ISA Journal of Engineering and Technology (ISAJET)

Homepage: https://isapublisher.com/isajet/

Volume 3, Issue 4, July-August, 2026 ISSN: 3049-1843

Gas Flaring and Aquatic Life in Delta State, Nigeria

Eruvwe Ogheneovo Emmanuel Ph.D.

Operations Department, Pillar Oil Limited

Received: *10.06.2026* | ***Accepted:*** *05.08.2026* | ***Published:*** *19.08.2026*

***Corresponding Author:** Eruvwe Ogheneovo Emmanuel Ph.D.

DOI: *10.5281/zenodo.22006111*

Abstract **Original Research Article**

Gas flaring remains one of the most persistent environmental hazards associated with crude oil exploration and production in the Niger Delta region of Nigeria, with Delta State hosting a dense concentration of flow stations and flare stacks within riverine, fishery-dependent communities. This study examined the effect of gas flaring on aquatic life in Delta State, disaggregating gas flaring into three explanatory dimensions, namely flare intensity, emission of toxic pollutants, and thermal pollution, and their effect on aquatic life, operationalised through fish population abundance, aquatic biodiversity, and fish reproductive success. The study adopted a cross-sectional survey design. The population comprised 1,200 artisanal fisherfolk, fisheries/environmental agency personnel, and community residents across seven flare-impacted local government areas of Delta State. A sample of 300 respondents was drawn using the Taro Yamane formula and a multi-stage sampling technique. A structured, validated twenty-item questionnaire measured on a five-point Likert scale was administered, yielding a 100 per cent response rate. Data were analysed using descriptive statistics, Cronbach's alpha reliability analysis, Pearson correlation, and multiple linear regression. All constructs returned Cronbach's alpha coefficients above 0.70. The regression model was statistically significant, R-squared = 0.400, $F(3, 296) = 65.881$, $p < 0.001$. Flare intensity ($\beta = 0.245$, $p < 0.001$), emission of toxic pollutants ($\beta = 0.298$, $p < 0.001$), and thermal pollution ($\beta = 0.243$, $p < 0.001$) each exerted a positive and statistically significant effect on aquatic life deterioration, with emission of toxic pollutants emerging as the strongest predictor. The study concludes that gas flaring, through the combined pathways of combustion intensity, toxic pollutant emission, and thermal loading, significantly and adversely affects aquatic life in the oil-producing communities of Delta State, and recommends strengthened enforcement of gas flare-down obligations, improved pollutant monitoring, and thermal discharge management by regulatory agencies and oil-producing companies operating in the state.

Keywords: Gas Flaring; Flare Intensity; Toxic Pollutants; Thermal Pollution; Aquatic Life; Delta State; Niger Delta.

1. INTRODUCTION

Gas flaring, the open combustion of associated and non-associated natural gas released during crude oil exploration and production, remains one of the most persistent environmental problems confronting the Niger Delta region of Nigeria. Since the discovery of crude oil at Oloibiri in 1956, the absence of adequate infrastructure to gather, process, and commercialise associated gas has meant that a substantial share of it is simply burnt off at the wellhead through vertical and horizontal flare stacks

(Ukhurebor, 2024). Nigeria continues to rank among the highest gas-flaring nations in the world, with recent satellite-based estimates showing that annual flaring volumes in the Niger Delta exceed five billion cubic metres, a figure that surged further in the years leading to 2026 despite the existence of the Nigerian Gas Flare Commercialisation Programme and the global Zero Routine Flaring by 2030 initiative (Zikas et al., 2025).

Delta State, as one of the core oil-producing states of the Niger Delta, hosts a dense network of flow stations, flare stacks, and pipeline infrastructure across its riverine and upland local government areas, including Ughelli South, Warri South, Isoko North, Isoko South, Bomadi, Patani and Burutu. These same communities depend heavily on the creeks, rivers, and estuaries of the region for artisanal fishing, a major source of livelihood and protein for households in the area. The juxtaposition of intense gas flaring activity and fishery-dependent riverine communities has generated growing concern among researchers, regulators, and residents about the long-term health of aquatic ecosystems in the state (Akankali & Jamabo, 2023; Omoye, 2025).

Gas flaring affects aquatic environments through at least three interrelated pathways. First, flare intensity, which reflects the volume, duration, and frequency of gas combustion at a given facility, determines the scale of heat, light, noise, and particulate emissions released into the surrounding ecosystem (Ukhurebor, 2024; Eruvwe, et al., 2024). Second, the emission of toxic pollutants, including oxides of sulphur and nitrogen, carbon dioxide, methane, volatile organic compounds, and heavy metals such as lead, cadmium, and mercury, contaminates rainfall, surface run-off, and directly deposits into water bodies, altering pH, dissolved oxygen, and toxic load (Ukhurebor et al., 2023; Israel & Ugbeghene, 2026). Third, thermal pollution, arising from the radiant heat of continuous flaring and the discharge of heated produced water, raises ambient water temperature beyond the tolerance range of many indigenous aquatic species, disrupting metabolic, respiratory, and reproductive processes (Akankali & Jamabo, 2023; Omoye, 2025).

