Assessment of Surface and Groundwater Quality in an Area Receiving Refinery Effluent in Ekerekana, Rivers State, Nigeria

Preye Kingsley Nimame, Ogboeli Goodluck Prince & Ibinabo Ogolo
Institute of Geo-Science and Environmental
Management, Rivers State University,
Nkpolu Oroworukwo, Port Harcourt
Corresponding Author:
Goodluck.ogboeli@ust.edu.ng
https://doi.org/10.56201/wjimt.v10.no10.2026.pg1.15

Abstract
Refinery wastewater can introduce organic pollutants, petroleum hydrocarbons, metals and microbial contaminants into receiving aquatic environments and potentially affect nearby groundwater resources. This study assessed the physicochemical, chemical, petroleum-related, metallic and microbiological characteristics of refinery effluents, Ekerekana River and nearby borehole water in the Port Harcourt refinery environment, Rivers State, Nigeria. Seven sampling locations were investigated, comprising effluent discharge points associated with the old and new refinery facilities, the effluent mixing point, a location immediately upstream of discharge into the receiving environment, a downstream river location, and two nearby boreholes. Nineteen water-quality parameters were analysed using standard laboratory procedures, and a weighted arithmetic Water Quality Index (WQI) was applied to selected parameters. Temperature ranged from 25.3 to 27.9°C, electrical conductivity from 27.7 to 388.0 µS/cm, total suspended solids from 1.26 to 4.10 mg/L and total dissolved solids from 25.8 to 194.3 mg/L. The water was generally acidic, with pH values ranging from 4.90 to 6.32. Biochemical oxygen demand, chemical oxygen demand, total petroleum hydrocarbons and iron were elevated at selected locations, while total heterotrophic bacterial counts indicated substantial microbial abundance. TPH concentrations ranged from 4.0 to 13.0 mg/L, while iron concentrations ranged from 0.319 to 1.260 mg/L. WQI values indicated substantial deterioration at several sampling locations. However, the negative WQI values reported for the boreholes require recalculation and should not be interpreted as valid water-quality classifications until the underlying computation is verified. The findings indicate that refinery-related wastewater constitutes an important potential source of water-quality degradation in the Ekerekana environment. Effective effluent treatment, regulatory monitoring, protection of domestic boreholes and provision of alternative potable-water supplies are recommended.

Keywords: *refinery effluent; Ekerekana River; groundwater; petroleum hydrocarbons; water quality index; water pollution; Rivers State; Nigeria*

1. Introduction

Water resources are fundamental to human survival, socioeconomic development and ecosystem functioning, supporting domestic water supply, agriculture, transportation, industrial activities and

aquatic ecosystems. However, increasing industrialisation and urban development place growing pressure on surface- and groundwater resources, particularly where wastewater treatment and pollution-control systems are inadequate. Industrial discharges can introduce organic matter, suspended solids, dissolved substances, petroleum hydrocarbons, metals and microorganisms into receiving waters, altering their physicochemical and biological characteristics. Studies in Nigeria have demonstrated that industrial and municipal discharges can significantly affect receiving-water quality, with implications for aquatic ecosystems and human uses (Fakayode, 2005; Jaji et al., 2007; Chindah et al., 2006).

Petroleum-refining activities are of particular environmental concern because they generate complex wastewater containing a mixture of organic and inorganic contaminants. Refinery effluents may contain petroleum hydrocarbons, phenolic compounds, suspended solids, dissolved substances and metals, depending on the refining processes, crude-oil characteristics and efficiency of wastewater treatment. Where such effluents are inadequately managed, their discharge can alter the physicochemical characteristics of receiving waters and increase the concentrations of oxygen-demanding and petroleum-related substances. Evidence from the Port Harcourt Refinery indicates that refinery effluent can influence the quality of the receiving environment, highlighting the importance of effective effluent management and monitoring (Ndem et al., 2021; Otukunefor & Obiukwu, 2005; Chukwujindu et al., 2026).

The environmental significance of petroleum-related pollution is particularly pronounced in the Niger Delta, where an extensive network of rivers, creeks, wetlands and other aquatic systems supports fishing, agriculture, transportation and domestic activities. The ecological and socioeconomic dependence on these water resources increases the potential consequences of industrial pollution. Previous studies in the region have documented deterioration in water quality associated with petroleum activities and industrial discharges. For example, Omoigberale and Ogbeibu (2007) reported changes in water-quality characteristics associated with oil exploration and production, while Chindah et al. (2006) demonstrated the influence of waste discharges on the physicochemical characteristics and biological communities of receiving streams.

Rivers State is a major petroleum-industrial centre within the Niger Delta and hosts extensive oil and gas infrastructure, including the Port Harcourt Refinery complex. The refinery operates within an environment characterised by interconnected surface-water and groundwater systems, making the management of industrial wastewater particularly important. Ekerekana River, located within the refinery-impacted environment, represents an important receiving water body for investigating the effects of refinery-related discharges. Previous research has reported changes in physicochemical characteristics associated with refinery effluent in the Niger Delta, including evidence of altered water-quality conditions following wastewater discharge (Otukunefor & Obiukwu, 2005; Ndem et al., 2021).

The quality of receiving waters is determined by the combined influence of physical, chemical and biological factors. Parameters such as pH, dissolved solids, oxygen-demanding substances, metals, petroleum hydrocarbons and microorganisms provide complementary information about the condition of an aquatic environment (Chapman, 1996; American Public Health Association et al., 1998). In particular, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) provide useful indications of biodegradable and chemically oxidisable substances, while petroleum hydrocarbons and metals may provide evidence of industrial contamination. Microbiological indicators are also important where water resources are used for domestic purposes.

