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Implications of Gas Flaring on Hydrocarbon and Heavy Metal Load Emission in the Lower Qua Iboe River Basin, Nigeria

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Abstract

This research investigates the impact of gas flaring on hydrocarbon and heavy metal load in the Lower Qua Iboe River Basin, a region within the oil-rich Niger Delta of Nigeria. While the economic benefits of oil and gas production are evident, the environmental and health consequences of gas flaring remain a significant concern. This study addresses a gap in recent, localized data regarding the specific effects of both onshore and offshore gas flaring on water quality. Water samples from ten purposively selected communities were analyzed for twenty parameters, including physicochemical properties, total coliform, and heavy metals. To complement this, 352 questionnaires and focus group discussions were used to gather data from residents. Furthermore, heavy metal analysis showed higher mean concentrations during the dry season, with Arsenic at 0.5260 mg/L, Cadmium at 0.6700 mg/L, and Copper at 0.7500 mg/L. Regarding TPH concentrations, finding shown that the water was contaminated with levels significantly above WHO guidelines. The findings were compared to previous research, which confirmed the link between gas flaring and persistent hydrocarbon pollution. The study concluded that the concentration of pollutants is directly influenced by proximity to the flare sites, with communities closer to flares showing higher levels of contamination and associated health risks. The findings highlight the urgent need for a multi-level mitigation approach to protect this vital water resource and the health of the local population.

Keywords

Gas flaring; Hydrocarbons; Heavy metals; Nigeria

1. Introduction

Gas flaring is an anthropogenic activity that characterizes the controlled combustion of natural gas and other associated gases, which contribute to global warming, resulting in wasteful emissions by upstream oil firms in oil fields during normal or unplanned over pressuring operation in many industrial processes, such as oil extraction. Combustion of fossil fuels such as Associated Petroleum Gas (APG) results in the emission of other greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), ethane, propane, isobutane, n-butane, isopentane, n-pentane, n-hexane, Hydrogen Sulphide (H_2S), Helium (He) and Nitrogen gas (N_2) [1].

Gas flaring, the practice of burning off excess natural gas during crude oil extraction, is a major source of environmental pollution, with significant implications for surface water quality [1]. This review examines existing literature on the effects of gas flaring on hydrocarbon and heavy metal concentrations in surface water, particularly in the Niger Delta region of Nigeria.

Gas flaring involves the incomplete combustion of hydrocarbons, which releases a cocktail of pollutants into the atmosphere, including unburned hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs) [2]. These pollutants are then deposited into the surrounding environment through atmospheric fallout and acid rain, contaminating surface water bodies [3].

Studies have consistently shown the presence of Total Petroleum Hydrocarbons (TPH) in surface waters near gas flare sites. For instance, research conducted in the Niger Delta found that TPH concentrations were significantly higher in water bodies closer to flare stacks compared to control sites [4]. The constant nature of flaring means that this pollution is persistent and not solely dependent on seasonal changes, leading to a constant input of hydrocarbons into aquatic ecosystems [5].

This hydrocarbon contamination can lead to several negative impacts. It can form an oily film on the water surface, which reduces oxygen exchange and harms aquatic organisms [6]. Furthermore, many of these hydrocarbon compounds are toxic and can be carcinogenic to humans and animals, posing a direct threat to the health of communities that rely on these water sources for drinking and other domestic uses [7].

In addition to hydrocarbons, gas flaring also releases particulate matter that contains various heavy metals. These metals, including lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), and nickel (Ni), are carried by wind and eventually settle in soil and water bodies [8]. Unlike hydrocarbons, many of these heavy metals are non-biodegradable and tend to accumulate in the sediment and living organisms over time, a process known as bio-accumulation [9].

Multiple studies have documented elevated concentrations of heavy metals in surface water and sediment near gas flaring sites. For example, a study in Delta State, Nigeria, found higher levels of copper (Cu), zinc (Zn), and iron (Fe) in water samples from gas flare-impacted locations compared to control sites [10]. Another study highlighted that while some heavy metal concentrations might be within permissible limits, their persistent presence represents a gradual increase in pollution over time [10].

