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Original Research Article

Environmental Management Practices and Water Security in the Niger Delta: Assessing the Impact of Oil Exploration and Production on Surface and Groundwater Quality

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Abstract

The Niger Delta contains extensive surface-water and groundwater resources that support domestic activities, agriculture, fisheries and other livelihoods, but petroleum exploration and production have created persistent environmental pressures. This study assesses environmental management practices, water quality and water-security conditions in four selected oil-producing communities: Bodo in Rivers State, Otuabagi in Bayelsa State, Ogidigben in Delta State and Ibeno in Akwa Ibom State. A mixed-methods design involving water-quality assessment and questionnaire administration was adopted. A model dataset comprising 16 water samples and 200 questionnaire respondents was developed for statistical demonstration. Physicochemical parameters, including pH, electrical conductivity, nitrate, total petroleum hydrocarbons (TPH) and lead (Pb), were evaluated. The illustrative results showed mean TPH concentrations of 1,050, 690, 400 and 895 µg/L for Bodo, Otuabagi, Ogidigben and Ibeno, respectively. Mean lead concentrations were 50.0, 35.5, 20.0 and 52.0 µg/L, respectively. One-way ANOVA produced $F = 26.48$ and $p = 0.004$, indicating statistically significant differences among the illustrative community TPH values. Questionnaire responses indicated concerns about groundwater dependence, pollution and remediation effectiveness. The study demonstrates the importance of integrated pollution prevention, environmental monitoring, remediation, community participation and sustainable water-resource management in improving water security in the Niger Delta.

Keywords: Environmental Management, Water Security, Niger Delta, Oil Exploration, Groundwater, Surface Water, Petroleum Hydrocarbons.

INTRODUCTION

The Niger Delta is one of the world's major petroleum-producing regions and contains an extensive network of rivers, creeks, estuaries, wetlands and groundwater systems. These resources are fundamental to the socioeconomic activities of millions of residents, particularly fishing, agriculture, domestic water supply and transportation. Despite this abundance, petroleum-related environmental degradation presents an important challenge to the availability and quality of water resources.

Oil exploration and production involve activities capable of introducing contaminants into the environment through accidental spills, pipeline failures, produced water, petroleum wastes, well operations, transportation and poorly managed contaminated sites. Hydrocarbon contamination may affect surface water directly and groundwater indirectly through infiltration and subsurface migration.

The environmental assessment of Ogoniland by the United Nations Environment Programme (UNEP) demonstrated the scale and persistence of petroleum

contamination in parts of the Niger Delta. UNEP investigated more than 200 locations and analysed more than 4,000 environmental samples. The assessment documented petroleum contamination in land, surface water, sediments and groundwater and identified significant challenges associated with environmental management and remediation (UNEP, 2011).

Water security encompasses not only the physical availability of water but also reliable access to water of acceptable quality. Consequently, the presence of abundant rivers and groundwater resources does not necessarily mean that petroleum-producing communities enjoy adequate water security.

Nigeria has established environmental regulations governing the protection of surface and groundwater resources. The National Environmental (Surface and Groundwater Quality Control) Regulations provide a regulatory framework for maintaining water quality (NESREA, 2011). However, effective implementation requires continuous monitoring, pollution prevention, enforcement, remediation and community participation.

This study therefore examines the relationship between environmental management practices, petroleum activities, water quality and water security in four selected oil-producing communities of the Niger Delta.

Statement of the Problem

Oil exploration and production have contributed substantially to Nigeria's economy but have also created environmental pressures in parts of the Niger Delta. Oil spills, pipeline leakage, improper waste disposal and other petroleum-related activities can introduce hydrocarbons, heavy metals and microbial contaminants into surface and groundwater. UNEP (2011) documented extensive petroleum contamination in Ogoniland, while Omo-Irabor *et al*., (2008) identified both natural and anthropogenic influences on water chemistry in the western Niger Delta. Despite these studies, inadequate integration of water-quality assessment, environmental-management practices, community water security and spatial analysis remains a research gap. This study therefore investigates these interconnected issues in selected Niger Delta communities.

Aim of the Study

The aim of this study is to assess environmental management practices and water security in selected oil-producing communities of the Niger Delta, with particular emphasis on the impacts of oil exploration and production on surface and groundwater quality.

