
Artificial Intelligence, Environmental Economics, and Sustainable Development: Oil Spill Monitoring and Management in Niger Delta

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ABSTRACT

The frequent oil spills in Niger Delta have continued to create serious environmental, economic, and social problems, despite several regulations and environmental management over the years. This study focuses on oil spill monitoring and management in the Niger Delta region of Nigeria through the application of artificial intelligence from the perspective of environmental economics and sustainable development. A mixed-methods research design using quantitative and qualitative data collected from environmental agencies, oil company staff, community leaders, environmental activists, intellectuals, and policymakers from Rivers, Bayelsa, Delta, and Akwa Ibom States were adopted for the study. Sustainable development theory, environmental Kuznets curve theory, and technology acceptance model were the study bases. Findings indicate that AI-driven technologies significantly improve the speed, accuracy, and efficiency of oil spill detection, environmental risk assessment, and remediation planning. It also finds that AI adoption positively impacts the environment, reduces environmental degradation and improves community livelihoods. However, challenges relating to data infrastructure, institutional capacity, funding, and policy implementation remain major obstacles. Study findings reveal that AI-based environmental monitoring systems can contribute to promoting sustainable environmental development and enhancing environmental accountability in the Niger Delta region of Nigeria. Policy recommendations are offered to governments, oil companies, environmental stakeholders, etc.

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INTRODUCTION

The rising synergy of artificial intelligence (AI), environmental economics, and sustainable development has altered contemporary approaches to environmental governance and natural resources management across the globe. With the intensification of environmental degradation due to industrialisation, urbanisation, climate change, and extractive economic activities, the governments and organisations are increasingly adopting advanced digital technologies for improving environmental monitoring, assessment of risk, and sustainability management. AI is one of the most beneficial technologies for improving environmental decision-making through predictive analytics, machine learning, remote sensing, big data analysis, and automated environmental monitoring systems (UNEP, 2024). The Niger Delta region of Nigeria with a high level of environmental degradation is a region where AI may be useful in environmental management.

Recent statistics on the environment also reveal the need to tackle the ecological degradation in the Niger Delta. According to the Nigerian Upstream Petroleum Regulatory Commission (NUPRC, 2025), hundreds of oil spills are still recorded annually in the different regions of Nigeria where petroleum production is still ongoing, with the Niger Delta region accounting for the bulk of cases due to the concentration of petroleum infrastructure. According to the National Oil Spill Detection and Response Agency (NOSDRA, 2025), pipeline failure, equipment malfunction, sabotage and illegal refining operations discharge thousands of barrels of crude oil annually into terrestrial and aquatic ecosystems. These incidents have caused extensive contamination of agricultural lands, mangrove forests, fresh water resources and fisheries, leading to tremendous environmental-economic losses for the households that are directly dependent on natural resources for their livelihoods. In addition to ecological degradation, the World Bank (2024) estimates that environmental pollution reduces agricultural productivity, fisheries output, ecosystem services, and household welfare in oil-producing communities. The environmental challenges facing the Niger Delta are therefore not just ecological issues but constitute major development and governance issues that require innovative technological interventions that can improve environmental surveillance, rapid response and evidence-based environmental management.

The Niger Delta is one of the most resourceful regions in the world as far as natural resources are concerned. Most of the crude oil extracted in Nigeria is from the Niger Delta, and it contributes greatly to national revenue generation. Despite the region's immense economic importance, decades of environmental degradation have resulted from repeated oil spills, gas flares, the vandalisation of pipelines, illegal refining, and weak environmental governance structures. According to reports that have emerged recently, the region has witnessed thousands of oil spill incidents over the last decades, thereby contaminating soil, groundwater, rivers, wetlands and biodiversity ecosystems (United Nations Development Programme [UNDP], 2024). The environmental impacts

have affected agriculture, fisheries, public health, livelihoods, and overall socio-economic development of host communities (Nriagu et al., 2016; Okonkwo et al., 2015). For over four decades of oil production, many communities in the Niger Delta still suffer from environmental degradation, poverty, unemployment, and weak infrastructure. Scholars have stated that the paradox of abundance and environmental underdevelopment is one of the defining features of the region (Watts, 2018; UNDP, 2006).

Environmental economics provides an important framework for understanding the relationship between economic activities and environmental sustainability. The discipline focuses on the need to internalise the environmental externalities of industrial production and resource extraction. Oil spills as a negative externality in the Niger Delta have been associated with enormous economic costs to local communities and the surrounding environment. The loss of agricultural productivity, falling fish stocks, health costs, loss of property value, and loss of ecosystem services are included (Udoinyang & Njoku, 2026; Okonkwo et al., 2015; Nriagu et al., 2016). As a result, monitoring and management of oil spills is necessary for sustainable development and environmental justice in the region.

Recent developments in AI have made new solutions available that can overcome many of the limitations of existing systems for monitoring oil spills. We use data from satellites, drones, machines, and algorithms to analyse emission levels in plants and trends in temperature and precipitation. Machine learning will also monitor deforestation, soil salinity, and other man-made conditions. These are estimation tools that can predict potential spilling, determine risk hotspots, and design response planning before environmental damage is extensive (Vinuesa et al., 2020). These technologies are gaining increasing attention among policymakers, environment agencies, and energy companies to improve environmental performance and sustainable outcomes.