The concentration of these heavy metals can be influenced by seasonal changes. During the dry season, reduced rainfall leads to less dilution, which can result in higher concentrations of pollutants in surface water [11]. This seasonal variability in concentration, combined with the continuous emission from flare stacks, creates a dynamic and complex pollution problem [12]. The presence of these metals is a major health concern, as prolonged exposure can lead to various diseases, including kidney damage, neurological disorders, and cancer [13].

Gas flaring releases a complex mixture of pollutants, including greenhouse gases (CO2, methane), particulate matter, sulfur dioxide (SO2), nitrogen oxides (NOx), volatile organic compounds (VOCs), and trace metals into the environment [4, 5]. These emissions contribute to climate change and have direct local impacts, such as acid rain, elevated temperatures, and contamination of soil and water resources. The deposition of these pollutants from gas flaring into nearby surface water bodies poses a serious threat to water quality [16].

Recent studies have shown that gas flaring contributes significantly to environmental pollution globally, with the World Bank reporting over 140 billion cubic meters of gas flared annually [6, 7]. For Nigeria alone, oil firms flared 211.73 million cubic meters of gas in 2023, contributing to the country's status as a major emitter of greenhouse gases in Africa [8, 9]. This practice represents a colossal waste of resources, estimated at 2.5 billion USD annually, and is a major source of contaminants like polycyclic aromatic hydrocarbons (PAHs) and heavy metals, which deteriorate the environment and affect public health in nearby communities [13, 14].

Previous research has documented hydrocarbon pollution and heavy metal accumulation in water bodies near oil facilities. However, there is a lack of recent, localized studies that specifically investigate the combined effects of onshore and offshore gas flaring on surface water quality in the Lower Qua Iboe River Basin. This knowledge gap limits the ability of policymakers and environmental regulators to implement targeted interventions and develop sustainable management strategies. Therefore, this study aims to:

1. Identify and map gas flaring sites in the study area.
2. Examine the variation in water physicochemical properties between the wet and dry seasons at gas flaring sites and compare the results with the WHO water quality standards.
3. Analyze the variation of heavy metals in surface water samples between the wet and dry seasons and compare the results with WHO standards.
4. Suggest measures that could curtail water pollution from gas flaring sites.

2. Materials and Methods

2.1 Study Area

This study was conducted in the Lower Qua Iboe River Basin, located in Akwa Ibom State, Nigeria. The basin is a

hydrologically important area that flows from the northern parts of the state into the Atlantic Ocean near Ibeno. The river system, which includes winding courses through coastal plains, marshes, and wetlands, serves as a primary water source for numerous communities for domestic use, fishing, and agriculture. The region is characterized by a tropical rainforest climate, with distinct wet (March to October) and dry (November to February) seasons. The Lower Qua Iboe River is a tidal system, and its hydrology is influenced by seasonal rainfall, runoff, and the tidal actions of the Atlantic Ocean [10, 11].

