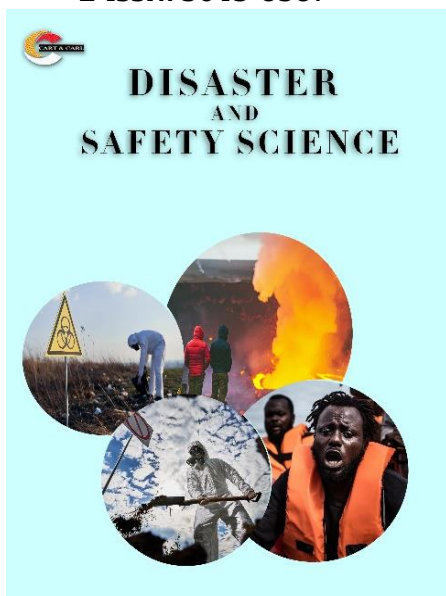




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Advanced Pipeline Surveillance Technologies and Infrastructure Security in Nigeria: Challenges, Opportunities, and Adoption Trends

Abstract

This study examines the challenges, opportunities, and adoption trends associated with advanced pipeline surveillance technologies and infrastructure security in Nigeria. Using a quantitative survey design, data were collected from pipeline operators, regulators, service providers, and industry experts to assess the causes and consequences of unplanned leaks, the effectiveness of existing management strategies, and the state of surveillance and monitoring practices within the sector. The findings reveal that corrosion and external damage constitute the most significant causes of pipeline leaks, while ageing infrastructure remains a major driver of increasing incident trends. Respondents identified environmental, economic, health and safety, and reputational impacts as severe consequences of pipeline failures. The results further indicate that spill incidents remain widespread across the industry, with over 90% of respondents reporting at least one spill event within the previous three years, suggesting that pipeline failures are systemic rather than operator-specific. Although current integrity management strategies were considered moderately effective, significant gaps remain in inspection coverage, maintenance practices, and real-time monitoring capabilities. The study highlights the growing importance of advanced surveillance technologies, including drones, smart sensors, satellite monitoring, fibre-optic systems, and integrated SCADA platforms, in improving pipeline security and leak detection. However, adoption is constrained by financial limitations, inadequate technical capacity, regulatory challenges, and infrastructure deficits. The study concludes that strengthening pipeline security in Nigeria requires greater investment in advanced monitoring technologies, enhanced regulatory enforcement, robust integrity data management systems, community participation, and sustained capacity development.

Keywords: Ageing Infrastructure, Corrosion, Infrastructure Security, Leak Detection, Oil And Gas Pipelines, Pipeline Integrity Management, Pipeline Surveillance

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Introduction

Oil and gas pipelines are among the most efficient, reliable, and cost-effective means of transporting crude oil, natural gas, and other hazardous materials over long distances. As global energy demand continues to increase, pipeline network

has expanded significantly across both developed and developing economies. Data from Europe and the United States demonstrate substantial growth in pipeline infrastructure over recent decades, reflecting the growing dependence of national economies on pipeline systems for energy transportation and distribution. While this expansion has improved energy accessibility and economic efficiency, it has also increased concerns regarding pipeline integrity, infrastructure security, environmental protection, and public safety.

Pipeline operators are under considerable financial, regulatory, and social pressure to prevent incidents that result in hydrocarbon leaks, spills, and operational disruptions. The primary objective of any pipeline transportation system is to achieve safe and uninterrupted operations with minimal failures. Achieving this objective requires accurate inspection



data, effective monitoring systems, and proactive integrity management practices capable of detecting defects before they develop into catastrophic failures (GE Oil & Gas, 2017). Consequently, pipeline integrity management has become a critical component of modern oil and gas operations, helping operators minimize environmental pollution, protect human lives, reduce revenue losses, maintain corporate reputation, and ensure regulatory compliance.