Although previous investigations have generated useful information on refinery and receiving-water quality, many have focused on individual components of the pollution pathway. An integrated assessment encompassing refinery effluent, the mixing or discharge zone, receiving river water and nearby groundwater can provide a more comprehensive understanding of spatial patterns in water quality. Such an approach also allows differences between the original effluent and conditions following dilution, mixing and downstream transport to be evaluated. The importance of integrated water-quality assessment is supported by previous Nigerian studies that have examined physicochemical characteristics and biological responses in receiving-water environments (Jaji et al., 2007; Mustapha, 2008; Okparanma et al., 2016).

Groundwater assessment is particularly relevant because boreholes constitute an important source of domestic water in many Nigerian communities. However, contamination of surface water does not necessarily demonstrate contamination of groundwater. The movement of industrial contaminants into groundwater depends on factors including soil and aquifer characteristics, infiltration processes, hydraulic connectivity and groundwater flow. Consequently, groundwater quality requires independent assessment rather than being inferred from the condition of adjacent surface water. This distinction is important because the Nigerian Standard for Drinking Water Quality provides specific requirements for water intended for human consumption (Nigerian Industrial Standards, 2015).

Assessment of water quality also requires appropriate interpretation of individual parameters against relevant standards. Drinking water should be evaluated using applicable drinking-water requirements, whereas industrial effluent should be assessed against appropriate environmental and discharge standards. The regulatory framework provided by the National Environmental Standards and Regulations Enforcement Agency (NESREA) is therefore relevant to environmental pollution control in Nigeria (National Environmental Standards and Regulations Enforcement Agency, 2007). This distinction is essential because applying drinking-water criteria directly to industrial effluent may result in inappropriate interpretation of pollution levels.

The Water Quality Index (WQI) provides an additional approach for synthesising information from multiple water-quality parameters. Water-quality indices convert individual measurements into numerical ratings and combine them to provide an overall indication of water-quality status (Brown et al., 1970; Yisa & Jimoh, 2010; Abbasi & Abbasi, 2012). The approach can simplify interpretation of complex datasets and facilitate communication of water-quality conditions. However, WQI results are dependent on the parameters selected, reference standards, weighting scheme and mathematical formulation; consequently, the index should complement rather than replace assessment of individual water-quality parameters.

Against this background, the present study assesses the physicochemical, chemical, petroleum-related, metallic and microbiological characteristics of refinery effluents, Ekerekana River and nearby borehole water. It further evaluates overall water-quality status using WQI and examines the spatial behaviour of selected contaminants along the direction of river flow. By integrating refinery effluent, receiving surface water and groundwater within a common assessment framework, the study provides baseline evidence for understanding water-quality conditions in the Ekerekana refinery environment and supports improved monitoring, pollution management and protection of aquatic and domestic water resources.

2. Materials and Methods

Study Area: The study was conducted in the Ekerekana River environment in Rivers State, Nigeria, within the vicinity of the Port Harcourt refinery complex. Sampling locations were established

around the refinery effluent-discharge canal and along the receiving Ekerekana River, including the area around Afibulu Street.

Ekerekana River forms part of the coastal aquatic environment of the Niger Delta and is influenced by tidal processes. The surrounding area comprises communities whose livelihoods include fishing and other activities dependent on aquatic resources. Residents reportedly undertake domestic activities using water from the river, while some households obtain drinking water from privately owned boreholes.

The proximity of refinery wastewater discharge pathways to domestic water sources makes the area environmentally important for assessing potential surface-water and groundwater quality concerns.

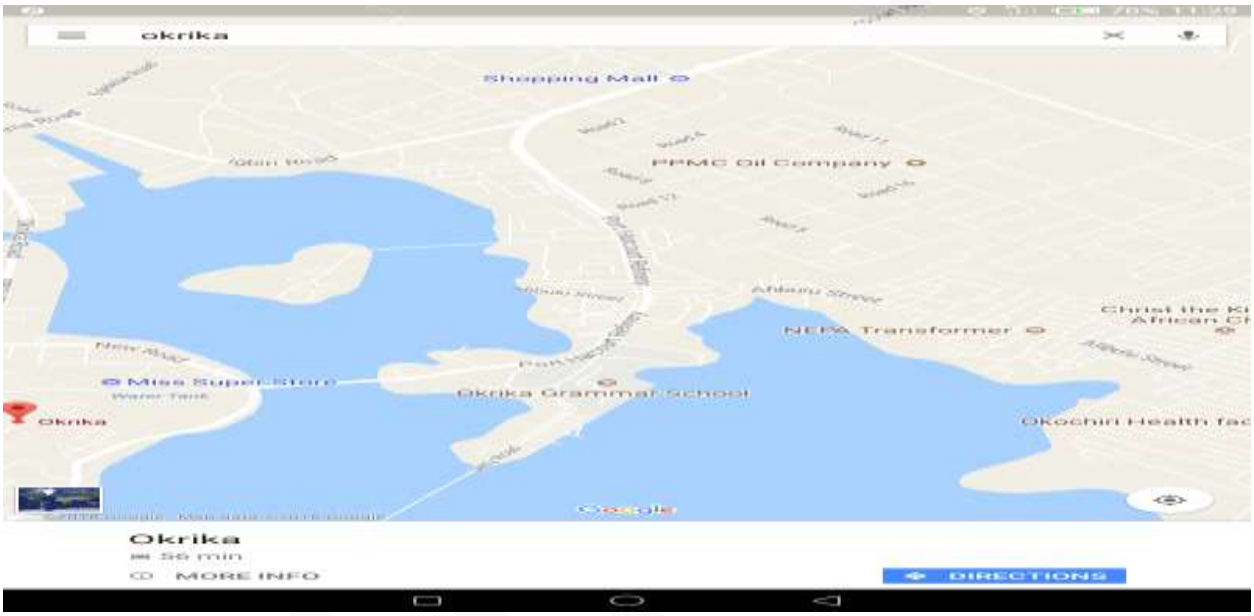


Figure 1. Map showing the study area and sampling locations in the Ekerekana environment. *Source: Google Earth/Google Maps and authors' field data. The final manuscript should replace this with a properly prepared GIS map showing coordinates, refinery facilities, river course, discharge point and borehole locations.*