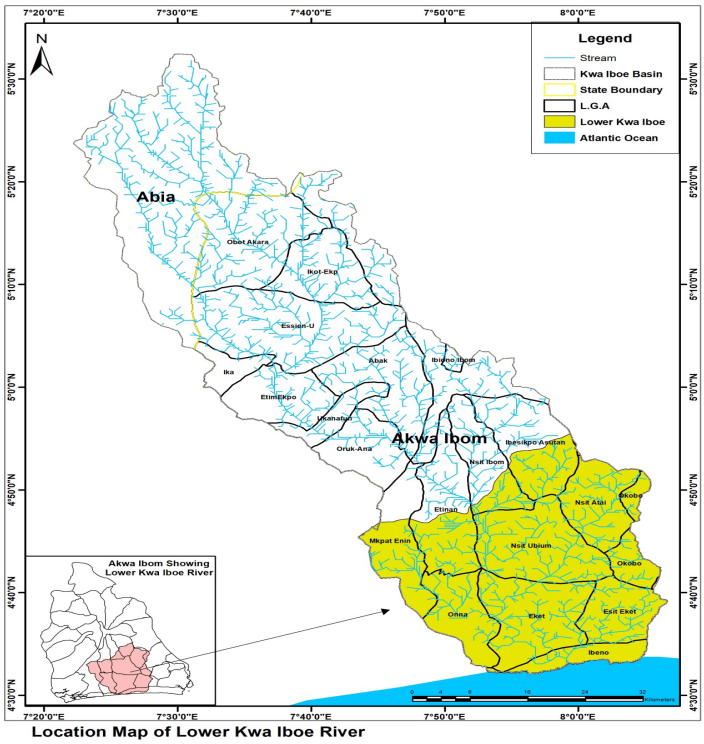

Figure 1. Location of the Study Area.

Source: Extracted from DEM and Administrative Map of Akwa Ibom State by the Author (2025).

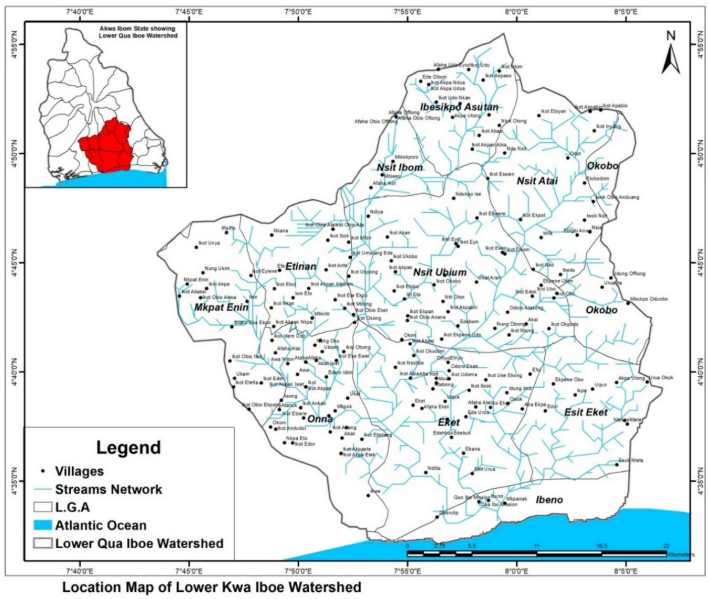

Figure 2. Lower Kwa Iboe Watershed showing Study Area.

The lower Qua Iboe River in Akwa Ibom State lies along Nigeria's southern edge, bordering the Atlantic Ocean. It is characterized by a diverse range of geographical features, including low-lying terrain, beaches, lagoons, mangrove swamps, and estuaries. This region is heavily influenced by tidal patterns and the flow of the Atlantic Ocean, which significantly impacts its ecosystem and the livelihoods of the people who live there. It spans several towns, including Oron, Ibeno, and Eket, all of which have strong cultural and economic ties to the water.

The lower Kwa Iboe River landscape includes extensive mangrove forests that are critical for environmental protection. These mangrove forests act as natural barriers against coastal erosion, absorb excess carbon, and provide habitats for diverse species of flora and fauna. The region also features a variety of wetlands and estuaries that host important ecosystems for fish and other aquatic life. The intertidal zones—where the land meets the sea—are rich in biodiversity, contributing to the overall ecological health of the region [5, 13].

The topography of the region is mostly flat, with little elevation above sea level. This feature makes the area highly susceptible to flooding and erosion, particularly during the rainy season. Rising sea levels caused by climate change pose a significant threat to the coastal communities and their infrastructure, making the region more vulnerable to natural disasters such as floods and storm surges.