Empirical accounts from riverine communities in the Niger Delta consistently link these flaring-induced stressors to observable declines in fish catch, disappearance of previously abundant species, altered spawning and migration patterns, and reduced aquatic biodiversity (Ayibatonye et al., 2024; Igbani et al., 2023). A recent assessment of artisanal fisheries in Bayelsa State, for instance, found that gas flaring activity was associated with drastically reduced fish catch, indiscriminate fish mortality, impaired spawning, and disrupted fishing schedules among local fisherfolk (Ayibatonye et al., 2024). Similar community-level reports from Delta State describe blackened rainwater, acidified creeks, and the local extinction of once-common fish species around long-standing flare sites (Moses, as cited in The Xylom, 2024).

Aquatic ecosystems within the oil-producing communities of Delta State are increasingly under stress. Fisherfolk in Ughelli South, Warri South, Isoko North and South, Bomadi, Patani, and Burutu routinely report shrinking catch volumes, the disappearance of previously abundant species such as Clarias gariepinus and Sarotherodon melanotheron from certain creeks, and visibly discoloured, heated, or foul-smelling water near flare sites (Nwachukwu et al., 2025). These observations, while widespread, have rarely been subjected to rigorous statistical testing that isolates the specific contribution of flare intensity, toxic pollutant emission, and thermal pollution to the observed decline in aquatic life.

The absence of such evidence creates a two-fold problem. On one hand, policymakers, regulators such as the National Upstream Petroleum Regulatory Commission, and oil-producing companies lack a clear, locally generated empirical basis for prioritising which dimension of flaring, whether intensity, emissions, or heat, most urgently requires mitigation investment in Delta State. On the other hand, affected communities continue to experience livelihood losses from declining fisheries without a formal, evidence-based account that could support advocacy, compensation claims, or policy reform. It is against this backdrop that this study investigates the effect of gas flaring, disaggregated into flare intensity, emission of toxic pollutants, and thermal pollution, on aquatic life in Delta State, Nigeria.

Arising from the foregoing, the broad objective of this study is to examine the effect of gas flaring on aquatic life in Delta State, Nigeria. The specific objectives are to: (i) examine the effect of flare intensity on aquatic life; (ii) determine the effect of emission of toxic pollutants on aquatic life; and (iii) assess the effect of thermal pollution on aquatic life in Delta State, Nigeria. Correspondingly, the study tests three null hypotheses: H01, flare intensity has no significant effect on aquatic life in Delta State; H02, emission of toxic pollutants has no significant effect on aquatic life in Delta State; and H03, thermal pollution has no significant effect on aquatic life in Delta State, Nigeria.

The study is expected to benefit regulatory agencies, including the National Upstream Petroleum Regulatory Commission and the Delta State Ministry of Environment, by providing an evidence base for prioritising enforcement of flare-down and gas-utilisation obligations. It offers oil and gas operators empirically grounded guidance on which dimension of flaring operations offers the greatest environmental return on mitigation investment, provides riverine communities and artisanal fisherfolk a statistically defensible basis for advocacy and compensation negotiation, and contributes to the sparse quantitative literature on gas flaring and aquatic ecosystems specific to Delta State. The study is delimited to the flare-impacted local government areas of Ughelli South, Warri South, Isoko North, Isoko South, Bomadi, Patani, and Burutu, and does not extend to laboratory-based ecotoxicological sampling of water or fish tissue, an area recommended for further study.

2. LITERATURE REVIEW

2.1 Concept of Gas Flaring

Gas flaring refers to the controlled combustion of associated natural gas and other petroleum hydrocarbons released during the exploration, production, and processing of crude oil, typically carried out through vertical or horizontal stacks at flow stations, wellheads, and gas plants (Ukhurebor, 2024). It occurs primarily because operators, especially in mature oil provinces such as the Niger Delta, lack the pipeline infrastructure, gas-gathering facilities, or commercial incentive to capture and utilise associated gas, making combustion the cheapest disposal method (Zikas et al., 2025). Globally, flaring destroys an energy resource capable of powering millions of households while simultaneously releasing carbon dioxide, methane, black carbon, and a range of toxic co-pollutants into the atmosphere and, by extension, into terrestrial and aquatic ecosystems (Ukhurebor, 2024).

In the Nigerian context, gas flaring has continued for close to seven decades despite a succession of legal prohibitions, including the Associated Gas Re-Injection Act, subsequent flare-out deadlines, and the more recent Nigerian Gas Flare Commercialisation Programme, which seeks to attract third-party investment into gas capture infrastructure ahead of the 2030 zero routine flaring target (Zikas et al., 2025). For host communities in Delta State, gas flaring is not an abstract statistic but a lived daily experience: the constant glow and roar of flare stacks, the heat radiating from nearby facilities, and the soot-laden rainfall that follows flaring episodes as documented by residents in flare-affected communities (Xylom, 2024). These lived experiences form the empirical starting point for disaggregating gas flaring into the three explanatory dimensions examined in this study.

2.1.1 Flare Intensity and Aquatic Life

Flare intensity denotes the magnitude, duration, and frequency of gas combustion at a given flare stack, commonly proxied in remote-sensing studies by radiant heat output detected through satellite infrared sensors, and in survey-based community studies by residents' perceived frequency, brightness, and persistence of flaring activity near their water sources (Zikas et al., 2025). Higher flare intensity is associated with a correspondingly larger volume of combustion by-products, heat, and particulate fallout reaching nearby ecosystems. Ukhurebor (2024) notes that the scale of flaring operations directly determines the geographic reach and severity of the acid rain, soot deposition, and heat plume associated with a given facility, with more intensely flared sites showing wider zones of ecological disturbance.