Despite technological advancements, pipelines remain vulnerable to numerous threats, including corrosion, material degradation, fatigue cracking, stress corrosion cracking (SCC), mechanical damage, operational failures, and third-party interference. Corrosion remains one of the most significant causes of pipeline deterioration worldwide. External corrosion is often influenced by environmental conditions such as soil chemistry, moisture content, chlorides, sulfates, and soil resistivity, while internal corrosion is associated with the characteristics of transported fluids and operational conditions. To mitigate these risks, operators employ protective coatings, cathodic protection systems, corrosion monitoring programmes, and in-line inspection technologies (Revie et al., 2015). Nevertheless, corrosion continues to account for a substantial proportion of pipeline failures globally.

The challenge of maintaining pipeline integrity has become increasingly complex as many pipeline systems approach or exceed their design life. Ageing pipelines are more susceptible to structural degradation, strength loss, coating failure, and external loading effects (Han & Weng, 2011; Li et al., 2019a, 2019b). In addition, rapid urbanisation and infrastructure development have increased the exposure of pipelines to third-party damage and unauthorized activities (Wang et al., 2019). Several high-profile pipeline incidents have demonstrated the devastating consequences of integrity failures. The East Harlem gas explosion in 2014, the Qingdao pipeline explosion in 2013, and the gasoline pipeline explosion in Mexico collectively resulted in significant fatalities, injuries, environmental damage, and economic losses (Gong & Li, 2018; Wang et al., 2019; Xing et al., 2020). These incidents highlight the urgent need for advanced surveillance and monitoring technologies capable of providing early warning of developing threats.

In response to these challenges, considerable research has focused on pipeline risk assessment, leak detection, and integrity management. Studies have employed numerical modelling, Bayesian networks, and hazard assessment techniques to analyse pipeline failures and operational risks (Ebrahimi-Moghadam et al., 2016; Fakhravar et al., 2017; Wang et al., 2017; Azari & Karimi, 2018; Li et al., 2019a, 2019b). However, much of the

existing literature has concentrated on failure causation and risk assessment rather than the practical adoption and effectiveness of advanced surveillance technologies for infrastructure protection, particularly in developing petroleum-producing countries.

Pipeline integrity management programmes generally comprise three interconnected stages: defect detection and identification, defect growth prediction, and risk-based management (Bate et al., 2010). These activities rely heavily on inspection and monitoring technologies such as in-line inspection (ILI), hydrostatic testing, non-destructive evaluation (NDE), and Supervisory Control and Data Acquisition (SCADA) systems (Antaki, 2003; Bai & Bai, 2014). Recent technological advancements have further expanded surveillance capabilities through the introduction of drones, satellite monitoring, fibre-optic sensing systems, smart sensors, artificial intelligence (AI), machine learning algorithms, and real-time data analytics. These technologies offer significant opportunities for improving leak detection, corrosion monitoring, intrusion detection, predictive maintenance, and overall infrastructure security.

In Nigeria, pipeline infrastructure remains critical to national revenue generation and energy security. However, the country's pipeline network faces persistent challenges associated with ageing assets, corrosion, inadequate maintenance, vandalism, crude oil theft, sabotage, and limited monitoring capabilities. These challenges have contributed to recurring pipeline failures, environmental degradation, production losses, and heightened security concerns. Although advanced surveillance technologies have demonstrated effectiveness in other jurisdictions, their level of adoption, implementation challenges, and potential contribution to infrastructure security in Nigeria remain insufficiently explored.

Against this background, this study investigates advanced pipeline surveillance technologies and infrastructure security in Nigeria, with particular emphasis on the challenges, opportunities, and adoption trends within the sector. The study seeks to contribute to the growing body of knowledge on pipeline integrity management by examining the factors driving pipeline failures, evaluating current monitoring practices, and identifying strategies for improving infrastructure protection through technology-driven surveillance systems. The findings are expected to provide valuable insights for operators, regulators, policymakers, and other stakeholders seeking to enhance pipeline reliability, reduce spill incidents, and strengthen the long-term sustainability of Nigeria's oil and gas infrastructure.