Study Design and Sampling Locations: A cross-sectional environmental water-quality assessment was conducted using seven sampling locations. The sampling design represented different stages of the refinery wastewater pathway: EW-OS: effluent from the old refinery, EW-NS: effluent from the new refinery, EW-MP: mixing point of old- and new-refinery effluents, EW-BD10: location approximately 10 m before discharge into the receiving environment, EW-DS50: river water approximately 50 m downstream of the discharge point, BH1: nearby domestic borehole, BH2: nearby domestic borehole.

Water Sample Collection: Water samples were collected in appropriately labelled sterile plastic and glass containers. Samples were placed in a cooler containing ice immediately after collection and transported to the laboratory for analysis. Sampling containers, preservation procedures and holding times should be reported separately for each parameter group in the final manuscript because requirements differ among microbiological, physicochemical and organic analyses.

Water-Quality Parameters: Nineteen parameters were analysed pH, temperature, electrical conductivity, total dissolved solids, total suspended solids, chloride, sulphate, salinity, sodium, potassium, magnesium, zinc, iron, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total petroleum hydrocarbons, polycyclic aromatic hydrocarbons and total heterotrophic bacterial count.

Physicochemical Analysis: Temperature, pH, electrical conductivity and related field parameters were measured using calibrated instruments. The original study reports the use of a Mettler Toledo 320 pH meter. pH measurements were conducted on water samples after agitation and equilibration. Dissolved Oxygen, BOD_5 and COD: Dissolved oxygen and biochemical oxygen demand were determined using standard water-analysis procedures. BOD_5 represents the oxygen consumed by microorganisms during biological degradation of biodegradable organic matter over a five-day incubation period. Chemical oxygen demand was determined using the dichromate oxidation method. The original manuscript describes refluxing the sample with potassium dichromate and sulphuric acid followed by titration with ferrous ammonium sulphate.
Chloride and Sulphate: Chloride was determined by argentometric titration using silver nitrate and potassium chromate indicator. Sulphate was determined using the laboratory procedure specified in the original analytical records.

Petroleum Hydrocarbons: Total petroleum hydrocarbons were determined using gas chromatography with flame ionisation detection (GC-FID). The manuscript reports the use of a procedure based on USEPA Method 8015 and quantification over the C8–C40 hydrocarbon range. However, the original description incorrectly refers to "soil sample" extraction in a study of water. This should be corrected to describe the actual water-sample extraction procedure. The solvent, extraction volume, extraction method, surrogate/internal standards, calibration range, recovery, detection limit and quality-control procedures should also be reported. Microbiological Analysis: Total heterotrophic bacterial counts were determined using culture-based procedures. Samples were inoculated onto nutrient agar and incubated at approximately 28°C for 24 hours. Representative colonies were subjected to morphological and biochemical characterisation. Metal Analysis: Iron, zinc, magnesium, calcium, sodium and potassium were analysed using atomic absorption spectrophotometry or the appropriate instrumental method. The final manuscript should provide the specific instrument model, wavelength, detection limits, digestion procedure, calibration range and analytical quality-control procedures.
Water Quality Index: The weighted arithmetic Water Quality Index method was applied. For each parameter the quality rating scale (Q_n) was calculated as:

$$Q_n = 100\left(\frac{V_n - V_i}{V_s - V_i}\right)$$

where $V_n$is the measured concentration of the n-th parameter, $V_i$is the ideal value, and $V_s$is the recommended standard value.
The unit weight (W_n) of each parameter was obtained from:

$$W_n = \frac{k}{V_s}$$

in which the proportionality constant $k$is defined as:

$$k = \frac{1}{\sum(1/V_s)}$$

The overall Water Quality Index was then computed as:

$$\text{WQI} = \frac{\sum Q_n W_n}{\sum W_n}$$

Ideal values (V_i) were set to zero for most parameters; for pH, $V_i = 7$, and for dissolved oxygen, $V_i = 14.6\text{mg L}^{-1}$.

Spatial Predictive Analysis: Relationships between selected water-quality parameters and distance from pollution sources were examined using regression models. Although the original analysis described quadratic formulations, the reported results correspond to linear models; the present account therefore treats the relationships as linear.