Many nations across the world have adopted AI to detect environmental changes. AI-supported satellite surveillance systems have improved the identification of oil spills in offshore oil operations in North America, Europe, and parts of Asia. Vessel Autonomous Oil Spill Detection, these systems use deep learning algorithms to differentiate oil slicks from other features on the ocean surface to improve detection and response times (EEA, 2025). As we have already seen through similar applications, there is a widespread belief that AI can support or help in biodiversity conservation, pollution control, climate adaptation, and disaster management efforts.

Although the environmental benefits of artificial intelligence are increasingly recognised, its success depends on the maturity of technology, the capacity of institutions, the coordination of regulations and the continued flow of funds. Many developing economies, such as Nigeria, lack the broadband connectivity, geospatial infrastructure, environmental databases, digital governance frameworks and technical skills that are needed to deploy sophisticated AI applications. The effectiveness of AI-enabled monitoring systems could also be compromised by institutional fragmentation among environmental agencies, financing constraints for digital transformation, cybersecurity concerns and limited stakeholder trust. These implementation barriers

imply that technological innovation cannot guarantee better environmental governance without accompanying institutional reforms, capacity development and long-term public investment. Therefore, the effectiveness of AI should be evaluated not only on the basis of technological capability but also in the broader governance environment within which environmental management is undertaken.

Decades of environmental regulation have not yet made Nigerian oil spill monitoring systems preventive but rather reactive. Current monitoring techniques rely mainly on manual field inspections, slow community reports, conventional satellite analysis and inconsistent institutional databases, resulting in delayed responses and incomplete environmental information. Traditional methods often fail to provide continuous real-time surveillance, predictive risk assessment, automated anomaly detection, or integrated environmental intelligence needed for prompt intervention. Thus, environmental degradation often gets worse before remedial measures are taken, thus increasing the costs of clean-up, the loss of biodiversity and the socio-economic burden on host communities. Artificial intelligence provides a strategic option by integrating machine learning, remote sensing, Internet of Things (IoT) sensors, drone surveillance and predictive analytics into a unified environmental monitoring architecture that can detect spills early, predict high-risk locations, prioritise emergency responses and enable evidence-based environmental governance. The limitations of conventional monitoring systems therefore form the principal justification for investigating AI-driven environmental management in the Niger Delta context.

These limitations often lead to delays in detecting and cleaning up spills and, consequently, to greater environmental and economic damage. The increasing global focus on the Sustainable Development Goals (SDGs) has further boosted the case for AI integration in environmental management systems. The use of AI applications may directly contribute to the attainment of various SDGs, such as SDG 6, Clean Water and Sanitation; SDG 13, Climate Action; SDG 14, Life Below Water; SDG 15, Life on Land; and SDG 17, Partnerships for Sustainable Development, through environmental monitoring and evidence-based policy intervention (United Nations, 2025). AI-powered systems for environmental monitoring could assist with early detection of spills, enhancing environmental accountability, facilitating community participation, and improving sustainable resource governance in the Niger Delta context.

While the field of artificial intelligence and sustainability has received increasing scholarly attention, empirical literature on artificial intelligence, environmental economics, and oil spill management of the Niger Delta has been limited. Much research existing to date emphasises either environmental impacts of oil exploration or technological innovations alone without adequately touching upon environmental-economic outcomes of sustainable development. This creates a significant research gap that requires further analysis.

The subject matter of this paper is the role of artificial intelligence in oil spill monitoring and environmental management in the Niger Delta from the perspective of environmental economics and sustainable development. The goal of the research is to find out whether the impact of artificial intelligence tools on better environmental

monitoring, climate change mitigation, and sustainable developmental outcomes is positive. By bringing together technology, economics, and sustainability dimensions, the paper intends to contribute to the emerging conversations around digital environmental governance and sustainable use of resources in developing countries. The study aims to examine the use of artificial intelligence in oil spill monitoring and environmental management for sustainable development in the Niger Delta region of Nigeria. The study objectives are specifically to: examine the extent to which artificial intelligence technologies are utilised for oil spill monitoring in the Niger Delta; evaluate the impact of AI-based monitoring systems on recognising and managing environmental issues in the Niger Delta; estimate the ecological and economic advantages of AI-based oil spill detection and reaction systems; explore how artificial intelligence can contribute to sustainable development outcomes in oil-producing communities; explore the challenges hindering the use of AI strategies for environmental management in the Niger Delta; and propose policy strategies for the integration of artificial intelligence for the benefit of the environment.

This study draws on three complementary theoretical perspectives. Sustainable Development Theory holds that present-day development should not compromise the wellbeing of future generations, underscoring the role of AI-enabled monitoring in balancing oil-driven economic growth with environmental and community sustainability (Ibaba, 2018; United Nations, 2025). The Environmental Kuznets Curve (EKC) Theory suggests that technological innovation, such as AI-based environmental monitoring, can help decouple economic development from environmental degradation even in resource-dependent economies (Dwivedi et al., 2023). The Technology Acceptance Model (TAM) explains that the adoption of AI technologies by government agencies, oil companies and communities depends on perceived usefulness, ease of use, and the availability of institutional support (Davis, 1989; Dwivedi et al., 2023). Together, these theories provide a coherent lens for understanding both the environmental-economic rationale for AI adoption and the behavioural and institutional conditions that shape its success in the Niger Delta.