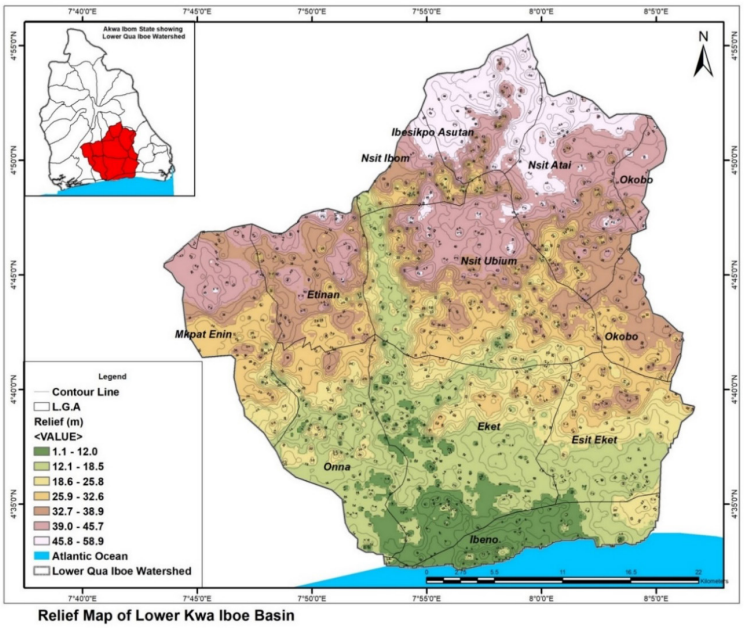

Figure 3. Lower Kwa Iboe River showing Relief.

The hydrology of the Lower Kwa Iboe River is influenced by several factors, including seasonal rainfall patterns, tidal actions, and the complex network of tributaries that feed into it. The river receives the majority of its water from rainfall, with the wet season extending from March to October. During this period, heavy rains increase the flow of water into the river, often resulting in flooding and the inundation of surrounding floodplains. The dry season, from November to February, is marked by lower water levels, which can expose parts of the riverbed, especially in its upper reaches.

Because the river is part of the Niger Delta's intricate network of waterways, it experiences significant tidal influence. The tides, driven by the gravitational pull of the moon and the sun, cause regular variations in water levels, particularly near the mouth of the river. These tidal forces can push seawater upstream, creating a mixing zone of freshwater and saltwater known as an estuary.

In addition, the river's flow is subject to seasonal changes in rainfall and runoff from the surrounding land areas, making its discharge highly variable.

The Lower Kwa Iboe River's hydrological regime is further complicated by human activities such as dam construction, deforestation, and agricultural practices, which can alter the natural flow patterns and impact water quality. The high rate of deforestation in the surrounding region has led to increased runoff and sedimentation in the river, affecting its hydrology and ecology [8].

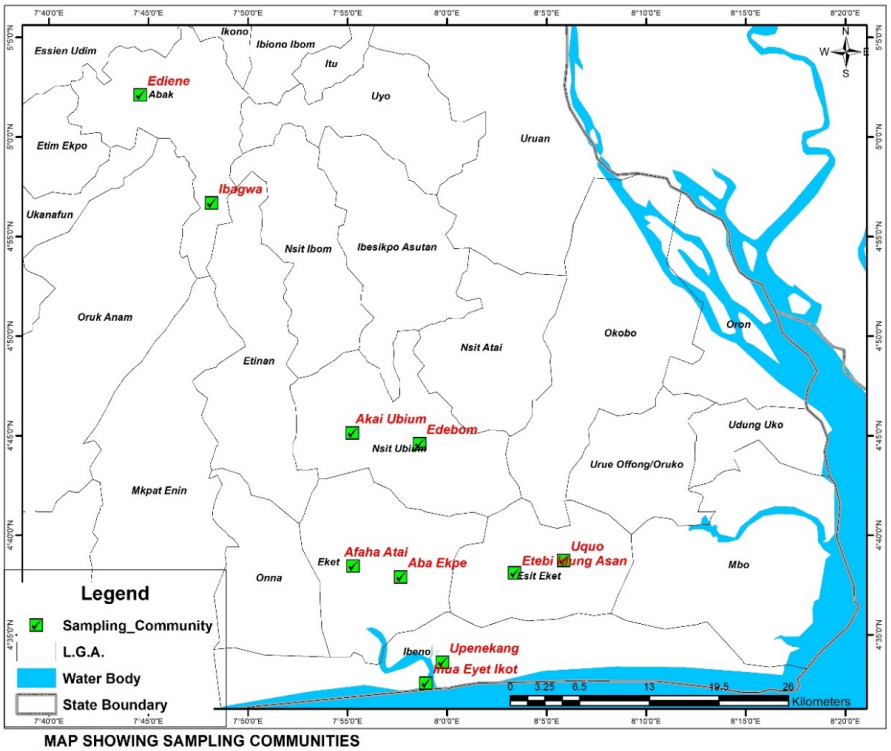

Figure 4. Map showing the Onshore Flared Site.