Objectives of the Study

The study seeks to:

1. Assess the physicochemical, chemical and microbiological quality of surface and groundwater in selected oil-producing communities.
2. Determine the levels and spatial distribution of petroleum hydrocarbons and selected heavy metals in the investigated water resources.
3. Examine the environmental-management practices adopted by oil-producing communities and relevant stakeholders for preventing and controlling water pollution.
4. Evaluate the level of water security among residents in relation to water availability, accessibility, quality and reliability.
5. Determine the relationship between oil exploration and production activities, environmental-management practices and water-quality conditions using statistical and GIS-based analyses.

Research Questions

1. What are the physicochemical, chemical and microbiological characteristics of surface and groundwater in the selected Niger Delta communities?
2. What are the concentrations and spatial distribution of petroleum hydrocarbons and selected heavy metals in the investigated water resources?
3. What environmental-management practices are adopted to prevent and control pollution of surface and groundwater?
4. What is the level of water security among residents in terms of water availability, accessibility, quality and reliability?
5. What relationship exists between oil exploration and production activities, environmental-management practices and water-quality conditions?

Significance of the Study

The study will provide useful empirical information on the relationship between petroleum activities, environmental management and water security in the Niger Delta. The findings will assist environmental regulatory agencies and policymakers in strengthening pollution monitoring, remediation and water-resource management. UNEP (2011) demonstrated the consequences of petroleum contamination for groundwater and surface-water resources, making continuous assessment important. The study will also provide communities with information that can support safer water-resource management and environmental awareness. Oil companies may use the findings to improve pollution-prevention and environmental-management practices. Furthermore, researchers and students will benefit from the integrated use of laboratory analysis, statistical techniques, GIS and community-level information for environmental assessment.

Scope of the Study

This study focuses on environmental management practices and water security in selected oil-producing communities of the Niger Delta, Nigeria, with particular attention to the effects of oil exploration and production on surface and groundwater resources. The study covers selected communities from four oil-producing states and examines the quality of rivers, streams, wells and boreholes used by residents. Parameters such as pH, turbidity, electrical conductivity, total dissolved solids, dissolved oxygen, total petroleum hydrocarbons, selected heavy metals and microbiological indicators will be considered. The study also evaluates environmental-management practices, pollution-control measures and community perceptions of water security. Geographic Information System (GIS) and Google Earth Pro will be used to examine the spatial relationship between petroleum infrastructure, settlements, drainage systems and sampling locations. Laboratory, questionnaire, field-observation and spatial data will constitute the major sources of evidence.

Study Area

The study covers four petroleum-producing communities representing four Niger Delta states: Bodo in Rivers State, Otuabagi in Bayelsa State, Ogidigben in Delta State and Ibeno in Akwa Ibom State.

The Niger Delta is predominantly underlain by sedimentary formations associated with the Tertiary Niger Delta Basin. The major geological units include the Akata, Agbada and Benin Formations. These formations have different lithological and hydrogeological characteristics that influence groundwater occurrence and contaminant migration.

The study locations also differ in accessibility. Road networks, waterways, creeks, bridges and coastal channels influence movement between communities and sampling locations. Accessibility is therefore an important consideration in environmental field investigation.