In recent years, scientific studies have shown interest in employing artificial intelligence (AI) in environmental monitoring. This is due to the ability of AI to recognize environmental disruptions and more (Rolnick et al., 2019; Vinuesa et al. 2020; Nriagu et al., 2016; NUPRC, 2025; UNEP 2011; Ibaba, 2018; Nriagu et al., 2016, Cho & Ackom, 2025; & Dwivedi et al., 2023). Modern research remarks that AI technologies like machine learning, deep learning, computer vision, remote sensing, and predictive analytics have revamped the environmental monitoring systems of developed and developing economies (Udoinyang et al, 2026; UNEP, 2024; UNDP, 2024; Kshetri, 2024; & NUPRC 2025).

Collectively, previous studies confirm that artificial intelligence enhances environmental monitoring through improved predictive analytics, satellite image processing, automated detection systems, and real-time decision support, yet most of this evidence comes from developed economies that emphasise technological performance over environmental-economic outcomes and institutional readiness in developing

petroleum-producing regions. Few studies integrate environmental economics, AI adoption, and sustainable development into a single analytical framework, leaving a clear gap in the literature. The purpose of this study is to examine how the adoption of artificial intelligence contributes to oil spill monitoring, environmental management, and sustainable development in the Niger Delta from an environmental-economic perspective, while also identifying the institutional and infrastructural challenges that shape its implementation.

METHOD

The present study used a convergent mixed-method research design in which quantitative and qualitative data were collected at the same phase of the study, analysed separately and integrated during interpretation. The convergent design was selected because the study aimed to establish the statistical relationships between artificial intelligence (AI), environmental monitoring, environmental management, environmental-economic performance and sustainable development and to explore stakeholders' experiences, institutional realities and implementation challenges, which could not be adequately captured by quantitative data alone. The convergent design enabled the simultaneous collection of complementary evidence from multiple stakeholder groups, thereby reducing the time required for data collection and allowing for methodological triangulation. This contrasts with explanatory sequential designs, which require qualitative data collection only after quantitative analysis, or exploratory sequential designs that begin with qualitative exploration. Integration occurred at the interpretation level by comparing quantitative findings with themes generated from the KIIs. Confidence in the findings was based on the convergent areas, while divergent areas provided greater insights into institutional barriers, governance challenges and contextual factors influencing AI adoption. Therefore, the convergent mixed-methods approach allowed for a more comprehensive understanding of AI-enabled environmental governance than the application of quantitative or qualitative methods alone.

The study was carried out in Rivers, Bayelsa, Delta and Akwa Ibom states, which together form the core petroleum-producing region of the Niger Delta. These states are selected on the basis of their significant share of Nigeria's crude oil production and are characterised by high incidences of oil spills, pipeline failure, illegal refining activities and the attendant environmental degradation. According to reports by the Nigerian Upstream Petroleum Regulatory Commission (NUPRC, 2025) and the National Oil Spill Detection and Response Agency (NOSDRA, 2025), these states are listed as environmental hotspots for which continuous monitoring and regulatory intervention are necessary. Furthermore, the selected states cover a variety of institutional actors such as environmental regulators, multinational oil companies, host communities, civil society organisations, and research institutions, thus offering a good setting for assessing the adoption of AI-enabled environmental monitoring systems under different governance contexts. Personnel from environmental regulatory agencies, oil and gas companies, environmental non-governmental organisations, academic institutions,

community development associations, and the environmental department of the local government formed the target population.

The study population comprised 12,850 stakeholders from environmental regulatory agencies, oil companies, environmental non-governmental organisations, academic institutions, community development associations and local government environmental departments. The minimum sample size was first estimated using the sample size formula of Cochran (1977):

$$n_0 = \frac{Z^2 pq}{e^2}$$

Where $Z = 1.96$ (95% confidence level), $p = 0.50$, $q = 0.50$ and $e = 0.05$.

This yielded an initial sample size of approximately 384 participants. Stakeholder groups vary across the four states; there is potential for non-response and the need to ensure adequate representation within each stakeholder category. Hence the sample size was increased by ~9.4% to a final target sample of 420 respondents. Oversampling is often recommended for multi-stakeholder population survey research to enhance representativeness and to compensate for incomplete responses. This study used a multi-stage sampling technique incorporating purposive sampling, stratified sampling, and simple random sampling to get proper representation from major stakeholders.

The multi-stage sampling procedure was performed in four stages. Rivers, Bayelsa, Delta and Akwa Ibom states were purposively selected in Stage one due to their strategic importance to the petroleum industry in Nigeria and their history of oil spill incidences recorded. In Stage Two, the respondents were divided into five stakeholder groups: environmental regulatory agencies, oil companies, community leaders, environmental non-governmental organisations (NGOs), and academics. In Stage Three, the sample was proportionally allocated to the stakeholder groups and states according to their estimated population sizes to ensure balanced representation. Thus, Rivers State gave 125 respondents, Bayelsa gave 100 respondents, Delta gave 95 respondents and Akwa Ibom gave 100 respondents. Stage Four was simple random sampling within each stakeholder category; individual respondents were selected using staff registers, organisational membership lists and community records. This process guaranteed that all the eligible participants in each stratum had an equal chance of being selected and that there was an adequate representation of the different stakeholder groups involved in environmental governance.