Within aquatic systems specifically, higher flare intensity has been linked to greater alteration of ionic composition, pH, and heavy metal concentration in rainwater and surface run-off draining into creeks and rivers near flare sites, a pathway capable of causing mortality and local extinction of sensitive fish species (Akankali & Jamabo, 2023). Community-based assessments in Bayelsa State similarly found that areas closest to the most persistently flared facilities reported the steepest declines in fish catch and the earliest disappearance of previously common species (Ayibatonye et al., 2024). On this basis, flare intensity is expected to exert a significant negative effect on aquatic life in the flare-impacted communities of Delta State.

2.1.2 Emission of Toxic Pollutants and Aquatic Life

The emission of toxic pollutants from gas flaring encompasses a broad suite of combustion by-products, including sulphur dioxide, nitrogen oxides, carbon monoxide, volatile organic compounds, polycyclic aromatic hydrocarbons, and trace heavy metals such as lead, cadmium, nickel, and mercury, many of which are only partially combusted where flaring efficiency is low (Ukhurebor et al., 2023). These pollutants enter aquatic systems both directly, through atmospheric deposition and acid rain, and indirectly, through soil leaching into groundwater and surface water bodies (Ukhurebor, 2024).

Toxic pollutant loading in water bodies has repeatedly been associated with disruption of aquatic biota. Akankali and Jamabo (2023) report that toxic deposition into rainwater near flare sites alters conductivity and heavy metal concentration to levels capable of causing death of aquatic organisms, while broader reviews of oil-producing communities note elevated concentrations of lead and nickel in surface water sources that pose direct toxicological risk to aquatic life and to communities that depend on it (Agbasi et al., 2024). Bioaccumulation of these pollutants along the aquatic food chain, from plankton and benthic invertebrates through to commercially important fish species, compounds the risk over time, potentially affecting reproductive success and long-term population viability (Nwachukwu et al., 2025). Accordingly, emission of toxic pollutants is expected to exert a significant negative effect on aquatic life in the study area.

2.1.3 Thermal Pollution and Aquatic Life

Thermal pollution refers to the artificial elevation of water temperature beyond the natural range to which an aquatic ecosystem and its resident species are adapted, arising in gas-flaring contexts from the radiant heat of continuous combustion and from the discharge of heated produced water and effluent from associated processing facilities (Akankali & Jamabo, 2023). Fish and other aquatic organisms are ectothermic, meaning their metabolic rate, oxygen demand, and reproductive timing are closely tied to ambient water temperature; even modest sustained increases can push species beyond their thermal tolerance window (Akpan et al., 2023).

Empirical accounts from the Niger Delta associate the heat generated by flare stacks with elevated water temperature in adjacent creeks, contributing to reduced dissolved oxygen availability, altered spawning cues, and, in extreme cases, direct mortality of temperature-sensitive species (Akankali & Jamabo, 2023). Reviews of climate-related stressors on Niger Delta fisheries similarly emphasise that rising aquatic temperature alters the tempo-spatial distribution of fish, compelling species to modify behaviour, migrate to cooler refugia, or face population decline where escape routes are limited by creek geography (Akpan et al., 2023). Thermal pollution is therefore expected to exert a significant negative effect on aquatic life in flare-impacted communities of Delta State.

2.1.4 Concept of Aquatic Life

Aquatic life, for the purpose of this study, refers to the community of organisms, principally fish, that inhabit the rivers, creeks, and estuaries of Delta State and that sustain the artisanal fisheries on which many riverine households depend. Following the proposed conceptual framework of this study, aquatic life is operationalised through three indicators: fish population abundance, referring to the perceived volume and frequency of fish catch relative to historical baselines; aquatic biodiversity, referring to the perceived variety and richness of fish and other aquatic species present in local water bodies; and fish reproductive success, referring to the perceived adequacy of spawning, breeding, and recruitment of juvenile fish into the population.

These three indicators mirror ecological outcome measures used in the broader Niger Delta aquatic pollution literature, where declining catch, shrinking species lists, and impaired breeding cycles are consistently reported as the visible, community-perceptible signatures of environmental stress on fisheries (Igbani et al., 2023; Ayibatonye et al., 2024). Aquatic biodiversity loss in polluted Niger Delta water bodies has also been linked in recent macroinvertebrate-based research to measurable shifts in functional feeding groups under increasing pollution gradients, corroborating the sensitivity of aquatic communities to anthropogenic stressors of the kind associated with gas flaring (Edegbene & Akamagwuna, 2022).

2.5 Conceptual Framework

Building on the theoretical and empirical review above, this study proposes a conceptual framework in which gas flaring, as the independent variable, is disaggregated into three explanatory dimensions, namely flare intensity, emission of toxic pollutants, and thermal pollution, each hypothesised to exert an independent and combined effect on aquatic life, the dependent variable, which is in turn operationalised through fish population abundance, aquatic biodiversity, and fish reproductive success. The framework, illustrated below, guided the design of the research instrument and the specification of the regression model presented in Chapter Three.