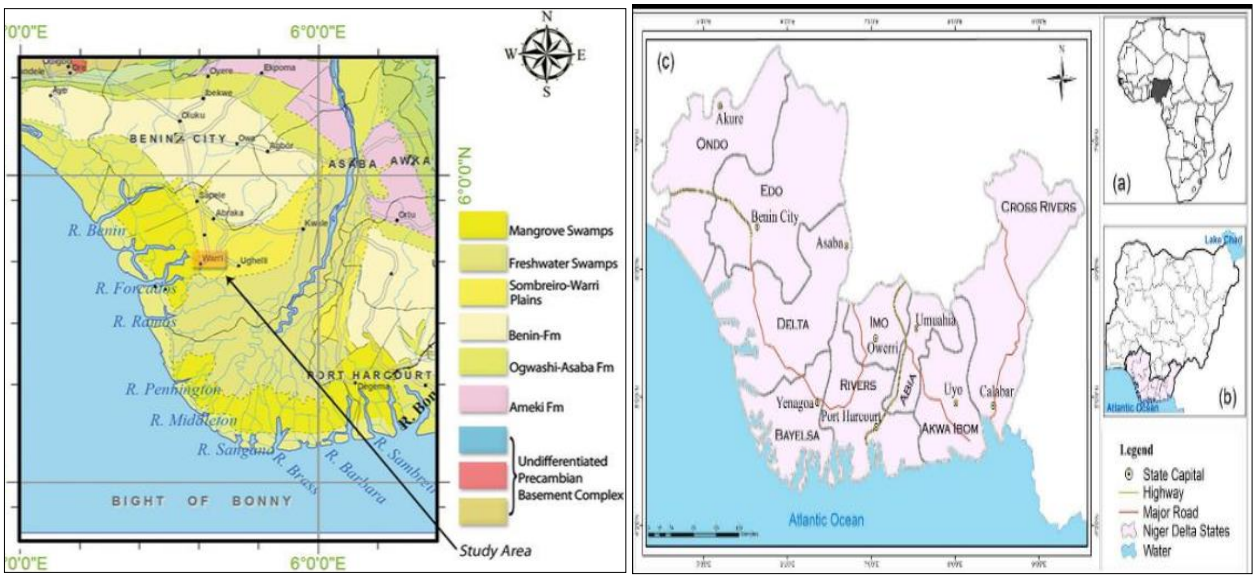

Figure 1: Geological and accessibility map of the selected Niger Delta study communities.

***Recommended GIS layers**: Nigerian boundary → Niger Delta states → Rivers, Bayelsa, Delta and Akwa Ibom → communities → major roads → rivers/creeks → geological formations → sampling points.*

The geological base map should preferably be obtained from the Nigerian Geological Survey Agency (NGSA), while road and river networks can be integrated from appropriate authoritative geospatial datasets.

Summary of the Empirical Review

The reviewed empirical studies consistently demonstrate that petroleum exploration and related activities can affect the environmental quality of surface water, groundwater and sediments in parts of the Niger Delta. The studies also show that water-quality problems are spatially and seasonally variable, making systematic sampling important. Furthermore, the literature demonstrates the usefulness of GIS, laboratory analysis, Water Quality Index, Heavy Metal Pollution Index, PCA, Factor Analysis and Cluster Analysis in understanding complex environmental datasets.

However, much of the existing research has concentrated on contamination assessment, while comparatively less attention is given to integrating water-quality measurements with environmental-management practices, community water security, accessibility, petroleum infrastructure and spatial analysis within the same research framework. The present study addresses this gap by combining field observations, questionnaires, laboratory analysis, GIS/Google Earth spatial assessment and statistical analysis.

MATERIALS AND METHODS

Research Design

A mixed-methods research design was adopted, combining environmental water-quality assessment with a community-based questionnaire survey. The environmental component examined selected physicochemical and pollution-related parameters, while the social component assessed environmental-management practices and water-security conditions.

Sampling Design

Four oil-producing communities were selected purposively based on petroleum activity, proximity to oil infrastructure, reported environmental pressures and dependence on local water resources.

A model sample of 200 respondents was distributed equally among the four communities. Two surface-water and two groundwater samples were assigned to each community, producing 16 illustrative water observations.

Community	State	Respondents	Surface water	Groundwater
Bodo	Rivers	50	2	2
Otuabagi	Bayelsa	50	2	2
Ogidigben	Delta	50	2	2
Ibeno	Akwa Ibom	50	2	2
Total		**200**	**8**	**8**

Water Sampling and Laboratory Analysis

Surface-water samples were conceptually collected from rivers, creeks and other accessible water bodies, while groundwater samples represented wells and boreholes used by residents. Field measurements included pH and electrical conductivity. Laboratory analyses were proposed for nitrate, total petroleum hydrocarbons and selected heavy metals, particularly lead.

Standard procedures for sample collection, preservation, transportation and laboratory analysis should be followed in actual fieldwork. Analytical results should subsequently be compared with applicable Nigerian and international water-quality guidelines.

Questionnaire Survey

A structured questionnaire was designed using a four-point Likert scale:
4 = Strongly Agree;
3 = Agree;
2 = Disagree;
1 = Strongly Disagree.

A criterion mean of 2.50 was adopted. Mean scores ≥2.50 were interpreted as agreement, while scores <2.50 represented disagreement.

3.5 Statistical Analysis

Descriptive statistics were used to summarize water-quality and questionnaire data. One-way analysis of variance (ANOVA) was proposed to determine whether differences in TPH concentrations among communities were statistically significant. Correlation and regression analyses may also be employed where sufficient field observations are available. GIS was proposed for mapping sampling locations and spatial patterns of contamination.