A structured questionnaire designed on a five-point Likert scale was used for quantitative data collection. The scale was in the form of Strongly Disagree (1) to Strongly Agree (5). The sections included demographic characteristics, AI adoption, environmental monitoring effectiveness, the environmental-economic impacts of AI, sustainable development outcomes, and challenges affecting AI implementation. Data collection involved twenty-four key informant interviews with representatives of the Nigerian Upstream Petroleum Regulatory Commission (NUPRC); the National Oil Spill Detection and Response Agency (NOSDRA), state ministries of environment, multinational oil companies, environmental scholars, and community leaders. In order

to assess whether the questionnaire has content validity, experts in environmental economics, sustainable development, and information technology were invited to review it. A pilot study involving 40 respondents from Edo State, which shares similar environmental characteristics but was excluded from the final study area, was conducted. The results of reliability testing using Cronbach's alpha for the study variables are between 0.82 and 0.91; thus, a score of 0.70 is good. The Statistical Package for Social Sciences (SPSS Version 29) was used to conduct quantitative data analysis with descriptive statistics and multiple regression analyses, whereas qualitative data were analysed using thematic analysis.

The qualitative analysis followed the six-step thematic analysis procedure proposed by Braun and Clarke. Interview recordings were transcribed verbatim before repeated reading to achieve data familiarisation. First, open codes were independently created by two researchers using QSR International (2023) NVivo software, and then clustered into higher order categories that reflected common patterns across stakeholder responses. Emerging themes were reviewed and refined. Themes were compared until conceptual consistency was reached. Coding discrepancies were discussed and resolved by consensus with an inter-coder agreement of about 91% indicating satisfactory coding reliability. Representative quotations were then chosen to illustrate each of the major themes presented in Table 6.

The University Research Ethics Committee and relevant state environmental authorities provided ethical approval for the study. We explained the study's purpose, voluntary participation, information confidentiality, anonymity, and the option to withdraw at any stage to the participants. All participants provided written informed consent before the commencement of data collection. As a result, we discovered that artificial intelligence can enhance environmental management, economic performance, sustainable development, and oil spill monitoring in the Niger Delta.

RESULT AND DISCUSSION

RESULT

Table 1: Selected States, Respondents, and Demographic Representation

State	Environm ental Agency Staff	Oil Company Personnel	Communi ty Leaders	Environmen tal NGOs	Academi cs	Total Responde nts
Rivers	40	35	25	15	10	125
Bayels	35	25	20	10	10	100
a						
Delta	30	25	20	10	10	95
Akwa	30	25	20	15	10	100
Ibom						
Total	135	110	85	50	40	420

Source: Authors' Fieldwork, 2026.

Table 1 shows the distribution of the 420 respondents across the four states and five stakeholder groups. Rivers State accounted for the largest share (125) given its position as Nigeria's leading oil-producing state, while Bayelsa, Delta and Akwa Ibom States each contributed 95-100 respondents. Balanced representation across government agencies, oil companies, community leaders, NGOs and academia strengthens the credibility.

Table 2: Demographic Characteristics of Respondents

Variable	Category	Frequency	Percentage (%)
Gender	Male	262	62.4
	Female	158	37.6
Age	18-30 years	75	17.9
	31-40 years	142	33.8
	41-50 years	126	30.0
	51 years and above	77	18.3
Education	Diploma	48	11.4
	Bachelor's Degree	178	42.4
	Master's Degree	135	32.1
	PhD	59	14.1
Occupation	Government	135	32.1
	Agencies		
	Oil Companies	110	26.2
	Community	85	20.2
	Leaders		
	NGOs	50	11.9
	Academics	40	9.6

Source: Authors' Fieldwork, 2026.

The demographic profile strengthens the credibility of the findings. Most respondents (63.8%) were aged 31-50 years with substantial professional experience, 88.6% held tertiary qualifications, and respondents were drawn fairly evenly across environmental agencies, oil companies, community leaders, NGOs and academia. This institutional diversity reduces single-source bias and supports the validity and generalisability of the results.

Table 3: Questionnaire Distribution and Retrieval Rate

State	Questionnaire Distributed	Questionnaire Returned	Response Rate (%)
Rivers	130	125	96.2
Bayelsa	105	100	95.2
Delta	100	95	95.0
Akwa Ibom	105	100	95.2
Total	440	420	95.5

Source: Authors' Fieldwork, 2026.

Of the 440 questionnaires distributed, 420 valid responses were retrieved, an overall response rate of 95.5% (Table 3). This exceeds the 70% threshold generally considered satisfactory for survey research, indicating sufficient data for robust statistical analysis.

Table 4: Descriptive Statistics of the Study Variables (N = 420)

Variables	Mean	Standard Deviation	Decision
AI Adoption for Oil Spill Monitoring	4.31	0.68	High
AI Improves Early Oil Spill Detection	4.45	0.61	High
AI Enhances Environmental Surveillance	4.28	0.73	High
AI Reduces Environmental Response Time	4.22	0.77	High
AI Enhance Improves Environmental Management Efficiency	4.36	0.66	High
AI Enhances Environmental Accountability	4.17	0.81	High
AI Supports Sustainable Development Goals	4.26	0.74	High
AI Reduces Environmental-Economic Losses	4.19	0.78	High
Institutional Support for AI Adoption Exists	3.21	0.95	Moderate
Adequate Digital Infrastructure is Available	2.87	1.02	Low
Environmental Agencies Possess AI Capacity	3.05	0.98	Moderate
Government Policies Supports AI Integration	3.18	0.89	Moderate

Source: Authors' Fieldwork, 2026.

Based on the descriptive analysis, respondents generally have a positive perception of the applicability of artificial intelligence tools in oil spill monitoring and environmental management in the Niger Delta. The top-rated variable, which is the improvement of early oil spill detection by AI, received a mean score of 4.45. Respondents agreed AI-driven technologies are effective for oil spillage identification. Likewise, respondents responded positively that AI helps in making environmental management efficient (Mean = 4.36) and in monitoring the environment (Mean = 4.28). The infrastructural and institutional limitations continue to pose hindrances to artificial intelligence adoption, as evidenced by the digital infrastructure (mean = 2.87) and institutional capacity (mean = 3.05) variables. In general, the grand mean of 3.88 shows overwhelming support from stakeholders for the integration of AI into environmental governance and oil spill management.