3. Results

Physicochemical Characteristics

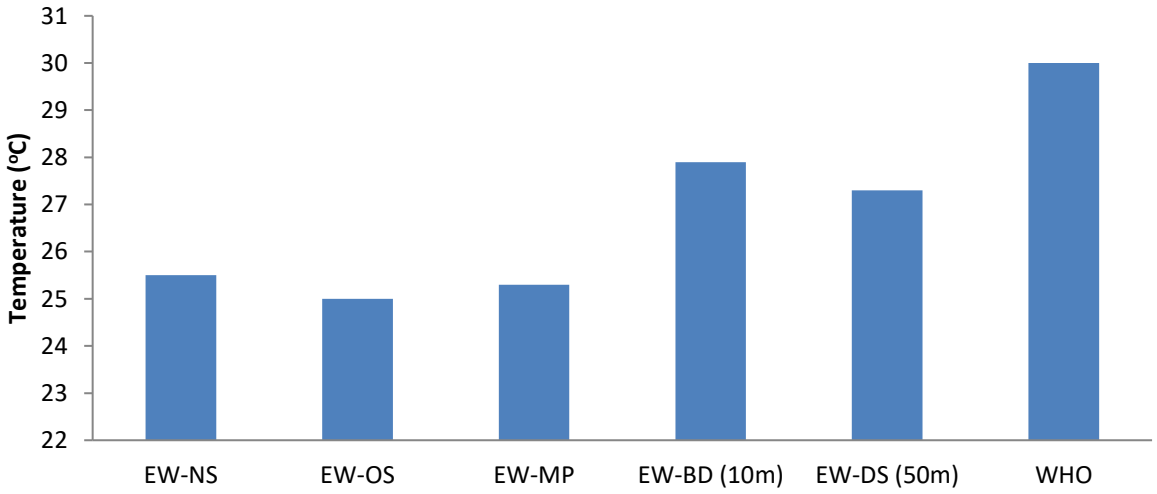


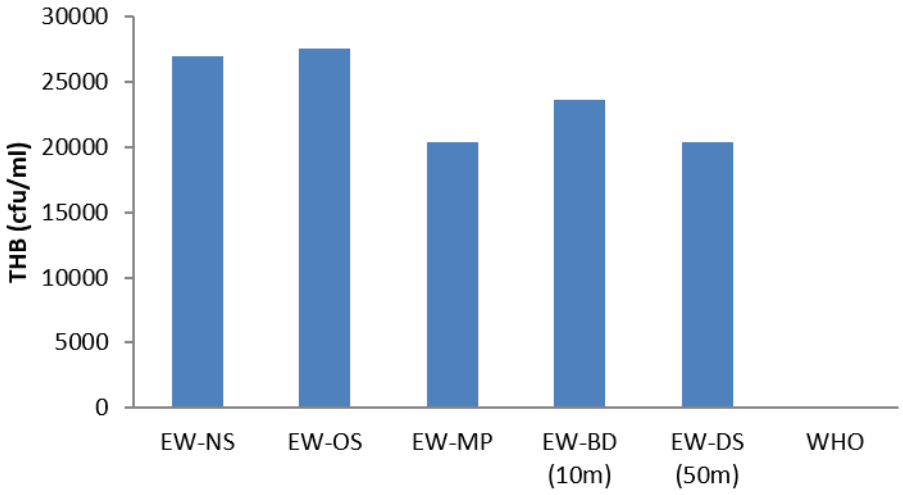
Figure 4.1: Temperature profile of sampling points compared to WHO recommended limit

Temperature across the sampling locations ranged from approximately 25.3 to 27.9°C. The observed values showed relatively limited spatial variation. Temperature in tropical aquatic systems is influenced by solar radiation, time of sampling, cloud cover, water depth, shading, flow conditions and tidal processes.

Electrical conductivity ranged from 27.7 to 388.0 µS/cm, while TDS ranged from 25.8 to 194.3 mg/L. TSS ranged from 1.26 to 4.10 mg/L. These relatively low TSS concentrations indicate that suspended particulate loading was not pronounced at the time of sampling. However, low TSS does not establish that the water is ecologically or chemically uncontaminated because dissolved pollutants and microbiological contaminants may remain present.

The study recorded acidic water conditions, with pH values ranging from 4.90 to 6.32. The acidic condition is environmentally important because pH influences metal mobility, chemical speciation and biological processes.

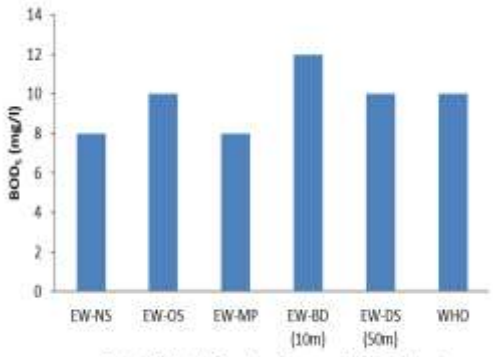
Microbiological Characteristics



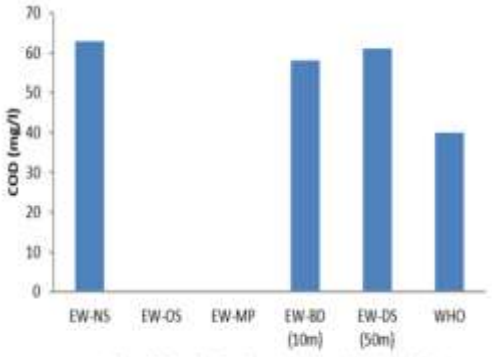
Selected Points in Ekerekana River and WHO Stardard

Total heterotrophic bacterial counts were elevated at the sampled locations. The reported values were in the order of (10^4) CFU/mL at several locations, with the highest reported concentration approximately (2.76\times10^4) CFU/mL.
The elevated THB values indicate substantial culturable bacterial abundance. However, THB alone cannot establish faecal contamination or the presence of specific pathogens. Consequently, the microbiological findings should be interpreted as evidence of elevated general heterotrophic bacterial abundance rather than direct evidence of disease-causing organisms.