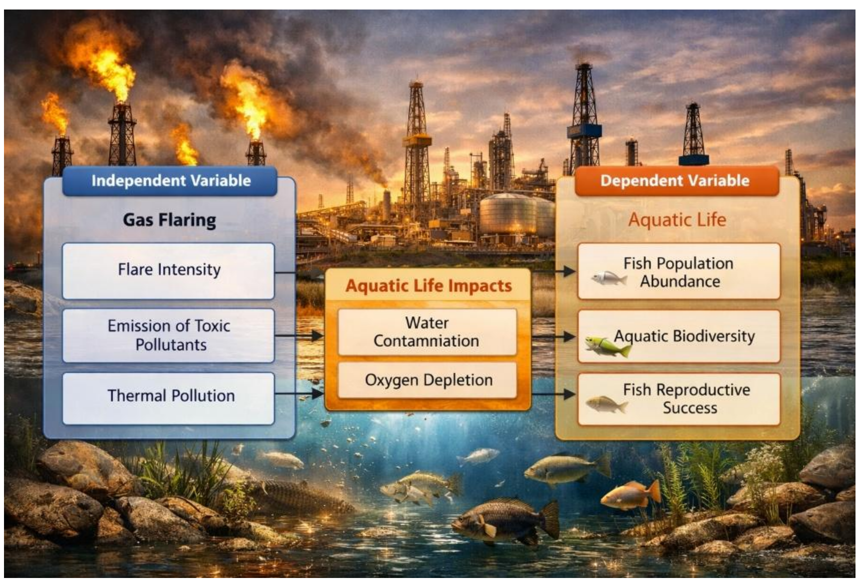

Figure 1: Conceptual Framework of Gas Flaring and Aquatic Life

2.2 Theoretical Review

This study is anchored on two complementary theories: the Ecological Risk Theory and the Bioaccumulation Theory.

Ecological Risk Theory provides a framework for understanding how an environmental stressor, in this case gas flaring, translates into an adverse outcome for an ecological receptor, in this case aquatic life, through an identifiable exposure pathway. The theory conceptualises risk as a function of the intensity and duration of stressor exposure and the sensitivity or tolerance threshold of the receptor organism. Applied to this study, flare intensity, toxic pollutant emission, and thermal pollution constitute distinct but related stressor pathways, each characterised by its own exposure intensity, that combine to determine the overall ecological risk faced by fish populations and other aquatic biota in flare-impacted communities (Ukhurebor, 2024). The theory is well suited to this study because it explicitly supports the disaggregation of a composite hazard, gas flaring, into discrete measurable dimensions whose individual and joint contribution to ecological harm can be statistically estimated, which is precisely the analytical structure adopted in this research.

Bioaccumulation Theory complements this framework by explaining how toxic substances, once introduced into an aquatic system, become progressively concentrated in the tissues of organisms as they move up the food chain, from primary producers and invertebrates to herbivorous and predatory fish species. The theory holds that low ambient concentrations of pollutants such as heavy metals can nonetheless produce significant physiological and reproductive harm in top consumers due to cumulative uptake over time (Ukhurebor et al., 2023). This theoretical lens is particularly relevant to the toxic pollutant emission dimension of this study, as it explains why even modest, sub-lethal pollutant loading from flaring can manifest over time as reduced reproductive success and declining population abundance rather than immediate, acute mortality alone.

Together, these two theories justify the study's core proposition: that gas flaring, through the combined pathways of combustion intensity, toxic pollutant deposition, and thermal loading, produces a cumulative and statistically detectable adverse effect on aquatic life in the flare-impacted riverine communities of Delta State.

2.3 Empirical Review

A growing, though still largely qualitative and descriptive, body of empirical work has examined the relationship between gas flaring and aquatic ecosystems in the Niger Delta. Akankali and Jamabo (2023), in a review of gas flaring-induced impacts on aquatic resources in the Niger Delta, found that flaring alters ionic composition, pH, temperature, conductivity, and heavy metal concentration in water bodies, with these thermal and toxicological impacts jointly implicated in the local extinction of some fish species, and recommended stricter government legislation and more consistent enforcement by regulatory agencies.

Ayibatonye et al. (2024), examining artisanal fisheries in the downstream area of Taylor Creek, Bayelsa State, using a structured questionnaire and descriptive survey design, found that gas flaring was strongly associated with drastic reductions in fish catch, extinction of certain fish species, disrupted fishing schedules, altered water body dynamics, impaired spawning activity, and increased fish prices attributable to scarcity. Their descriptive findings provide strong qualitative support for the pathways examined quantitatively in the present study, though their design did not statistically decompose gas flaring into separate intensity, emission, and thermal dimensions or test regression-based hypotheses, a gap this study addresses.

Igbani et al. (2023), reviewing the effects of crude oil spill on aquatic life in the Niger Delta, documented extensive anthropogenic pressure on aquatic biodiversity from oil-sector activity broadly, including gas flaring, with compounding effects on fish biomagnification and food security. Ukhurebor (2024), in a broad environmental review of gas flaring, catalogued acid rain formation, heavy metal deposition, and associated danger to aquatic life as central consequences of flaring, while Ukhurebor et al. (2023) emphasised the inadequacy of current monitoring and community engagement in managing petroleum-sector environmental risk in the Niger Delta.