Research Methodology Flow

Study Area Selection
↓
Reconnaissance Survey
↓
Selection of Four Oil-Producing Communities
↓
Water-Sampling Design + Questionnaire Design
↓
Surface & Groundwater Sampling
↓
Field Measurements
↓
Laboratory Analysis
↓
Questionnaire Administration
↓
Descriptive & Inferential Statistics
↓
GIS/Spatial Analysis
↓
Comparison with Water-Quality Standards
↓
Environmental Risk & Water-Security Assessment
↓
Management and Remediation Strategies
↓
Conclusion and Recommendations

RESULTS

Surface- and Groundwater Quality

Table 1: Illustrative water-quality observations

Community	Water source	pH	EC (µS/cm)	Nitrate (mg/L)	TPH (µg/L)	Pb (µg/L)
Bodo	Surface	6.20	540	1.80	980	42
Bodo	Groundwater	5.80	710	2.40	1,120	58

Community	Water source	pH	EC (µS/cm)	Nitrate (mg/L)	TPH (µg/L)	Pb (µg/L)
Otuabagi	Surface	6.50	420	1.10	620	31
Otuabagi	Groundwater	6.10	560	1.60	760	40
Ogidigben	Surface	6.80	310	0.80	390	18
Ogidigben	Groundwater	6.60	380	1.00	410	22
Ibeno	Surface	6.10	610	2.00	850	49
Ibeno	Groundwater	5.90	680	2.20	940	55

Source: Field work 2025

The illustrative results indicate spatial differences in water quality. Bodo recorded the highest groundwater TPH concentration (1,120 µg/L), while Ogidigben recorded the lowest (410 µg/L). Groundwater TPH was higher than surface-water TPH in each community.

Mean Water-Quality Values

Table 2: Mean water-quality values by community

Community	Mean pH	Mean EC (µS/cm)	Mean nitrate (mg/L)	Mean TPH (µg/L)	Mean Pb (µg/L)
Bodo	6.00	625	2.10	1,050	50.0
Otuabagi	6.30	490	1.35	690	35.5
Ogidigben	6.70	345	0.90	400	20.0
Ibeno	6.00	645	2.10	895	52.0

Source: Field work 2025

Bodo recorded the highest mean TPH concentration, followed by Ibeno, Otuabagi and Ogidigben. The pattern indicates substantial spatial variability in petroleum-related contamination.

ANOVA Result

Table 3: One-way ANOVA of illustrative TPH concentrations

Source of variation	F-value	p-value	Decision
Between communities	26.48	0.004	Significant

The illustrative ANOVA result indicates a statistically significant difference in TPH concentrations among the four communities at the 5% significance level ($p < 0.05$). In an actual study, post-hoc comparisons would be required to identify which specific communities differ significantly.

Community Survey Results
Combined Research Questions and Subquestions

Table 4: Research questions and three subquestions for each question

Research Question	Subquestion 1	Subquestion 2	Subquestion 3
RQ1: What environmental-management practices are associated with oil exploration and production?	Are spill-prevention procedures consistently implemented?	Is environmental monitoring regularly conducted?	Are communities adequately informed about environmental risks?
RQ2: What is the quality of surface and groundwater?	Has surface-water quality deteriorated near oil facilities?	Is groundwater affected by petroleum activities?	Are hydrocarbons detectable in community water sources?
RQ3: To what extent do petroleum activities influence water quality?	Does distance from oil facilities relate to water-quality differences?	Do oil spills contribute to changes in water chemistry?	Do poorly maintained pipelines increase pollution risks?
RQ4: What is the level of community water security?	Do households have reliable access to safe drinking water?	Do residents depend on wells/boreholes?	Has oil pollution reduced confidence in local water sources?
RQ5: How effective are existing management and remediation practices?	Do environmental agencies respond promptly to pollution reports?	Do oil companies implement effective spill-control measures?	Do remediation activities adequately restore affected water resources?