Biochemical and Chemical Oxygen Demand



Selected Points in Ekerekana Stream and WHO Standard



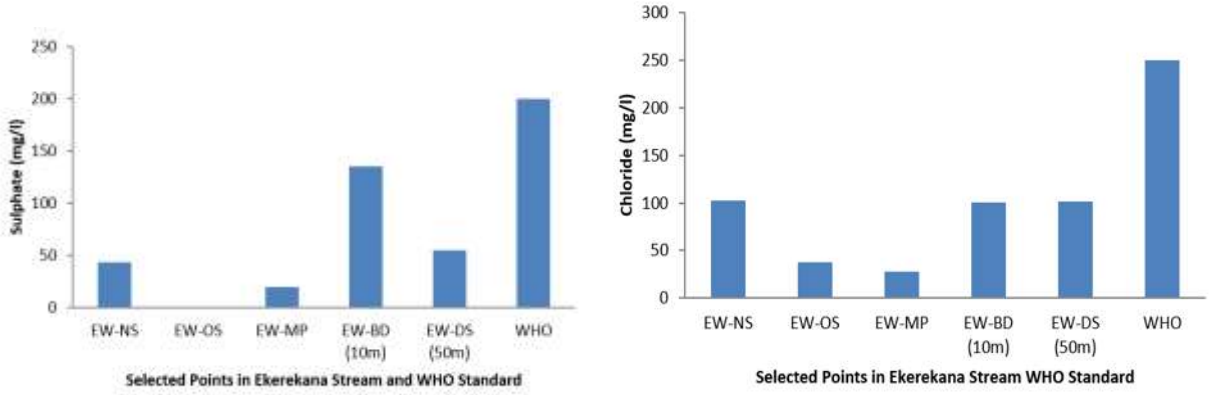
Selected Points in Ekerekana Stream and WHO Standard

BOD_5 concentrations were elevated at several locations. The original manuscript reports values ranging from 10.20 to 24.76 mg/L and a mean concentration of 15.14 mg/L, while the abstract

reports a different range of 8–12 mg/L. This discrepancy must be resolved against the original laboratory dataset before publication.

COD was elevated at selected sampling points, with reported values including 63 mg/L at EW-NS, 58 mg/L at EW-BD10 and 61 mg/L at EW-DS50. Other reported values include 45 mg/L before discharge and approximately 66 mg/L after discharge, while an additional value of 128 mg/L is reported for an effluent location. These values should be reconciled with the laboratory results and presented in a single verified results table.

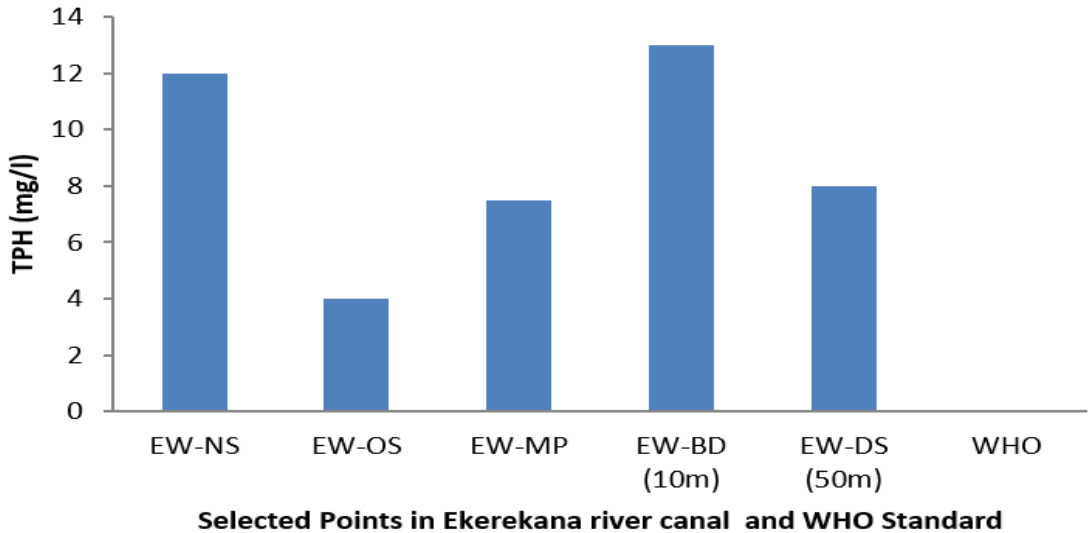
Sulphate and Chloride



Reported sulphate concentrations ranged from below 1 mg/L to approximately 135 mg/L. The highest value occurred at EW-BD10. Chloride concentrations were reported to remain below the drinking-water benchmark used in the original analysis.

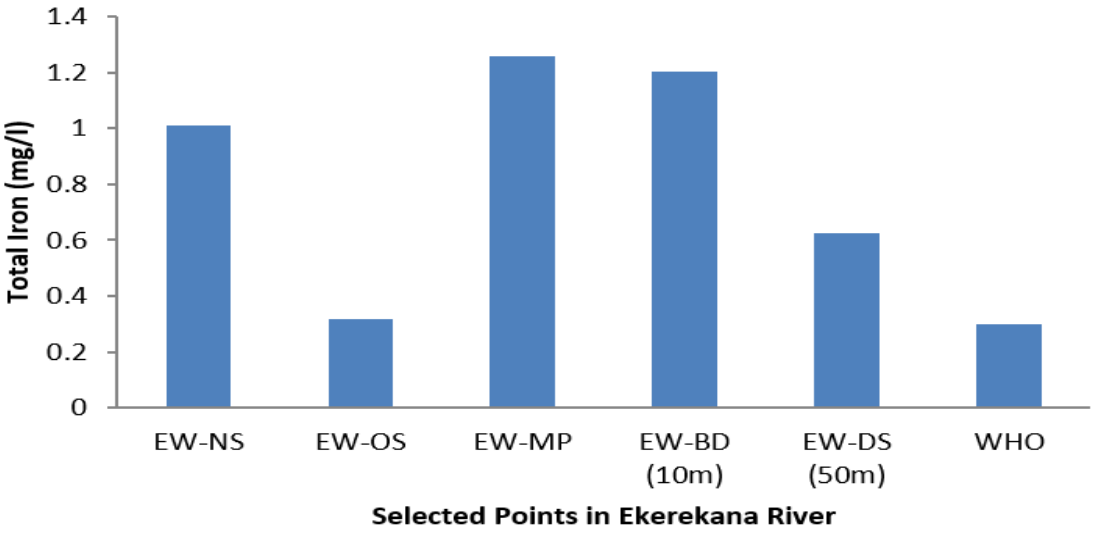
The relatively moderate concentrations of chloride and sulphate indicate that these parameters were not the dominant indicators of contamination in the sampled water. However, their spatial distribution may be influenced by tidal exchange, saline intrusion and effluent mixing.