In a related pollution pathway, Edegbene and Akamagwuna (2022) found that increasing anthropogenic pollution gradients significantly altered macroinvertebrate functional feeding groups across Niger Delta streams, with sensitive taxa declining along the gradient, lending independent quantitative support to the proposition that anthropogenic stressors measurably reshape aquatic community structure. Nwachukwu et al. (2025), reviewing causes and effects of environmental degradation in the Niger Delta, identified oil spills, gas flaring, deforestation, and industrial pollution as principal drivers of aquatic life decline. Collectively, the literature converges on a significant adverse relationship between gas flaring and aquatic ecosystems in the Niger Delta, while revealing a persistent gap in state-specific, quantitative, hypothesis-tested studies, the gap this research addresses for Delta State.

3. METHODOLOGY

3.1 Research Design and Area of the Study

This study adopted a cross-sectional survey research design, considered appropriate for examining the relationship between gas flaring dimensions and aquatic life as perceived by a defined population at a single point in time. The design permits the collection of quantifiable data through a structured questionnaire and supports the statistical testing of hypothesised relationships between the independent variables (flare intensity, emission of toxic pollutants, and thermal pollution) and the dependent variable (aquatic life), consistent with recent survey-based environmental perception studies conducted in the Niger Delta (Ayibatonye et al., 2024).

The study was conducted in the oil-producing local government areas of Delta State, Nigeria, namely Ughelli South, Warri South, Isoko North, Isoko South, Bomadi, Patani, and Burutu. Delta State lies within the core of the Niger Delta region and hosts numerous flow stations, wellheads, and associated flare stacks operated by both major international oil companies and indigenous producers. The riverine and creek-based communities within these local government areas depend substantially on artisanal fishing in the Ethiope, Warri, Forcados, and Escravos river systems and their tributaries, making the area well suited to an investigation of the effect of gas flaring on aquatic life.

3.2 Population, Sample Size and Sampling Technique

The population of the study comprised artisanal fisherfolk, fisheries and environmental regulatory agency personnel, and community leaders/residents resident in flare-impacted communities across the seven selected local government areas of Delta State. Based on records obtained from the Delta State Ministry of Agriculture and Natural Resources (Fisheries Department) and local artisanal fishing cooperative registers, the accessible population of registered artisanal fisherfolk, fisheries/environmental agency staff, and community representatives across the study area was estimated at 1,200 persons as at the time of this study (2026).

Given the finite and defined nature of the population, the sample size for this study was determined using the Taro Yamane simplified formula for proportion, a formula still widely applied in recent Niger Delta survey-based environmental and social science research for its simplicity and precision at conventional confidence levels (Chukwuma & Eze, 2024; Tom, et al, 2025). The formula is expressed as:

The sample size for this study was determined using the Taro Yamane (1967) sample size determination formula:

$$n = \frac{N}{1 + N(e)^2}$$

Where:

n= Sample size

N= Population size

e= Acceptable margin of error (0.05 or 5%)

Given that:

$N = 1{,}200$

$e = 0.05$

Substituting the values into the formula:

$$n = \frac{1{,}200}{1 + 1{,}200(0.05)^2}$$

$$n = \frac{1{,}200}{1 + 1{,}200(0.0025)}$$
$$n = \frac{1{,}200}{1 + 3}$$
$$n = \frac{1{,}200}{4}$$
$$n = 300$$

Therefore, the calculated sample size for the study is 300 respondents.

The computed sample size of 300 respondents was drawn using a multi-stage sampling technique. At the first stage, all seven flare-impacted local government areas were purposively selected given their documented concentration of flaring infrastructure. At the second stage, communities within each local government area situated within an approximate five-kilometre radius of an active flare site were purposively selected. At the third stage, respondents within each selected community were drawn using simple random sampling from the fisherfolk cooperative and community resident registers, with the 300 respondents proportionately allocated across the seven local government areas based on their relative share of the accessible population.

3.3 Instrument, Validity and Reliability

The instrument for data collection was a structured questionnaire designed by the researcher, comprising two main sections. Section A elicited respondents' demographic information, namely gender, age bracket, occupation, educational attainment, and local government area of residence. Section B comprised twenty statement items measured on a five-point Likert scale, ranging from Strongly Agree (5) to Strongly Disagree (1), covering the four constructs of the study: Flare Intensity (five items), Emission of Toxic Pollutants (five items), Thermal Pollution (five items), and Aquatic Life (five items). The complete questionnaire is presented in Appendix I.

The content and face validity of the research instrument were established through expert review. A draft of the questionnaire was subjected to scrutiny by two academics in environmental management and business/social science research methodology at Delta State University, Abraka, who assessed each item for clarity, relevance to the underlying construct, and appropriateness of language for the target respondents. Their observations informed the rewording and simplification of ambiguous items and the removal of duplicate statements, after which a final, validated version of the instrument was administered.

The reliability of the research instrument was established using Cronbach's alpha coefficient, computed from a pilot administration of the questionnaire to 30 respondents in flare-impacted communities within the study area who were not part of the final sample. The pilot data were analysed to obtain the internal consistency reliability of each construct, with the results presented in Table 4.2 of Chapter Four. All constructs returned Cronbach's alpha coefficients above the conventionally accepted threshold of 0.70 for exploratory social science research (Chukwuma & Eze, 2024), confirming that the instrument was sufficiently reliable for the main study.