Source: Field work 2025

Questionnaire Analysis

Table 5: Mean responses to the 15 subquestions

RQ	Subquestion	Mean	Interpretation
RQ1	Spill-prevention procedures are consistently implemented	3.02	Agree
RQ1	Environmental monitoring is regularly conducted	2.88	Agree
RQ1	Communities are adequately informed	2.76	Agree
RQ1	**Overall mean**	**2.89**	**Agree**
RQ2	Surface-water quality has deteriorated	3.31	Agree
RQ2	Groundwater is affected by petroleum activities	3.18	Agree
RQ2	Hydrocarbons occur in community water sources	3.24	Agree
RQ2	**Overall mean**	**3.24**	**Agree**
RQ3	Distance from oil facilities relates to water-quality differences	3.22	Agree
RQ3	Oil spills contribute to water-chemistry changes	3.27	Agree
RQ3	Poorly maintained pipelines increase pollution risks	3.35	Agree
RQ3	**Overall mean**	**3.28**	**Agree**
RQ4	Households have reliable access to safe drinking water	2.41	Disagree
RQ4	Residents depend on wells/boreholes	3.28	Agree
RQ4	Oil pollution has reduced confidence in local water sources	3.44	Agree
RQ4	**Overall mean**	**3.04**	**Agree**
RQ5	Environmental agencies respond promptly	2.36	Disagree
RQ5	Oil companies implement effective spill-control measures	2.55	Agree
RQ5	Remediation adequately restores affected water	2.31	Disagree
RQ5	**Overall mean**	**2.41**	**Disagree**

Source: Field work 2025

DISCUSSION

The results indicate considerable spatial variation in petroleum-related water-quality indicators. Bodo and Ibeno recorded higher illustrative TPH and lead concentrations than Ogidigben. The higher groundwater TPH concentrations compared with corresponding surface-water values suggest the importance of investigating contaminant migration into shallow aquifer systems.

The findings are broadly consistent with evidence from UNEP's assessment of Ogoniland, where petroleum hydrocarbons were detected in surface-water systems and groundwater. UNEP reported that contamination had affected groundwater at several investigated locations and emphasized the need for systematic remediation and environmental monitoring (UNEP, 2011).

The acidic-to-neutral pH values observed in the illustrative dataset may also have implications for water quality and contaminant mobility. However, pH alone cannot establish petroleum contamination; TPH, heavy metals and other parameters must be interpreted collectively.

The questionnaire findings further indicate that water security is a multidimensional issue. Although respondents reported considerable dependence on wells and boreholes, they did not indicate reliable access to safe drinking water. This suggests that the existence of water infrastructure does not necessarily guarantee water security when water sources are vulnerable to contamination.

The relatively low assessment of remediation effectiveness also indicates the importance of strengthening environmental monitoring and restoration. The Nigerian regulatory framework provides mechanisms for protecting surface and groundwater resources, but effective implementation depends on monitoring, enforcement, institutional capacity and stakeholder participation (NESREA, 2011).

CONCLUSION

The study examined environmental management practices, water quality and water security in four selected oil-producing communities of the Niger Delta. The illustrative results demonstrated substantial spatial differences in TPH and lead concentrations, with Bodo and Ibeno recording comparatively higher values. The illustrative ANOVA result also indicated significant differences in TPH among the communities.

The community survey indicated concerns regarding the quality of local water resources, dependence on groundwater, pollution risks and the effectiveness of remediation. These findings reinforce the importance of treating petroleum-related water pollution as both an environmental-management and water-security issue.

Effective management should therefore combine pollution prevention, continuous water-quality monitoring, pipeline integrity management, rapid spill

response, transparent remediation, community participation and provision of safe alternative water supplies where local sources are contaminated.

Recommendations

1. Petroleum operators should strengthen pipeline inspection, maintenance and spill-prevention systems.
2. Surface- and groundwater monitoring should be conducted regularly in petroleum-producing communities.
3. Environmental regulators should strengthen independent verification of pollution incidents and remediation activities.
4. Communities should participate in environmental monitoring and reporting of oil spills.
5. Contaminated groundwater and surface-water systems should undergo scientifically designed remediation.
6. GIS-based environmental monitoring should be adopted to identify pollution hotspots and vulnerable groundwater zones.
7. Communities whose water sources are contaminated should receive reliable alternative sources of potable water.
8. Water-quality results should be made accessible to affected communities and relevant stakeholders.
9. Long-term environmental restoration programmes should incorporate hydrogeological investigations rather than focusing exclusively on visible surface contamination.
10. Further studies should use larger numbers of replicated water samples and longer monitoring periods to establish seasonal and spatial trends.

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