Multi Regression Analysis

To assess the overall contribution of artificial intelligence (AI) to sustainable development, the study estimated a hierarchical multiple regression model. The analysis was carried out in two steps. In Model 1, AI adoption was included as the main explanatory variable for sustainable development outcomes. In Model 2, environmental monitoring efficiency, environmental management effectiveness, and environmental-economic benefits were introduced as explanatory mechanisms through which AI adoption contributes to sustainable development. These variables are therefore best interpreted not as independent causal factors separate from AI adoption, but as operational dimensions representing the pathways through which AI influences sustainable development outcomes.

Table 5: Multiple Regression Results

Variables	Beta Coefficient (β)	Standard Error	t-value	p-value
Constant	0.842	0.274	3.073	0.002
AI Adoption	0.411	0.065	6.323	0.000
Environmental Monitoring Efficiency	0.356	0.071	5.014	0.000
Environmental Management Effectiveness	0.287	0.069	4.159	0.000
Environmental- Economic Benefits	0.261	0.064	4.078	0.000

Source: Authors' Fieldwork, 2026.

Based on the regression results, artificial intelligence adoption has a positive influence on sustainable development in the Niger Delta ($\beta = 0.411$, $p < 0.05$). Improving the efficiency of environmental monitoring, including leak detection and greater surveillance, can assist in more sustainable development ($\beta = 0.356$, $p < 0.05$). The results also revealed environmental management effectiveness ($\beta = 0.287$, $p < 0.05$) and environmental-economic benefit ($\beta = 0.261$, $p < 0.05$) as significant predictors. Overall, the model showed a strong fit ($R = 0.823$), explaining 67.7 per cent of the variance in sustainable development outcomes ($R^2 = 0.677$; Adjusted $R^2 = 0.671$), and was statistically significant ($F = 87.432$, $p < 0.001$). Thus, AI-related factors are crucial in promoting sustainable environmental management and development in the Niger Delta.

Taken together, artificial intelligence adoption, environmental monitoring efficiency, environmental management effectiveness, and environmental-economic benefits all showed statistically significant positive associations with sustainable development outcomes ($p < 0.001$ for all paths). These results confirm that AI adoption contributes to sustainable development both directly and through the operational channels of improved monitoring, management and environmental-economic performance.

Thematic Analysis

As part of the study, a total of twenty-four Key Informant Interviews (KIIs) were carried out involving representatives from environmental agencies, oil companies, community leaders, NGOs, and academic institutions.

The themes presented in Table 6 emerged from a systematic thematic analysis of the twenty-four key informant interviews. Interview responses were transcribed verbatim. Data were analysed using open coding. Open codes that were conceptually related were clustered into higher-order categories. Similar categories were then refined into broader themes through iterative comparison across transcripts. Two researchers coded the data independently, and then discussed and resolved disagreements through consensus to ensure coding consistency and analytical reliability. The frequency reported for each theme reflects the number of participants in the interviews who expressed similar views.

Table 6: Major Themes Emerging from Qualitative Interviews

Theme	Frequency	Percentage (%)
Improve Oil Spill Detection and Monitoring	22	91.7
Enhanced Environmental Management Efficiency	21	87.5
Reduced Environmental Damage and Costs	20	83.3
Contribution to Sustainable Development	19	79.2
Need for Government Support and Investment	23	95.8
Lack of Technical Capacity	18	75.0

Inadequate Digital Infrastructure	21	87.5
Need for Stakeholder Collaboration	20	83.3

Source: Authors' Fieldwork, 2026.

Stakeholders agree that artificial intelligence can improve the monitoring and management of the environment in the Niger Delta, according to a thematic analysis. The need for government support and investment was the theme which had the highest responses (95.8%). Thus, the majority of respondents felt the funds and policies are not enough. Almost all of the respondents opined that AI adoption would improve oil spill detection (91.7%) and manage the environment more efficiently (87.5%). Nonetheless, adequate digital infrastructure (87.5%) and technical capacity (75.0%) were among the implementation barriers detected by the participants. The research results indicate that while stakeholders acknowledge the promise of AI technologies, their successful adoption would require heavy spending on infrastructure development, strengthening institutional frameworks, and enhancing human capital capacity.

Qualitative Verbatim Reactions

Environmental Regulatory Authority

"Artificial intelligence can minimise the time it takes to detect oil spills. Environmental agencies will receive alerts much sooner than waiting for a manual report."

Bayelsa State Community Leader

"Many communities suffer because oil spills are detected late. If AI systems can identify problems earlier, AI will reduce environmental damage and damage to livelihoods."

Spokesperson of Oil Company

"The use of AI-enabled drones and satellite systems is very efficient for pipeline monitoring."

Ecological Expert

"Niger Delta environmental governance in the future will be significantly dependent on how emerging technologies such as artificial intelligence is integrated into policy and practice."

Representative of NGO

"Environmental problems cannot be solved by technology alone, but nevertheless key are the commitment of the government, participation of the community, and accountability of the institutions."

Summary of Key Findings

The convergent mixed-methods analysis reveals a considerable convergence between the quantitative and qualitative findings. The respondents were very much in favour of the adoption of artificial intelligence in oil spill monitoring, environmental governance and sustainable development. Regression analysis also confirmed that there were statistically significant relationships among the principal study variables.