Literature Review

In recent time vandalism, illegal bunkering and oil theft activities leads to loss of revenues to the Nigerian Government and the oil firms that own the assets from which oil is stolen, pipeline vandalism, river and land pollution, environmental degradation, increased criminality and insecurity in the Niger Delta region. The impact of these illegal activities includes: It has been indicated in the preceding sections that oil pipeline vandalism is principally motivated by the criminal intent of the vandals who break into pipelines to drill products for pecuniary gains. The criminal intent notwithstanding, there are other factors which tend to predispose people to indulge in oil pipeline vandalism. Prominent among these factors are scarcity of petroleum products, widespread poverty and ignorance (illiteracy) among Nigerians, poor protection of the pipelines as well as shallow lying of the pipelines. The vandalism mostly take place in poor courtiers because international Oil and Gas companies often fail to buy or protect their pipelines as they would have to do by law in rich countries. The easily accessible pipes, which often run through slums and informal settlements in burgeoning cities, are tempting to desperately poor communities, who often have no electricity and must rely on oil lamps for lightening and power (Vidal, 2011; Mmeji et al., 2017). In tandem with the above, Vidal (2011 ; Mmeji et al., 2017) identified the following as causative and predisposing factors of oil pipeline vandalism in Nigeria which include (i) Inordinate ambition to amass wealth, (ii) Culture of criminal impunity and corruption in Nigeria, (iii) Poor policing /protection of oil pipelines, (iv) Political sabotage as in the case of the Niger Delta militancy and (v) Widespread poverty of the rural and urban-slum dwellers as well as (vi) Scarcity of petroleum products and (vii) Flourishing of the oil black market in Nigeria and the likes.

The implication of pipeline vandalism on business activities in Nigeria can be viewed from two broad Perspectives according to Achumba, Ighomereho and Akpan (2013), the perspective of potential business investment and the perspective of existing business enterprise. According to them, pipeline vandalism discourages business investment as it makes investment unattractive to business investors. This is because it accelerates the cost of doing business either through direct loss of goods and properties or the cost of taking precautions against business risks and uncertainty. These costs could have a negative impact on business development and progress. The thick arrow connecting the insecurity of an environment and business investment means that pipeline vandalism can be a huge blockade to business activities.

Ezeoba (2011) reported a study by World Bank on investment climate in nine African countries in which it was found that 29% of business operators in Africa and 36% in Nigeria perceived insecurity (particularly, insurgency and militancy) as major constraint on investments. This situation has damaging consequence of giving signal to the international community that Nigeria is not a safe and secure place and as such not suitable for investment and business activities to take place. In that case, foreign firms and entrepreneurs would decline to invest and this is particularly important in view of the efforts being made to create the desired atmosphere to attract foreign direct investment. So, it is a strong disincentive to business investment as it scares away potential investors. This is because such environments or economies are considered high risk zones due to the high level of uncertainty about the safety of investment and lives of the managers and their staff.

The Nigeria insecurity situation arising from many cases of pipeline vandalism, actually halted many Oil and other business operations in the country which results in the outright closure of many enterprises especially in the areas or zones where incidences of insecurity is rife and are on daily occurrence, in a bid to protect lives of operators and business property. Generally, it is extremely difficult for businesses activities to thrive under a situation of continued pipeline attacks. Ordinary citizens having small and medium scale businesses cannot open shops for business transactions due to the risk factor which business owners and managers dread and wish to avoid by relocating their businesses elsewhere. In the case of Nigeria, there is also evidence of some Oil companies winding up their operations due to the persistent attacks by Oil pipeline vandals. Some even relocate to other peaceful parts of the country, some firms shifts their operations to other countries like Ghana and South Africa where the investment climate is more conducive (Nwagbosa, 2012).