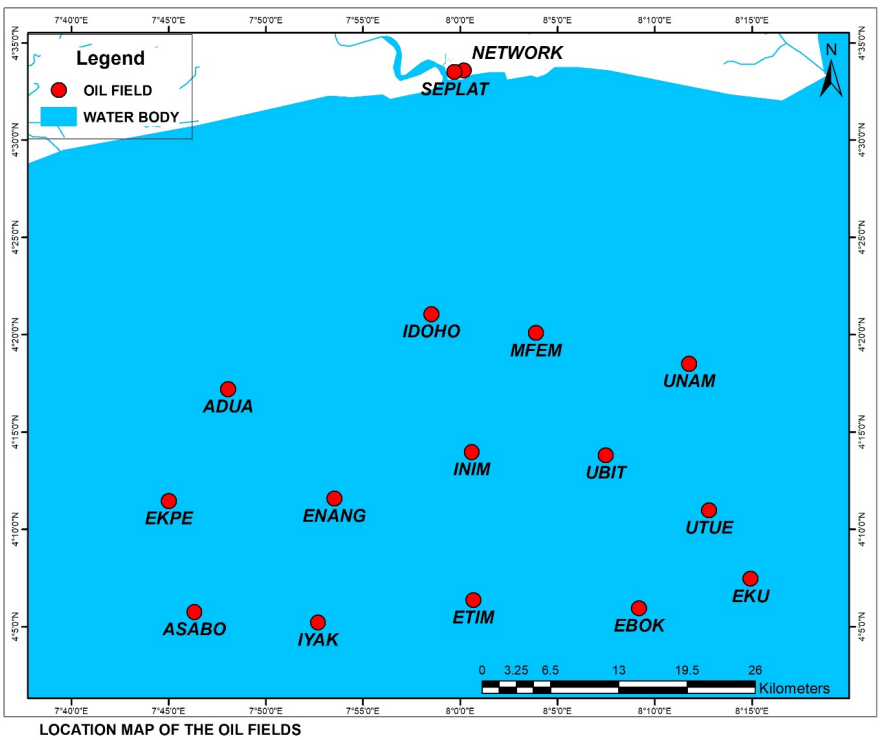

Figure 5. Map showing offshore oil fields with flared sites.

2.2 Methods

The study adopted both a laboratory analysis and a survey design. A reconnaissance survey was conducted to identify onshore flare stacks. The geographical coordinates of both the flare stacks and the ten selected sampling points were recorded using a Garmin GPS model 78Sc Global Positioning System. The ten sampling sites were selected purposively in the following five Local Government Areas: Esit Eket, Eket, Ibeno, Ibesikpo Asutan, and Okobo.

Water Sampling: Water samples were collected monthly over the course of one year (2024-2025) to capture both wet and dry season variations. At each site, three replicate samples were collected from a depth of 30 cm below the surface using a grab sampler and stored in sterile 1-liter plastic bottles. The samples were immediately placed in a cooler with ice and transported to the laboratory within 6 hours for analysis. In-situ measurements of parameters like temperature and pH were taken on-site to prevent changes in their values.

Survey Data: A total of 352 copies of questionnaires were administered to residents of the sampled communities to gather information on the perceived impacts of gas flaring on their health and water use. Focus group discussions (10 discussants interviewed at the same time in the same spot) were also conducted to complement the questionnaire data.

2.2.1 Analytical Methods and Quality Assurance

Laboratory analysis was performed to determine 20 physicochemical parameters and heavy metal concentrations. The following standard protocols were used:

Physicochemical Parameters: Parameters such as pH, Total Dissolved Solids (TDS), Electrical Conductivity (E. Cond), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) were analyzed according to the American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater [17].

Hydrocarbons: Total Petroleum Hydrocarbon (TPH) was measured using a Spectrophotometer.