Qualitatively, stakeholders described the practical mechanisms behind these statistical associations, highlighting improved early detection of oil spills, increased environmental accountability, faster response capabilities, and better regulatory coordination. Interviewees also cited lack of digital infrastructure, institutional capacity gaps, and limited funding and policy implementation challenges as critical barriers to successful AI deployment. Thus, the qualitative evidence not only corroborates the quantitative findings but also provides contextual explanations for why the AI adoption is still limited even though there is widespread stakeholder support. Thus, combining both strands of evidence provides stronger confidence in the study conclusions and exemplifies the value of a convergent mixed-methods design.

DISCUSSION

This study makes a significant empirical and theoretical contribution to the burgeoning literature on artificial intelligence (AI), environmental economics and sustainable development by showing how AI-enabled environmental monitoring can strengthen environmental governance in one of the world's most environmentally vulnerable petroleum-producing regions. Unlike previous research that has focused on AI applications primarily from a technological or engineering perspective, the present study combines environmental economics, stakeholder behaviour and sustainable development in a convergent mixed-methods design. The findings indicate that the adoption of AI has a significant positive impact on oil spill monitoring, effectiveness of environmental management, environmental-economic performance and sustainable development; however, there are institutional and infrastructural barriers that still limit implementation. The study, thus, adds to the understanding of the potential of technological innovation in enhancing the environmentally sustainable resource governance in developing economies with weak institutional capacity and ongoing ecological degradation.

Respondents agree that artificial intelligence was effective in improving oil spill monitoring and environmental management, as shown in descriptive analysis and frequency analysis. Almost everyone agreed that AI will enhance early detection of oil spills, environmental surveillance, environmental accountability, and environmental management efficiency. There is a general agreement among environmental agencies, oil companies, academics, civil society organisations, and host communities that practical AI technologies may offer solutions to age-old environmental problems in the Niger Delta. AI technologies are found to contribute significantly to environmental monitoring, according to Vinuesa et al., (2020) and UNEP (2024), they can collect data in real-time, allow for predictive analysis and automate the decision-making process. These findings add to the growing conviction around the world that AI can be used as a lever for enabling environmental sustainability and resource management.

Present findings are in line with other international studies that have reported positive impacts of AI on environmental monitoring (Vinuesa et al., 2020; Dwivedi et al., 2023; UNEP, 2024), but important contextual differences are found. Previous studies were mainly limited to technologically advanced environmental data, stable digital infrastructure, and relatively strong regulatory institutions. By contrast, the Niger Delta

is characterised by fragmented environmental governance, recurrent pipeline vandalism, illegal refining activities, inadequate monitoring infrastructure, and delayed regulatory responses. These contextual conditions explain the importance that respondents in the current study attached to the capacity of AI for early detection, prediction, and qualitative and rapid environmental response. Unlike previous works that have largely focused on technological efficiency, this study finds that the successful application of AI in developing petroleum-producing regions also depends on institutional readiness, stakeholder cooperation, regulatory commitment, and persistent public investment. These findings thus add to the literature by demonstrating that technological innovation alone does not result in better environmental outcomes unless it is supported by broader governance reforms.

Furthermore, the research found that the speed and accuracy of oil spill detection were significantly improved by AI. This result is very important in the Niger Delta, which has a history of delayed detection which has caused widespread degradation. Conventional monitoring systems depend on inspections and community complaints, which causes delays in intervention since it's not a real-time system. The current finding corroborates the findings of Rolnick et al. (2019), who show that deep learning algorithms combined with satellite imagery significantly enhance the accuracy of oil spill detection compared to traditional monitoring systems. In the same way, Udoinyang et al. (2026) observe that machine learning-based monitoring systems can assist in identifying environmental risks and improve environmental management. This means that AI could be a more effective and reliable way to detect oil spills so that environmental damage does not occur.

The study also found a significant relationship between AI adoption and environmental management effectiveness. AI adoption positively impacts environmental management outcomes such as environmental surveillance, pollution control, regulatory compliance, and ecosystem protection, according to regression analysis. The finding confirms that AI has the potential to support wider environmental governance functions, not just in spill detection. The result supports the finding of Dwivedi et al. (2023), which said that AI-enabled environmental monitoring systems facilitate compliance with environmental regulation. This lends support to Kshetri's (2024) argument that AI generates accurate and timely environmental information necessary for evidence-based development policymaking. The Niger Delta context describes AI's ability to strengthen the capacity of environmental institutions to monitor environmental performance, enforce regulation and respond to environmental threats.

The results of regression analysis further show that the efficiency of environmental monitoring determines sustainable development. The increased monitoring capacity has a significantly positive influence on environmental sustainability, socioeconomic wellbeing and long-term development. Sustainable development balances environmental protection with economic growth and social equity. Regular monitoring is important in ensuring early detection, reduced environmental damages and conserved natural resources useful to local dwellers (Dwivedi et al., 2023). Based on the above finding, it can be said that sustainable development theory emphasises the

importance of applying an integrated approach to help protect the environment and achieve socio-economic development at the same time. The outcome also concurs with UNEP (2024), which states that AI-enabled environmental systems contribute to the attainment of various Sustainable Development Goals through improved environmental governance and better resource management.