On general economic implications, pipeline vandalism has resulted in untoward consequences which results to economic losses, environmental degradation, fire disaster and death of innocent citizens and public officials (Ugwuanyi, 2013). The economic losses associated with oil pipeline vandalism are arrived at by quantifying the monetary value of lost products and the cost of pipeline repairs. This has amounted to billions of Naira over the years. For instance, the NNPC had from 2009 to 2012 lost about 165 Billion Naira to Oil products thefts and repairs of vandalized pipeline equipment (Ugwuanyi, 2013). Furthermore, Annual Statistical Bulletin of the NNPC shows that oil spills are significantly on the rise in Nigeria. The incidence of oil spills and its attendant consequence on environmental degradation had jeopardizes the land, vegetation and habitation of the affected areas. This has been exemplified in desolation of

farmlands, loss of aquatic and wild lives, as well as water and air pollution. These conditions have implications for public health and safety of the people. On the fire disasters arising from pipeline explosions, it was reported that over 2,500 lives have been lost to explosion from vandalized pipelines in the last 15 years and also, death of innocent citizens and public officers, particularly security personnel have been on the increase due to massive acquisition of superior weapons and sophistication in armed-banditry (Ugwuanyi, 2013).

These illegal activities have posed a big threat to Nigeria's economy. Its socio-economic impacts include environmental degradation, loss of economic activities for the communities, loss of revenues to the government resulting in inadequate funding for development initiatives, increased criminality in Niger Delta region, lack of security due to illegal activities and bad image for the country (Duru, 2013; Okere, 2013). As a result of vandalism, maintenance of oil terminals and declaration of force majeure, the militants nearly destroyed the oil industry and, by extension, the national economy which depends heavily on oil revenue (Tamuno, 2011; Adishi and Hunga, 2017).

Oil thefts, illegal bunkering and pipeline vandalism have resulted in increasing loss of the nation's revenue which could have accrued from the sale of crude oil on international market. As reported recently, Nigeria was at the risk of N1.458 billion (\$7.29 million) daily revenue loss on its crude exports as Shell declared force majeure on 162,000 barrels per day, Bonny light crude export (force majeure is a legal declaration which a party uses to state that it may not be able to meet its contractual obligations in a deal) (Adishi and Hunga, 2017). In February, 2016 the NNPC was reported to have incurred N24.23 billion operational deficits, while in March 2016, the report indicated that it has declared N18.89 billion losses.

Also, due to the loss of revenue to illegal bunkering, Nigeria is no longer selling enough crude oil to meet her budgetary provisions. The government is failing to meet some of its obligation and domestic debt is rising rapidly. Gaskia (2013) noted that the negative impacts of vandalism and crude oil theft include the destruction of aquatic and farmlands, economic sabotage which explains the shortfall of Nigeria's budget and divestments by some International Oil Companies, IOCs, with attendant job losses thereby compounds the unemployment situation in Nigeria and economic recession ravaging the country today (Gaskia, 2013).

Environmental Pollution and Degradation in the Niger Delta

The process of breaking, vandalising and tapping oil from oil installations may lead to the damage of oil pipelines;

it causes many leaks that cause immense environmental degradation (Odalonu, 2015). Crude oil theft involves breaking of pipelines and siphoning of crude oil products. This act invariably leads to oil facilities damage and oil spillage. Oil spillage causes degradation of the environment; it destroys farms, lands and forests thereby reducing arable land for farming, Spills into water ways, destroy marine and aquatic life, flora, fauna, resort centers and result in the pollution of potable water (Badejo and Nwilo 2007). Oil theft activities and pipeline vandalism in the Niger Delta compounds oil spillages from other sources and exacerbates the problem of environmental degradation and pollution of water-ways (Ogbuefin, 2007). Vandalism is responsible for a large percentage of oil spills. Oil spills result in ground water poisoning, destruction of agricultural land, fishery and livestock and fast disappearing mangrove forests. There are complaints of oil contamination of boreholes which makes the water undrinkable in the region. This makes the water undrinkable even after some treatment. Also, some native have been known to use or drink polluted water out of frustration and the negative effects cannot be over emphasized (Ufford, 2013; Alawode and Ogunleye, 2013). In fact, farmland, fish ponds, rivers, etc., have been destroyed and rendered unviable for agriculture, fisheries and aquaculture. Thus, thousands of household and families of the Niger Delta have been impoverished, or have become securely locked into poverty as a result of this scale of environmental devastation (Gaskia, 2013). This problem has left many Niger Delta communities further impoverished since their means of livelihood, fishing and farming, have been ruined by constant spills and leakages.