Petroleum Hydrocarbons



TPH concentrations ranged from 4.0 to 13.0 mg/L. The highest reported value occurred at EW-BD10, while the lowest was recorded at EW-OS.
The presence of TPH at the refinery effluent and downstream locations indicates petroleum-related contamination. Because TPH is a composite measure of hydrocarbon fractions, the environmental interpretation would be strengthened by reporting individual hydrocarbon fractions and PAHs.

Metallic Characteristics



Iron concentrations ranged from 0.319 to 1.260 mg/L. The highest reported concentration occurred at the effluent mixing point, while the lowest was recorded at the old-refinery effluent location.
The elevated iron concentrations indicate that iron was an important component of the measured inorganic contaminant load. Potential sources include refinery-related processes, corrosion, suspended mineral material and natural geochemical contributions. However, source attribution cannot be established from iron concentrations alone.
The manuscript also reports zinc and other metals, but their numerical results are not sufficiently presented in the supplied version. A complete table of all metal concentrations is required for publication.

Water Quality Index
Reported WQI values were:

Sampling location	Reported WQI
EW-OS	94.63
EW-NS	274.39
EW-MP	347.46
EW-BD10	321.28
EW-DS50	166.95
BH1	−188.34
BH2	−103.43

The values indicate substantial variation among sampling locations, with the highest positive WQI values at the effluent mixing and pre-discharge locations. However, the negative values reported for BH1 and BH2 are methodologically questionable and require recalculation from the original parameter dataset.
The WQI results should therefore be considered provisional until the calculation is independently verified.

Spatial Relationships

The original analysis reported high coefficients of determination for the relationships between distance from pollution sources and selected parameters: total heterotrophic bacteria (THB; $R^2 = 0.9941$), biochemical oxygen demand (BOD; $R^2 = 0.9899$), chemical oxygen demand (COD; $R^2 = 0.9965$) and iron ($R^2 = 0.9868$).
These apparently strong associations must be interpreted with caution. Because the regressions were based on a very small number of spatial observations, the elevated R^2values may reflect overfitting rather than robust predictive relationships. High coefficients of determination obtained from limited sampling points should not be regarded as evidence of reliable predictive performance in the absence of independent validation.

4. Discussion

The findings indicate that the Ekerekana refinery environment exhibits varying degrees of water-quality degradation, particularly with respect to acidity, oxygen-demanding substances, petroleum hydrocarbons, iron and microbial abundance. This pattern is consistent with the complex composition of petroleum-refinery wastewater, which may contain hydrocarbons, phenols, sulphides, suspended and dissolved solids, nutrients and metals. The composition and environmental effects of refinery effluent vary with crude-oil characteristics, refining processes, operational conditions and treatment efficiency (Kumar et al., 2022; Thorat & Sonwani, 2022; Ogboeli et al., 2024). The acidic pH values recorded at several sampling locations are environmentally important because pH influences metal solubility, chemical speciation, nutrient availability and microbial activity. However, pH should be interpreted according to the type and intended use of the sampled water. WHO does not prescribe a health-based guideline value for pH, but recognises it as an important operational parameter affecting treatment, corrosion and disinfection (World Health Organization [WHO], 2022)? Therefore, refinery effluent should be evaluated against applicable industrial-effluent requirements, while borehole water should be assessed against relevant drinking-water standards. Elevated BOD and COD at selected locations indicate organic and chemically oxidisable pollutant loading. Refinery wastewater commonly contains petroleum hydrocarbons and phenolic compounds capable of contributing to oxygen demand (Kumar et al., 2022; Thorat & Sonwani, 2022). Sustained organic loading may reduce dissolved oxygen through microbial decomposition and consequently stress aquatic organisms (Neff et al., 2005). However, because the present study provides limited dissolved-oxygen and biological-community data, the findings demonstrate pollutant loading rather than definitive ecological impairment. Similarly, the relatively low TSS and TDS observed at some locations do not necessarily indicate good overall water quality, since petroleum hydrocarbons, metals and microbiological contaminants may remain elevated despite low solids concentrations.
TPH was detected in refinery-associated surface-water samples, confirming the presence of petroleum-related contamination within the study environment. The relatively high concentration