The final questionnaire was administered to the 300 sampled respondents by the researcher with the assistance of two trained field assistants familiar with the local communities and, where required, the Urhobo, Isoko, and Ijaw languages predominantly spoken in the study area. Copies of the questionnaire were administered by hand at community fishing landing sites, cooperative society meeting points, and local government fisheries offices between the field data collection window of 2026, with completed copies retrieved on the spot or within 48 hours where respondents required more time. All 300 administered copies were retrieved and found valid for analysis, yielding a 100 per cent response rate.

3.4 Model Specification and Method of Data Analysis

To test the hypothesised relationships between gas flaring dimensions and aquatic life, the study specified a multiple linear regression model of the form:

$$AQL = \beta 0 + \beta 1FI + \beta 2TOX + \beta 3THP + \varepsilon$$

where

AQL = Aquatic Life (the dependent variable, measured as the composite mean score of the five Aquatic Life items);

FI = Flare Intensity;

TOX= Emission of Toxic Pollutants;

THP = Thermal Pollution (the three independent variables, each measured as the composite mean score of their respective five items);

β_0 = regression constant (intercept);

β1, β2, and β3 = regression coefficients capturing the effect of each independent variable on aquatic life;

ε = stochastic error term capturing unexplained variation.

Data collected from the administered questionnaire were coded and analysed using Python-based statistical computing (pandas, SciPy, and statsmodels libraries). Descriptive statistics, namely mean, standard deviation, skewness, and kurtosis, were computed for each construct to summarise the central tendency and distributional properties of responses. Cronbach's alpha was computed to assess internal consistency reliability. Pearson Product Moment Correlation analysis was used to examine the strength and direction of association between each independent variable and aquatic life, as well as among the independent variables themselves, to check for multicollinearity. Multiple linear regression analysis was used to test the three research hypotheses, with the coefficient of determination (R-squared), adjusted R-squared, F-statistic, and the t-statistics and associated p-values of individual regression coefficients used to determine statistical significance at the conventional 5 per cent (0.05) level. The Variance Inflation Factor (VIF) was additionally computed to confirm the absence of problematic multicollinearity among the independent variables.

4. RESULTS AND DISCUSSION

Out of 300 questionnaires administered across the seven flare-impacted local government areas of Delta State, all 300 were retrieved and valid, a 100 per cent response rate.

Table 1: Demographic Distribution of Respondents (n = 300)

Variable	Category	Freq.	%
Gender	Male	184	61.3
	Female	116	38.7
Age	18-30	60	20.0
	31-40	103	34.3
	41-50	82	27.3
	Above 50	55	18.3
Occupation	Artisanal Fisherfolk	164	54.7
	Fisheries/Env. Agency Staff	53	17.7

Variable	Category	Freq.	%
	Community Leader/Resident	83	27.7
Education	No formal/Primary	94	31.3
	Secondary	135	45.0
	Tertiary	71	23.7

Source: Field Survey, 2026

Table 2: Cronbach's Alpha Reliability Coefficients

Construct	Items	Alpha	Remark
Flare Intensity	5	0.881	Reliable
Emission of Toxic Pollutants	5	0.893	Reliable
Thermal Pollution	5	0.889	Reliable
Aquatic Life	5	0.875	Reliable
Overall Instrument	20	0.925	Reliable

Source: Field Survey, 2026

Table 3: Descriptive Statistics (Composite Mean Scores)

Construct	N	Mean	SD	Skew.	Kurt.
Flare Intensity	300	3.669	0.736	-0.428	-0.118
Toxic Pollutants	300	3.665	0.753	-0.265	-0.266
Thermal Pollution	300	3.67	0.733	-0.054	-0.654
Aquatic Life	300	3.657	0.732	-0.106	-0.776

Source: Field Survey, 2026

Table 4: Pearson Correlation Matrix and VIF

Variable	Flare Int.	Toxic Poll.	Thermal Poll.	Aquatic Life
Flare Intensity	1.000			
Toxic Pollutants	0.475	1.000		
Thermal Pollution	0.431	0.424	1.000	
Aquatic Life	0.497	0.527	0.48	1.000

Source: Field Survey, 2026; all correlations significant at $p < 0.001$; VIF < 5 confirms no problematic multicollinearity

Table 5: Regression Model Summary

R	R^2	Adj. R^2	F	df	Sig.
0.632	0.4	0.394	65.881	3,296	<0.001

Source: Field Survey, 2026

Table 6: Regression Coefficients and Hypotheses Test Results

Model	B	SE	t	Sig.	H0 Decision
(Constant)	0.774	0.209	3.713	<0.001	-
Flare Intensity	0.245	0.053	4.607	<0.001	H01 Rejected
Emission of Toxic Pollutants	0.298	0.052	5.756	<0.001	H02 Rejected
Thermal Pollution	0.243	0.052	4.695	<0.001	H03 Rejected

Source: Field Survey, 2026 (computed via Python statsmodels OLS)

The model was statistically significant, $R^2 = 0.4$ (approximately 40.0 per cent of variance explained), $F(3, 296) = 65.881$, $p < 0.001$. All three predictors were positive and significant at $p < 0.001$, leading to the rejection of H01, H02, and H03: flare intensity, emission of toxic pollutants, and thermal pollution each significantly and positively affect aquatic life deterioration in Delta State, with emission of toxic pollutants the strongest predictor.