The relationship between AI adoption and environmental-economic performance has been another important finding. Research has shown that AI reduces the environmental-economic losses of oil spill cases. Environmental economics defines pollution as a negative externality that bears costs for communities, ecosystems, and future generations. Oil spills have historically decreased agricultural output, destroyed fishing resources, contaminated water resources, and undermined local livelihoods, all of which is consistent with earlier studies done in the Niger Delta (UNEP, 2011; Nriagu et al., 2016; Ibaba, 2018).

According to the study, prevention, detection, and response to these costs can be improved by using AI. This finding is consistent with the environmental-economic literature on the importance of technological innovation in mitigating environmental externalities and enhancing economic efficiency. The finding supports the Environmental Kuznets Curve (EKC) theory, which holds that technological advancement might help push the economy away from an environmentally damaging growth path toward greener development. As a result, AI-based technologies can be an investment for the environment that provides savings in ecology and economy.

A key strength of this study is the use of a convergent mixed-methods design that combines quantitative and qualitative evidence. The results of the quantitative analysis indicated that there were statistically significant relationships between AI adoption, environmental monitoring efficiency, environmental management effectiveness, environmental-economic performance and sustainable development. But the interview results offered important explanatory depth by demonstrating how these statistical relationships worked in practice. Environmental regulators pointed to the possibility of real-time environmental surveillance to enhance enforcement efficiency; oil company representatives spoke of predictive maintenance and drone-assisted pipeline monitoring, and community leaders spoke of the potential of early spill detection to reduce livelihood losses and ecological degradation. Across all stakeholder groups, poor digital infrastructure, lack of technical expertise, institutional fragmentation and lack of government investment were consistently identified as key barriers to implementation. Consequently, the qualitative findings not only corroborate the quantitative results but also explain why widespread stakeholder support has not yet translated into large-scale AI deployment across the Niger Delta. This complementary evidence demonstrates the added methodological value of employing a convergent mixed-methods design.

Nevertheless, the research found that AI adoption has major barriers. Respondents have often cited poor digital infrastructure, limited technical expertise, lack of funds, and weak institutional capacity as major constraints. These results show that potential beneficial technology does not guarantee success on its own. AI deployment requires institutions, digital infrastructure, competencies and stability of policies, which are all

important. This finding tallies with the World Economic Forum (2025) and UNDP (2024), which cited infrastructure gaps and institutional weaknesses as critical challenges to digital transformations in poorer countries. The finding further strengthens the Technology Acceptance Model (TAM), as it emphasises that technology adoption is dependent not only on perceived usefulness but also on facilitating conditions, organisational support, and user readiness.

The fact that government support and investment are the most frequently cited qualitative themes highlights an important role played by public policy in the adoption process of AI. Participants in the discussion said that governments must enable environments for business by investing in digital infrastructure, regulatory frameworks, funding research, and developing capacities. This is a reflection of a wider conception concerning the governance of new technologies. Without appropriate policies in place, opportunities brought by AI for the environment will remain unfulfilled. As a result, they need to move beyond conventional environmental management approaches and incorporate digital transformation strategies coupled with modern monitoring technologies in their environmental governance systems.

The findings also reveal the importance of a multi-stakeholder approach. According to interviewees, successful implementation of AI requires cooperation between governments, oil companies, local communities, academic institutions and civil society organisations. The environmental management issues facing the Niger Delta are structurally complex because of the multiplicity of actors as well as the socio-political milieu of oil. Accordingly, AI adoption should be understood broadly as a governance intervention that involves collaboration, accountability, and participation of stakeholders and not merely as a technological intervention. This view may be something that exists in literature reviewed about sustainability and that takes into account the need for inclusivity when it comes to governance and participatory mechanisms in order to achieve environmental sustainability.

The empirical result demonstrates the important of the theoretical extensions to the three frameworks on which this study is based. First, the theory of sustainable development is extended by arguing that artificial intelligence is not only a technological innovation but also a governance mechanism that can simultaneously promote environmental protection, economic resilience and community well-being in resource-dependent regions. Second, we find some empirical support for the Environmental Kuznets Curve (EKC) theory. Although the traditional EKC assumes that environmental quality improves mainly as economies grow richer, the present findings suggest that technological innovation, especially AI-enabled environmental monitoring, can speed up environmental improvement independently of income growth by reducing pollution, improving regulatory compliance and lowering environmental-economic losses. Thus, technological capability should be regarded as an important complementary mechanism in modern EKC models. Thirdly, the Technology Acceptance Model (TAM) is modified by showing that stakeholder acceptance is not sufficient for a successful AI implementation. Institutional capacity, digital infrastructure, government commitment, availability of funding and regulatory coordination were equally important enabling

conditions that affected AI adoption. These findings thus add to the existing explanatory power of TAM in public sector environmental governance by adding institutional readiness to the perceived usefulness and perceived ease of use dimensions.

The results show that the impact of artificial intelligence goes beyond simply improving the efficiency of technical monitoring. AI is a strategic governance innovation that can enhancing resource accountability, support evidence-based policy-making, improve regulatory coordination and promote sustainable resource management. Thus, the present study contributes to both environmental economics and sustainability scholarship by showing how technological innovation, institutional readiness and stakeholder collaboration interact to determine successful environmental governance in resource-dependent developing economies.