Economic Losses to the International Oil Companies

The activities of vandals in Niger Delta has led to several shut-ins and shut-downs of operation by international oil companies and thus resulted in decline in production capacity as well as loses of revenues to the companies and government. International oil companies (IOCs) operating in Nigeria are counting heavy losses as surge in illegal bunkering and supply disruption have impacted on their earnings (Asu, 2013). However, there will be urgent need by the oil companies and Federal Government to repair the pipelines and clean-up of oil spills in the environment and this involve huge capital expenditure and it invariably leads to lose of revenues to the oil companies and government. And According to the Minister of Power, Works and Housing, Babatunde Raji Fashola, (Adedoyin, 2016; Adishi and Hunga, 2017) the attack on the Nigeria gas company's pipeline connected to Chevron Nigeria Limited's facility at Escravos is costing the country a whopping sum of N470 million daily. The attack has impacted negatively on the Olorunsogo Nigerian National Integrated Power Project (NIPP) plant with 600 megawatts capacity, as well as

other power plants. The sabotaged gas pipeline which contributes to the Escravos Lagos Pipeline System (ELPS) has led to a loss of 160 Million standard cubic feet of gas per day (MMSFCD – Million Standard Cubic Feet per Day) of gas daily, at a cost of \$2.50 per thousand standard cubic feet. This loss means about \$400,000 loss to the country on a daily basis in gas volume. This is in addition to losses to be incurred daily from affected Power generation (\$1,988,223 daily). The total daily loss to the country is therefore estimated at N470, 479,931. Repairs of the damaged pipeline are estimated as costing (\$609,137). Raji Fasholu (Adedoyin, 2010; Adishi and Hunga, 2017), continuing, he said: –For instance, available records show that six incidences of vandalism from December 2014 to February 2015 which affected the Trans Forcados Pipeline (at Oben, Sapele, Oredo) and Escravos Lagos Pipeline System (CNL) led to a loss of 1,100 mmscfd. According to industry experts, a loss of 200 mmscfd is equivalent to a Power reduction of 700MW. Added that while the industry –is currently generating about 4120Mwh/h on average (as at 17/01/2016), it is without doubt that performance would have been better without the additional setback caused by the vandals. The money that could have been spent on other areas of oil exploration and production are (now) used for pipeline repair, maintenance and cleaning oil spills (Alawode and Ogunleye, 2011).

Insecurity in the Niger Delta Region-A Threat to Nigeria National Security

The gravitation of damage caused by vandalism and illegal bunkering often force oil companies to shut pipelines down. As a result of this, Nigeria is producing oil at minimal volume of 1.4million barrels per day or less. This post a serious threat to national security particularly as Nigeria depends heavily on oil exports for survival (Mono-economy). Apart from its economic loss, negation of investment onshore exploration and production, security risks and damage to equipment, illegal oil bunkering fuels conflict and militancy through increased armed proliferations and drug abuse which have destabilized the Niger Delta region (Garuba, 2010). Katsouris and Sayne (2013) noted that oil theft has been the major cause of violent conflict in the Niger Delta. Most of the illegal bunkering actors exchange the crude oil for heavy arms at the high sea, while others use the proceeds to import arms into the region, with the principal aim of using the arms to secure their illegal activities in the region. The arms are used for attacks and counter attacks from different gang groups and security agents, as every group is bound to have adequate arms and begun-battle ready to enable them remain in the business. This has resulted in proliferation of small heavy arms, small arms and light weapons in the region, leading to constant attacks and counter attacks by different groups, and insecurity of lives and properties in the region (Wilson,