Heavy Metals: Concentrations of heavy metals, including Mercury, Lead, Cadmium, Chromium, Arsenic, and Copper, were determined using Flame Absorption Spectrophotometry (FAS) as outlined in USEPA (U.S. Environmental Protection Agency) protocols [18].

Quality Assurance/Quality Control (QA/QC): To ensure data reliability, a strict QA/QC program was implemented. This included the analysis of field blanks to detect any contamination during sampling and transport, and duplicates were analyzed to verify the precision of the analytical methods. The instruments were calibrated using certified reference materials before each batch of analysis to ensure accuracy.

Table 1. Coordinate and Attributes of Gas Flaring Sites/Sampled Rivers

LGA	No. Assigned to the flared site	Community	No. of flared sites	Coordinate	Elevation	Distance from nearby flared sites
Nsit Ubium	Site 1	Akai Ubium	None	4^0 41’ 05’’ N 7^0 59’ 17’’ E	15.9m	9.3km from Uquo oil field
Nsit Ubium	Site 2	Edebom	None	4^0 41’ 44’’ N 7^0 57’ 48’’ E	17.6m	11.6km from Uquo oil field
Eket	Site 3	Afaha Atai	None	4^0 37’ 4’’ N 7^0 58’ 22’’ E	9.77m	5.5km from Uquo field
Eket	Site 4	Aba Ekpe	None	4^0 38’ 13’’ N 8^0 00’ 16’’ E	10.43m	3.8km from Uquo oil field
Esit Eket	Site 5	Etebi Idung Asan	None	4^0 38’ 32’’ N 8^0 00’ 45’’ E	9.80m	12.8km from Uquo oil field
Esit Eket	Site 6	Uquo	1	4^0 35’ 01’’ N 8^0 00’ 45’’ E	9.73m	30m away from flared site
Ibeno	Site 7	Inua Eyet Ikot	5 offshore 2 onshore	4^0 33’ 39’’ N 8^0 00’ 44’’ E	8.76m	50m away
Ibeno	Site 8	Upenekang	None	4^0 33’ 55’’ N 7^0 58’ 51’’ E	9.31m	3-4km from Inua Eyet Ikot oil field
Abak	Site 9	Ibagwa	Control point – none	4^0 53’ 17’’ N 7^0 47’ 22’’ E	19.4	40km from Uquo oil field
Abak	Site 10	Ediene Abak	Control point – none	4^0 58’ 50’’ N 7^0 47’ 49’’ E	16.7	48km from Uquo oil field

Source: Field Data (2025)

3. Results and Findings

Table 2. Heavy Metal and Hydrocarbon Content in the Dry Season

S/N	Parame-ters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
1.	As	0.01	0.8	0.4	0.011	0.063	0.081	0.9	0.8	0.11	0.63
2.	Hg	<0.001	<0.001	<0.071	<0.064	<0.045	<0.007	<0.004	<0.093	<0.060	<0.051
3.	Pb	0.612	0.040	0.565	0.958	0.640	0.503	0.282	0.004	0.093	0.840
4.	Cd	0.1	0.6	0.4	0.7	0.6	0.5	0.6	0.4	0.2	0.6
5.	Cu	0.8	0.5	0.3	0.6	0.8	0.8	0.6	0.4	0.5	0.5
6.	Cr	0.934	1.455	0.644	0.826	1.622	0.853	0.765	0.982	0.824	1.201
7.	TPH	0.93	0.83	0.82	0.94	0.86	0.95	0.83	0.79	0.72	0.93

Source: Field data, 2025

Table 3. Heavy Metal and Hydrocarbon Content in the Wet Season

S/N	Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
1.	As	0.07	0.81	0.48	0.61	0.85	0.44	0.61	0.28	0.81	0.30
2.	Hg	<0.71	<0.21	<0.66	<0.53	<0.50	<0.74	<0.49	<0.93	<0.60	<0.56
3.	Pb	0.8	0.04	0.2	0.6	0.4	0.6	0.8	0.5	0.1	0.7
4.	Cd	0.8	0.5	0.6	0.8	0.6	0.6	0.5	0.9	0.6	0.8
5.	Cu	0.6	0.7	0.5	0.8	0.8	0.7	0.5	0.8	1.6	0.5
6.	Cr	0.563	1.727	1.632	1.310	0.766	1.532	0.533	0.998	0.632	0.830
7	TPH	0.65	0.81	0.72	0.36	0.73	0.35	0.89	0.92	0.86	0.98