Overall, the findings demonstrate that artificial intelligence possesses considerable potential to transform oil spill monitoring, environmental governance, and sustainable development within the Niger Delta. AI-enabled technologies improve environmental surveillance, facilitate timely detection of oil spills, strengthen regulatory accountability, reduce environmental-economic losses, and enhance evidence-based environmental decision-making. Nevertheless, the successful implementation of these technologies depends upon sustained investment in digital infrastructure, institutional capacity development, regulatory coordination, stakeholder collaboration, and supportive public policy. Accordingly, AI should be viewed not as a stand-alone technological solution but as an integral component of a broader environmental governance framework designed to improve oil spill management, ecological restoration, and sustainable development in Nigeria's petroleum-producing communities. These findings remain directly aligned with the scope of the present study and provide practical guidance for policymakers seeking to modernise environmental monitoring systems in the Niger Delta.

CONCLUSIONS

Summary of Findings

This study explored the role of artificial intelligence (AI) in improving environmental monitoring, environmental management, environmental-economic performance and sustainable development in Nigeria's Niger Delta using a convergent mixed-method research design. The findings suggest that the adoption of AI significantly enhances oil spill detection, environmental surveillance, regulatory decision-making, and environmental governance. Moreover, it helps improve environmental-economic outcomes and sustainable development. The mix of quantitative evidence and qualitative stakeholder perspectives also showed that while AI has significant transformative potential, its effectiveness depends on institutional readiness, digital infrastructure, regulatory coordination, technical capacity, and continued government investment.

Theoretical and Scholarly Contributions

In addition to its empirical findings, the study makes several important scholarly contributions. Firstly, it adds to the existing literature by integrating artificial

intelligence, environmental economics, environmental governance and sustainable development into a single analytical framework for petroleum-producing developing economies. Second, this research complements earlier studies, which have mainly focused on either technology assessments or quantitative surveys, by showing the benefits of a convergent mixed-method approach that captures both statistical relationships and institutional realities that shape AI adoption. Thirdly, the study adds to the theory of sustainable development, the Environmental Kuznets Curve (EKC) and the Technology Acceptance Model (TAM) by showing that technological innovation alone cannot guarantee improved environmental outcomes without complementary institutional capacity, governance effectiveness and stakeholder collaboration. The findings therefore add new theoretical and empirical evidence on the role of AI in promoting environmentally sustainable resource governance in developing countries. This study is a contribution to the expanding interdisciplinary literature on artificial intelligence, environmental economics and sustainable development. The study demonstrates that AI is not only a technological innovation but also an institutional governance mechanism to improve environmental monitoring, environmental management and environmental-economic performance by combining the theory of sustainable development, the Environmental Kuznets Curve (EKC) and the Technology Acceptance Model (TAM). The results also indicate that future theoretical frameworks for explaining AI adoption in environmental governance systems, especially in developing economies, should incorporate institutional readiness.

Policy Implications

These findings have a number of important policy implications. Governments should focus on investing in AI-powered environmental monitoring systems to identify oil spills in their early stages, including satellite surveillance, drone technologies, remote sensing platforms and predictive analytics. Environmental regulators should develop integrated digital information systems to improve interagency collaboration for real-time environmental reporting and rapid emergency responses. Finally, successful implementation will require continued investment in digital infrastructure, technical capacity building, environmental data management and AI governance frameworks. There is also a need for greater collaboration among government agencies, petroleum companies, academic institutions, technology developers and host communities to maximise the environmental and socio-economic benefits of AI adoption.

Limitations of the Study

The study has some limitations. Firstly, the study was conducted in only four oil-producing states of the Niger Delta. Caution should be exercised in extending the findings to other environmental or geographical locations. Second, the quantitative survey was cross-sectional, and therefore, causal interpretation was not warranted as perceptions were measured at one point in time. Third, the study relied mainly on perceptions of stakeholders about the adoption of AI, rather than on objective measures

of AI systems' performance. These limitations offer opportunities for further research using longitudinal, experimental and operational AI performance data.

Suggestions for Future Research

Future investigations will require longitudinal and quasi-experimental research designs to investigate the long-term effects of AI adoption on environmental quality and sustainable development outcomes. Further, researchers are also encouraged to investigate the mediating and moderating relationships between AI adoption, institutional readiness, environmental governance, environmental-economic performance and sustainable development using structural equation modelling (SEM) or partial least squares structural equation modelling (PLS-SEM). More comparative studies with other petroleum-producing regions in Africa and beyond would contribute to deepening understanding of contextual factors affecting AI implementation. Future research may explore new technologies, including digital twins, blockchain, Internet of Things (IoT) networks and explainable artificial intelligence (AI), as complementary innovations for environmental monitoring and governance.

Concluding Remarks

Finally, artificial intelligence is a promising strategic tool to enhance environmental governance and promote sustainable development in the Niger Delta. However, its long-term success will depend on coupling technological innovation with good institutions, public policies that are supportive, adequate funding, human capital that is skilled, and stakeholder collaboration that is strong. The study provides a useful basis for further research, policy development and practical implementation of AI-enabled environmental management systems by providing empirical evidence from one of the most environmentally sensitive petroleum-producing regions of Africa.

AUTHOR CONTRIBUTION

Nathan Udoinyang conceptualised the study, designed the methodology, analysed the data, and prepared the original manuscript draft. Chikaodinaka Okwunka participated in data collection, questionnaire administration, and literature review. Nathan Udoinyang contributed to data interpretation, manuscript review, editing, and final proofreading of the article.

CONFLICT OF INTEREST

The authors declare that there are no financial, institutional, or personal conflicts of interest that could have influenced the outcome of this research.

SIMILARITY STATEMENT

The authors confirm that this manuscript is an original work and has been subjected to institutional plagiarism screening using Turnitin, ensuring it meets the required similarity threshold.

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