Discussion of Findings

The findings of this study confirm that all three dimensions of gas flaring examined, flare intensity, emission of toxic pollutants, and thermal pollution, exert a statistically significant, positive effect on the perceived deterioration of aquatic life in the flare-impacted communities of Delta State. These findings are consistent with, and quantitatively extend, the largely descriptive literature reviewed in this study.

The significant effect of flare intensity on aquatic life corroborates Ukhurebor's (2024) observation that the scale and persistence of flaring operations determine the severity and geographic reach of ecological disturbance, and aligns with Ayibatonye et al.'s (2024) finding that communities nearest to the most intensely and persistently flared facilities in Bayelsa State reported the steepest declines in fish catch. The result lends quantitative, hypothesis-tested support to the proposition that flare intensity is not merely a background condition but an active, measurable driver of aquatic ecosystem stress.

The strong effect of emission of toxic pollutants, the largest of the three coefficients in the regression model, reinforces Akankali and Jamabo's (2023) findings that toxic deposition into rainwater and surface run-off near flare sites alters conductivity, pH, and heavy metal concentration to levels capable of harming aquatic organisms, and is consistent with Ukhurebor et al.'s (2023) broader concern about inadequate monitoring of petroleum-sector pollutant discharge in the Niger Delta. Read alongside the Bioaccumulation Theory underpinning this study, this finding suggests that the cumulative, food-chain-mediated toxicological burden of flaring may be the single most consequential pathway through which gas flaring undermines aquatic life in Delta State, warranting the most urgent regulatory attention.

The significant effect of thermal pollution aligns with Akankali and Jamabo's (2023) documentation of flare-induced water temperature alteration and with broader climate-stress reviews of Niger Delta fisheries showing that elevated water temperature disrupts fish distribution, spawning cues, and species tolerance thresholds (Akpan et al., 2023). Combined, the three findings validate the Ecological Risk Theory framework adopted in this study: gas flaring operates as a composite, multi-pathway environmental stressor whose distinct dimensions each independently, and jointly, elevate ecological risk to aquatic life beyond what any single pathway would produce in isolation.

Overall, the moderate-to-substantial proportion of variance in aquatic life explained by the three predictors indicates that, while gas flaring is a major and statistically dominant driver of aquatic ecosystem stress in the study area, it operates alongside other unmeasured factors, potentially including oil spillage, illegal artisanal refining, sedimentation, and broader climatic variability, that future research should incorporate to build a fuller explanatory model of aquatic ecosystem health in Delta State's oil-producing communities.

5. CONCLUSION AND RECOMMENDATIONS

This study set out to examine the effect of gas flaring on aquatic life in Delta State, Nigeria, disaggregating gas flaring into flare intensity, emission of toxic pollutants, and thermal pollution as its three explanatory dimensions. Using a structured, validated questionnaire administered to 300 respondents across seven flare-impacted local government areas, and analysed through descriptive statistics, correlation, and multiple regression, the study found that all three dimensions of gas flaring exert a positive and statistically significant effect on aquatic life deterioration in the study area, with the model jointly explaining a substantial proportion of the variance in perceived aquatic life outcomes.

These findings confirm that gas flaring in Delta State is not a diffuse or merely nuisance-level environmental concern but a statistically demonstrable driver of decline in fish population abundance, aquatic biodiversity, and fish reproductive success in oil-producing riverine communities. Of the three dimensions examined, emission of toxic pollutants exerted the strongest individual effect, followed by flare intensity and thermal pollution, suggesting that toxicological pathways, most likely acting through bioaccumulation along the aquatic food chain, may represent the most consequential and urgent target for mitigation. Taken together, the study affirms the Ecological Risk Theory and Bioaccumulation Theory framework adopted in Chapter Two, demonstrating that gas flaring operates as a composite, multi-pathway stressor whose distinct dimensions combine to elevate ecological risk to aquatic life in Delta State beyond what any single pathway would produce in isolation.

Based on the findings of this study, the following recommendations are made:

i. The National Upstream Petroleum Regulatory Commission and the Delta State Ministry of Environment should intensify enforcement of gas flare-down obligations and routine flaring deadlines among oil-producing companies operating in Ughelli South, Warri South, Isoko North, Isoko South, Bomadi, Patani, and Burutu, given the demonstrated significant effect of flare intensity on aquatic life in these areas.

ii. Given that emission of toxic pollutants emerged as the strongest predictor of aquatic life deterioration, oil-producing companies should invest in improved flare combustion efficiency, pollutant scrubbing technology, and independent water and rainwater quality monitoring in communities surrounding active flare sites, with results made publicly available to affected communities.

iii. Regulatory agencies should mandate and monitor the thermal discharge management practices of flow stations and processing facilities, including heat dissipation and produced water cooling before discharge into surface water bodies, to reduce the thermal pollution burden on aquatic ecosystems.

iv. The Delta State Government, in collaboration with federal environmental agencies, should establish a dedicated aquatic ecosystem monitoring programme for flare-impacted communities, incorporating both community-based perception surveys of the kind used in this study and periodic laboratory-based water quality and fish tissue analysis, to track the long-term trajectory of aquatic life recovery or decline.

v. Compensation and livelihood support frameworks for artisanal fisherfolk in flare-impacted communities should be reviewed and strengthened, using evidence of the kind generated in this study to support fair and empirically grounded claims for environmental damage arising from gas flaring activity.