Source: Field data, 2025

The data analysis, based on Table 2 (Dry Season) and Table 3 (Wet Season), systematically explores the concentrations of heavy metals (As, Hg, Pb, Cd, Cu, Cr) and Total Petroleum Hydrocarbons (TPH) across ten sites in the Lower Qua Iboe River. The findings reveal pervasive contamination, with distinct seasonal variations and a strong correlation to local anthropogenic activities, primarily gas flaring [22, 23].

The analysis of the six heavy metals demonstrated significant variability across both the dry and wet seasons, pointing to differential impacts of pollution sources.

3.1 Dry Season Heavy Metal Findings (Table 2)

During the dry season, when lower water volume reduces pollutant dilution, several metals showed high concentrations at specific sites.

i. **Lead (Pb):** Showed the highest peak at Site 4 (0.958) and Site 10 (0.840), with a sharp drop to a minimum of 0.004 at Site 8. This spatial variability suggests localized pollution inputs, possibly from runoff or specific industrial discharges near the peak sites.
ii. **Chromium (Cr):** Peaked at Site 5 (1.622), indicating a significant contamination hotspot. This high value, along with the peak in Lead, implies contamination from industrial sources, such as gas flaring and associated activities, which are known to emit these heavy metals.
iii. **Arsenic (As) and Copper (Cu):** As peaked at Site 7 (0.9), while Cu peaked at 0.8 (Sites 1, 5, and 6). The wide distribution of these metals suggests a more diffuse, regional contamination alongside localized sources.
iv. **Mercury (Hg):** Concentrations were consistently below the detection limit (<0.001 to <0.093) at all sites, indicating either non-detection or concentrations too low to be measured by the method used.
v. **Cadmium (Cd):** Levels were relatively uniform across sites, ranging from 0.1 to 0.7, suggesting a more homogeneous low-level background contamination.

3.1.1 Wet Season Heavy Metal Findings (Table 3)

The wet season generally saw concentrations comparable to, or in some cases, higher than those of the dry season, despite the expected increased dilution. This suggests that surface runoff during rainfall may introduce additional contaminants into the river system.

i. **Chromium (Cr):** The highest concentration was recorded at Site 2 (1.727), even higher than the dry season peak, suggesting that runoff may be a key pathway for Cr introduction during the wet season.
ii. **Copper (Cu):** Reached its maximum concentration at Site 9 (1.6), significantly higher than the 0.8 maximum observed in the dry season. This dramatic increase may be attributed to seasonal factors like increased erosion and leaching from contaminated soil into the river.
iii. **Arsenic (As):** Peaked at Site 5 (0.85).
iv. **Lead (Pb):** Peaked at Site 1 and Site 7 (0.8).
v. **Cadmium (Cd):** Showed its highest level at Site 8 (0.9).
vi. **Mercury (Hg):** Similar to the dry season, Hg was consistently below the detection limit (<0.21 to <0.93) across all sites.

The presence of elevated levels of As, Pb, Cd, Cu, and Cr in both seasons confirms persistent heavy metal pollution, which is highly indicative of continuous inputs from anthropogenic activities, particularly gas flaring and its associated industrial and transportation activities.

3.1.2 Total Petroleum Hydrocarbon (TPH) Contamination

The analysis of TPH levels provides a clear and consistent indicator of extensive hydrocarbon contamination in the river.

3.1.2.1 Critical Exceedance of Regulatory Guidelines

Across both the dry and wet seasons, the TPH concentrations recorded at all sites were alarming.

Dry Season TPH: Ranged from 0.72 to 0.95 mg/L (Site 6).

Wet Season TPH: Ranged from 0.35 to 0.98mg/L (Site 10). The wet season average concentration of 0.80 mg/L is a critical metric.