at EW-BD10 may reflect proximity to the discharge pathway, while its continued detection at EW-DS50 suggests that petroleum hydrocarbons remained measurable downstream. Such persistence is consistent with the complex nature of refinery-derived hydrocarbon mixtures (Kumar et al., 2022; Thorat & Sonwani, 2022). Nevertheless, TPH is a broad indicator and cannot establish the toxicity of individual hydrocarbon constituents. Further investigation should therefore include hydrocarbon fractions and priority polycyclic aromatic hydrocarbons (PAHs), together with sediment and biota where appropriate. Elevated iron at selected sampling points indicates a potential metal-related water-quality concern. Iron may originate from industrial processes, corrosion, particulate matter and natural mineral dissolution; hence, the higher concentration near the effluent mixing area suggests a possible industrial contribution but does not establish source attribution. Iron and zinc should also be interpreted independently because their concentrations, sources and environmental behaviour differ. Groundwater metals should be compared with applicable drinking-water standards, while source attribution would require hydrogeological information such as borehole depth, screened interval, hydraulic gradient and groundwater-flow direction. The high THB counts indicate substantial bacterial abundance but do not establish faecal contamination or the presence of pathogens. Consequently, describing the detected organisms as opportunistic pathogens is unsupported without appropriate microbial identification. For domestic-water assessment, *Escherichia coli* and total coliforms provide more specific evidence of faecal contamination, with pathogen-specific analyses conducted where warranted (WHO, 2022). The elevated THB values should therefore be regarded as an indication of increased bacterial abundance and a basis for further microbiological investigation rather than direct evidence of waterborne disease risk. The inclusion of BH1 and BH2 provides useful information on groundwater conditions within the refinery environment. However, the presence of contaminants in groundwater cannot, by itself, establish contamination by refinery effluent. Demonstrating such a relationship requires evidence of groundwater-flow direction, hydraulic gradient, aquifer characteristics, borehole construction, proximity to contamination sources and preferably background or control boreholes. The groundwater findings should therefore be interpreted as evidence of groundwater-quality conditions within the refinery-impacted vicinity rather than definitive proof of refinery-derived aquifer contamination. The WQI results provide an integrated summary of water-quality conditions, with the relatively high positive values at EW-NS, EW-MP and EW-BD10 indicating substantial deterioration under the adopted classification system. WQI is useful for integrating multiple parameters into a single index, but its interpretation depends on the selected parameters, standards, weights, ideal values and calculation method (Brown et al., 1972; Sahu & Sikdar, 2008; Ogboeli et al., 2024). It should therefore complement, rather than replace, parameter-specific assessment. The negative WQI values reported for BH1 and BH2 require particular attention. Such values are inconsistent with the expected behaviour of conventional weighted arithmetic WQI formulations and should be independently recalculated. The underlying concentrations, permissible limits, ideal values, quality ratings and unit weights should be presented transparently to ensure reproducibility (Brown et al., 1972; Sahu & Sikdar, 2008). The reported WQI values should consequently be treated cautiously until the calculations are verified. The observed relationships between distance from the discharge pathway and selected contaminants provide preliminary evidence of spatial variation. Such variation may result from dilution, dispersion, sedimentation, biodegradation, chemical transformation or additional pollutant inputs. However, the high reported R^2 values should not be interpreted as evidence of validated predictive models because the number of sampling locations was limited and

observations along the same river may exhibit spatial dependence. The absence of confidence intervals, residual diagnostics, significance testing and independent validation further restricts model interpretation. These relationships are therefore better described as exploratory spatial associations. Overall, the study demonstrates multiple water-quality pressures within the Ekerekana refinery environment, particularly acidity, oxygen-demanding substances, petroleum hydrocarbons, iron and microbial abundance. The findings are broadly consistent with the recognised environmental complexity of refinery wastewater (Kumar et al., 2022; Neff et al., 2005; Thorat & Sonwani, 2022). Although the spatial patterns suggest that refinery wastewater may contribute to contamination around discharge and mixing zones, the available evidence does not establish that all contaminants originate exclusively from refinery operations or that refinery effluent has definitively contaminated the underlying aquifer. The integrated assessment of refinery effluent, river water and groundwater represent an important strength of the study. Nevertheless, future investigations should incorporate seasonal sampling, control locations, detailed hydrogeological characterisation, petroleum fractions and PAHs, pathogen-specific microbiological analyses and independently verified WQI calculations. These measures would strengthen contaminant-source attribution and improve understanding of pollutant transport and water-resource risks within the Ekerekana refinery environment.

5. Study Limitations

This study has several limitations that should be considered when interpreting the findings. First, the seven sampling locations provide limited spatial coverage and may not fully represent contaminant variability within the refinery–river–groundwater system. Second, the limited sampling period restricts assessment of seasonal and temporal variations associated with rainfall, river discharge, tidal influence and changes in refinery operations.

Third, the absence of a clearly defined upstream or background control site limits definitive attribution of observed contamination to refinery effluent. Fourth, groundwater assessment was based on only two boreholes, with limited hydrogeological information on borehole depth, screened intervals, static water levels and groundwater-flow conditions, thereby restricting assessment of contaminant transport and source attribution. Fifth, the negative WQI values reported for BH1 and BH2 require independent verification, including review of the selected parameters, standards, weights and calculation procedure. Sixth, inconsistencies in reported values, particularly for BOD, temperature and TDS, should be reconciled against the original laboratory records before publication.

Seventh, reliance on total heterotrophic bacterial counts (THB) limits microbiological interpretation because THB does not directly indicate faecal contamination or specific pathogens. Finally, the regression analyses were based on few spatial observations and lacked independent validation; therefore, the high R^2 values should be interpreted as exploratory spatial associations rather than definitive predictive relationships.

6. Conclusion

This study demonstrates evidence of water-quality degradation within the Port Harcourt refinery–Ekerekana River environment, particularly in relation to acidic conditions, elevated oxygen-demanding substances, petroleum hydrocarbons, iron and heterotrophic bacterial abundance. The findings suggest that refinery wastewater and other local pollution sources may contribute to deterioration of the receiving aquatic environment.

The detection of contaminants in nearby boreholes highlights the need for continued groundwater monitoring; however, the available evidence does not establish refinery effluent as the definitive source of groundwater contamination. Similarly, the WQI results indicate deterioration at several sampling points, but the negative values reported for BH1 and BH2 require recalculation before definitive groundwater classifications are made.

The study underscores the need for effective refinery wastewater treatment, regular monitoring of Ekerekana River and surrounding groundwater, and protection of domestic water sources. Strengthened regulatory enforcement, routine water-quality surveillance and provision of safe alternative water supplies are recommended to reduce potential environmental and public-health risks in the affected communities.