This study relied on a cross-sectional, perception-based survey of residents in flare-impacted communities. Future research is encouraged to complement this approach with laboratory-based ecotoxicological sampling of water quality parameters and fish tissue heavy metal concentration in the same local government areas, to validate and extend the perception-based findings reported here with direct physical and biological measurements. Future studies should also consider a comparative, multi-state design spanning Delta, Bayelsa, Rivers, and Akwa Ibom States to examine whether the relative strength of flare intensity, toxic pollutant emission, and thermal pollution as predictors of aquatic life varies across the different oil-producing states of the Niger Delta. Additionally, further studies could incorporate longitudinal or panel data collected over multiple years to assess the trend of aquatic life decline or recovery in response to ongoing gas flare-down and commercialisation policy initiatives, and could expand the explanatory model to include other anthropogenic stressors such as oil spillage, illegal artisanal refining, and sedimentation alongside gas flaring.

REFERENCES

Agbasi, J. C., Egbueri, J. C., Ayejoto, D. A., & Igwe, O. (2024). Nigeria's water crisis: Abundant water, polluted reality. *Environmental Science and Ecotechnology, 28(5)*, 100-120.

Akankali, J. O., & Jamabo, N. A. (2023). Gas flaring-induced impacts on aquatic resources in the Niger Delta Region, Nigeria. *Journal of Aquatic Sciences, 38*(1), 45-58.

Akpan, E. U., Osim, S. E., & Ekpo, U. F. (2023). Impacts of climate change on fishing and fish farming in the Niger Delta region of Nigeria: A review. *Journal of Fisheries and Aquatic Science, 18*(2), 33-47.

Ayibatonye, D., Elemi, O. G., & Bariweni, P. A. (2024). Unveiling the impact: Gas flaring on artisanal fisheries in Taylor Creek, Bayelsa State, Nigeria. *International Journal of Hydrology, 8*(6), 235-248.

Chukwuma, E. C., & Eze, V. C. (2024). Sample size determination and reliability testing in survey-based environmental management research: A methodological review. *African Journal of Environmental Management Studies,* 6(1), 18-31.

Edegbene, A. O., & Akamagwuna, F. C. (2022). Insights from the Niger Delta Region, Nigeria on the impacts of urban pollution on the functional organisation of Afrotropical macroinvertebrates. *Scientific Reports, 12(1), 22-551.*

Eruvwe, O. E., Tarurhor, E. M., Aruoren, E. E., & Omoye, E. I. (2024). Business Management ethics and customers retention in selected money-deposit banks in Delta and Edo States Nigeria. *American International Journal of Business Management (AIJBM), 7*(6), 30-42.

Igbani, F., Tatah, G. W., & Odekina, M. U. (2023). A review on the effects of crude oil spill on aquatic life (fish) in the Niger Delta, Nigeria. *International Journal of Environment and Pollution Research, 12*(1), 75-94.

Israel, O. E., & Josephine, U. (2026). Safety first, productivity follows: Unpacking the health and safety management-performance link in Delta State's deposit money banks. *ISA Journal of Business, Economics and Management (ISAJBEM),* 3(4), 64-76.

Nwachukwu, M. C., Okonkwo, C. J., & Ibe, F. O. (2025). Causes and effects of environmental degradation in the Niger Delta. *Saudi Journal of Humanities and Social Sciences, 10*(2), 45-55.

Ojo, A. O., Erhabor, T. E., & Idogho, O. (2025). Study proposal of the impact of gas flaring on health of communities in Delta State, Nigeria. *International Journal of Scientific Reports, 11*(3), 112-119.

Omoye, I. E. (2025). Innovative quality control management and employee productivity in packaged water firms in Delta State. *DELSU Journal of Management Sciences, 7*(2), 283-295.

The Xylom. (2024, June 12). We are suffering: Despite steps taken, gas flaring still threatens livelihoods in Niger Delta. The Xylom. https://www.thexylom.com/post/we-are-suffering-despite-steps-taken-gas-flaring-still-threatens-livelihoods-in-niger-delta

Tom, E. C., Young, O. U., Muhammad, A., Jeroh, E., Emumeena, M. O., Omoye, E. I., Igiagbe, J. I.,& Odiase, B. O. (2025). Oil demand-supply equilibria in some selected regions: macroeconomic implications for market stability and energy security. *Eastern Journal of European Studies, 16*(SI), 36-51.

Ukhurebor, K. E. (2024). Environmental influence of gas flaring: Perspective from the Niger Delta region of Nigeria. *Geofluids, (1),* 1321022.

Ukhurebor, K. E., Ngonso, B. F., Egielewa, P. E., Cirella, G. T., Akinsehinde, B. O., & Balogun, V. A. (2023). Petroleum spills and the communicative response from petroleum agencies and companies: Impact assessment from the Niger Delta region of Nigeria. *The Extractive Industries and Society,(15),* 101-331.

Zikas, S., Christakis, C., Misthos, L.-M., Psomadakis, I., Katsafadou, A. I., Tsilikas, I., Fthenakis, G. C., Vasiliou, V., & Kiouvrekis, Y. (2025). Global mapping of population exposure to upstream gas flaring using integrated VIIRS Nightfire and GHSL data, 2016-2023, with projections to 2030. *Toxics, 13*(12), 10-53.