These TPH values are significantly higher than the World Health Organization (WHO) guideline for drinking water, which is often cited as 0.01 mg/l. The widespread and severe exceedance of this standard confirms that the water in the study area is contaminated with hydrocarbons.

3.1.3 Correlation with Pollution Source

The data explicitly support the role of gas flaring as a major pollution source. Samples from communities closer to flare stacks (e.g., Uquo Esit Eket and Inua Eyet Ikot mentioned in the original text) consistently exhibited considerably higher concentrations of contaminants compared to control points located farther away. The elevated TPH levels are consistent with a persistent pollution source associated with crude oil and gas operations, validating conclusions from previous research on contamination within the catchment [21, 22].

The comprehensive data analysis unequivocally confirms that the Lower Qua Iboe River is subject to significant and continuous pollution from heavy metals and hydrocarbons.

i. **Contaminants of Concern:** Pb, Cr, Cu, and TPH emerged as the primary contaminants with high concentrations, particularly at localized hotspots.
ii. **Source Confirmation:** The spatial pattern of pollution, especially the high TPH and heavy metal concentrations near operational sites, establishes a clear link between gas flaring and the observed environmental degradation.
iii. **Risk:** The elevated levels of these toxic substances pose a serious ecological and public health risk to the aquatic life and local communities that depend on the river for water, fishing, and other uses. The reduced water volume during the dry season likely exacerbates toxicity due to less dilution, while wet season runoff contributes to contaminant dispersal.

Focus group participants consistently expressed a sense of helplessness and frustration regarding the pervasive effects of gas flaring. The discussions highlighted three primary areas of concern:

1. **Water Contamination and Scarcity:** Participants universally reported a noticeable decline in the quality of their primary water sources, including rivers, streams, and rainwater. Many described the water as having an oily sheen and a foul odor, making it unsuitable for drinking, cooking, and even bathing. "Our river used to be clean, now it's black and smells of crude," one discussant lamented. The questionnaire data supported this, with a high percentage of respondents reporting changes in water color and smell. The contamination has forced communities to

seek alternative, often more expensive or distant, water sources, leading to a significant burden on daily life.

2. **Adverse Health Effects:** A majority of the discussants linked a range of health problems directly to gas flaring. Common ailments reported included respiratory issues, eye irritation, skin rashes, and chronic headaches. Several participants noted a rise in these conditions, particularly among children and the elderly. They believe that the constant exposure to smoke and chemical fallout from the flares is the cause. The questionnaire results validated these anecdotal reports, with a large number of respondents confirming that they or a family member had experienced such health issues.
3. **Impact on Livelihoods:** The discussions revealed a severe impact on traditional livelihoods, particularly fishing and farming. Fishermen reported a drastic reduction in fish catch, which they attributed to the death of aquatic life caused by water contamination. Farmers noted that crop yields had decreased and some plants appeared stunted, linking this to the effects of acid rain from the flaring. This economic hardship has forced many to abandon their traditional professions, leading to increased poverty and food insecurity within the communities.

4. Conclusion and Recommendations

The findings of this study provide clear evidence that gas flaring in the Lower Qua Iboe River Basin is a major source of surface water pollution. The continuous release of pollutants leads to a persistent, year-round contamination with TPH and heavy metals, which are detrimental to both aquatic ecosystems and human health. The intensity of this pollution is directly correlated with the distance from the flare stack.

To mitigate this environmental catastrophe, the following recommendations are proposed:

1. **Strict Regulatory Enforcement:** The Nigerian government must enforce stricter regulations and set a definitive deadline for ending gas flaring, compelling oil and gas companies to invest in technologies for gas utilization.
2. **Community-Based Monitoring:** Local communities should be empowered with resources and training to conduct their own water quality monitoring to hold oil companies accountable.
3. **Remediation and Restoration:** Remediation efforts should be initiated in the most affected areas to decontaminate surface water and restore the ecological balance of the river basin.
4. **Public Health Intervention:** The government should provide alternative, safe drinking water sources for communities in close proximity to flare sites and launch public health campaigns to educate residents on the risks of using contaminated water.

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