaland University.

Sonone, S. S., Jadhav, S., Sankhla, M. S., & Kumar, R. (2020). Water contamination by heavy metals and their toxic effect on aquaculture and human health through food Chain. Lett. Appl. NanoBioScience, 10(2), 2148-2166.

WHO. (2005). Nutrients in drinking water (7117242299). Retrieved from https://www.who.int/publications/i/item/9241593989.

World bank (2021). Population, total – Nigeria. Retrieved from https://data.worldbank.org/indicator/SP.POP.TOTL?locations=NG

Zipper, C. E., Burger, J. A., Barton, C. D., & Skousen, J. G. (2013). Rebuilding soils on mined land for native forests in Appalachia. Soil Science Society of America Journal, 77(2), 337-349.