7. Recommendations

1. Refinery wastewater treatment and regulatory monitoring: Refinery effluent should undergo effective treatment and quality verification before discharge, while environmental regulators should routinely monitor effluent and Ekerekana River using applicable Nigerian industrial-effluent and environmental standards.
2. Protection and monitoring of domestic water sources: Boreholes near industrial discharge pathways should be periodically tested for physicochemical, petroleum-related, metallic and microbiological contaminants, while reliable potable-water supplies should be provided to reduce dependence on potentially vulnerable water sources.
3. Improved spatial and temporal monitoring: Future studies should incorporate upstream/background controls, multiple downstream sampling points, additional boreholes and seasonal sampling to improve assessment of contaminant distribution, transport and source attribution.
4. Enhanced contaminant and groundwater assessment: Future investigations should include detailed hydrogeological parameters, petroleum fractions and priority PAHs, as well as specific microbiological indicators such as *E. coli* and total coliforms, particularly where domestic-water safety is concerned.
5. Strengthened WQI methodology: WQI calculations should be independently verified and transparently reported, including the parameters, standards, quality ratings, unit weights and classification thresholds used, to ensure accuracy and reproducibility.

References

Abbasi, T., & Abbasi, S. A. (2012). *Water quality indices*. Elsevier.

American Public Health Association, American Water Works Association, & Water Environment Federation. (1998). *Standard methods for the examination of water and wastewater* (20th ed.). American Public Health Association.

Brown, R. M., McClelland, N. I., Deininger, R. A., & Tozer, R. G. (1970). A water quality index—Do we dare? *Water and Sewage Works, 117*(10), 339–343.

Chapman, D. (Ed.). (1996). *Water quality assessments: A guide to the use of biota, sediments and water in environmental monitoring* (2nd ed.). E & FN Spon.

Chindah, A. C., Braide, S. A., Obianefo, F., & Obunwo, C. C. (2006). Water quality and periphyton community of a stream system receiving municipal waste discharges in Rivers State, Niger Delta, Nigeria. *Estudios de Biología, 28*(64), 73–89.

Chukwujindu, I.C., Gobo, A. E. & Ogboeli, G. P. (2026). Assess The Frequency, Intensity, and Spatial Patterns of Flooding and Erosion Hazards Across Ogbaru Local Government Area, Anambra State, Nigeria. IRE Journals 10(2) 1735-1747 DOI: https://doi.org/10.64388/IREV10I2-1722450

Fakayode, S. O. (2005). Impact assessment of industrial effluent on water quality of the receiving Alaro River in Ibadan, Nigeria. *AJEAM-RAGEE*, 10, 1–13.

Federal Environmental Protection Agency. (1991). *Guidelines and standards for environmental pollution control in Nigeria*. FEPA.

Jaji, M. O. O., Bamgbose, O., Odukoya, O., & Arowolo, T. A. (2007). Water quality assessment of Ogun River, southwestern Nigeria. *Environmental Monitoring and Assessment, 133*, 473–482.

Lekwot, V. E., Adamu, I. C., & Chikogu. (2012). Public health effect of effluent discharge of Kaduna Refinery into River Romi, Kaduna. *Greener Journal of Medical Sciences, 2*(3), 61–69.

Mustapha, M. K. (2008). Assessment of the water quality of Oyun Reservoir, Offa, Nigeria, using selected physicochemical parameters. *Turkish Journal of Fisheries and Aquatic Sciences, 8*, 309–319.

National Environmental Standards and Regulations Enforcement Agency. (2007). *National Environmental Standards and Regulations Enforcement Agency (Establishment) Act, 2007*. Federal Republic of Nigeria.

Ndem, B. E., Unuafe, B. O., & Egbe, J. E. (2021). Economic impacts of effluent composition of a process industry on the receiving environment: A study of Port Harcourt Refining Company. *Advance Journal of Economics and Marketing Research, 1*(1).

Nigerian Industrial Standards. (2015). *Nigerian Standard for Drinking Water Quality (NIS 554:2015)*. Standards Organisation of Nigeria.

Nwankwo, A. C., & Aribibia, A. (2019). [The complete and verified bibliographic details of this study should be inserted after checking the original publication.]

Ogboeli G. P. N., Chilaka, S. N. & Dan, I. C. (2024). River Basin Network Channel and Flood Menace Control in Greater Port Harcourt, Rivers State. *Global Scientific Journal* 12 (12):47-53

Ogboeli G. P. N., Chilaka, S. N., Abam, T. K. S., Onwuteka, J.N. (2024). Spatial Map Flood Vulnerability Matrix of Communities in the Greater Port Harcourt. *International Journal Multidisciplinary Research in Science, Engineering and Technology*, 7(11):16416-16431

Okparanma, R. N., Jumbo, R. B., & Chukwu, F. N. (2016). Combined effects of municipal and industrial wastes on the quality of the New Calabar River, Nigeria. *International Journal of Water Resources and Environmental Engineering, 8*(8), 103–112.

Omoigberale, M. O., & Ogbeibu, A. E. (2007). Assessing the environmental impacts of oil exploration and production on the water quality of Osse River, southern Nigeria. *Global Journal of Environmental Sciences, 6*(1), 1–14.

Otukunefor, T. V., & 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.

Total Petroleum Hydrocarbon Criteria Working Group. (1998). *Composition of petroleum mixtures*. Amherst Scientific Publishers.

United States Environmental Protection Agency. (1996). *Method 8015: Nonhalogenated organics using GC/FID*. U.S. Environmental Protection Agency.

World Health Organization. (2022). *Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda*. World Health Organization.

World Health Organization. (2022). *Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda*. World Health Organization.

World Health Organization. (2026). *Guidelines for drinking-water quality: Fourth edition incorporating the first, second, and third addenda*. World Health Organization.

Yisa, J., & Jimoh, T. (2010). Analytical studies on water quality index of River Landzu. *American Journal of Applied Sciences, 7*(4), 453–458.