2014). In same vein, Onwueanyi (2012) positioned that: “Many of the arms in circulation in the Niger Delta, including a variety of sophisticated weapons, have been purchased with money derived directly or indirectly from illegal bunkering. Adding that insecurity in some parts of the country results in part, from accessibility of oil-purchased arms with oil theft and illegal bunkering serving as a major contributor to Nigeria’s violent crime, armed robbery, piracy and kidnapping”.

The illegal practice helps other transitional criminal networks to spread across the Gulf of Guinea, creating global links between bunker’s, pirates and traffickers in arms and drugs. Wilson (2014) noted that the violence and crisis is caused by illegal bunkering and vandal activities in Niger Delta region is spreading rapidly to other parts of Nigeria and beyond.

The heavy arms in the possession of the youths and the constant attacks on oil and non-oil facilities for Economic and political benefits of the actors, youths from other geo-political regions see the illegal activities as very lucrative and are recruited into the business activities as a means of economic empowerment. The same youths irrespective of geo-political region of origin are empowered with arms and they use same to cause violence in different parts of the country, they are also sometimes used by the politicians to either attack political opponents or rig elections, thereby increasing the insecurity challenge of the nation (Odalonu, 2015).

Oil theft and illegal bunkering activities are carried out in the high seas and oil export terminals, thereby increasing the activities of the sea pirates in the sub-region (Wilson, 2014). The pirates attack oil investors and their investments, while the state security agents give counter attack to the pirates, thereby leading to constant violence and attacks in the Gulf of Guinea. As a result of violence perpetuated by these acts actors and sea pirates, its post threat on the peace and security of the West African States, particularly those along the coastal areas, where the oil vessels pass through to Europe, America and Asia (Wilson, 2014). Crude Oil is the major catalyst that drives the Nigerian economy and by implication the determinant of its entire socio-political configuration.

Consequently, anything that covertly or overtly affects oil production in Nigeria poses a direct threat to her national economy, political stability, territorial integrity and national security (Odalonu, 2015; Adishi and Hunga, 2017).

Akali (2015) examined the disaster preparedness and response strategies in Kenya through review of past literatures and disaster experienced in the past. The study revealed that disaster preparedness strategies adopted in the studied area includes precautionary measures, taken in advance of an imminent threat of a

disaster in order to empower the society to respond to and cope with the potential impact of a disaster. The study concluded that disasters are more likely when there are no preparedness and response strategies in place, therefore, recommended the need to promote disaster awareness culture and capacity building for disaster preparedness and response at all levels.

Kapucu (2008) examined the household preparedness in response to disasters and the role of non-profit organizations in the public's preparedness. The study adopted the context of hurricane preparedness of Central Florida residents, using the mail survey method as a data collection tool. The study finding emphasized the importance of household and individual preparedness in response to natural disasters, specifically to hurricanes. If individuals are not ready, then nobody is ready. The study concluded that even with significant experience of disasters among households, they can be complacent in response to disasters.

Guerdan (2009) examined the disaster preparedness and disaster management among community-based physician through survey research design. The finding revealed that disaster preparedness and disaster management have received a high level of attention in the aftermath of the United States' recent experience with both natural and manmade events. The pilot study revealed that only 25% of the respondents of the two medical staffs had had any disaster medicine training in the past two years. In general, the self-assessment scores revealed a low level of competency as judged by the respondents. The study concluded that several hundred thousand community-based physicians in the United States are essentially an untapped resource.

Using a well-designed questionnaire, Bhat, Anees, Geelani, Nusrat, Jan, Zargar (2017) examined disaster awareness and preparedness among students was conducted by. The finding revealed that there is a general lack of information among students regarding disaster awareness and preparedness. This highlights the need for disaster safety education. The level of practice was largely negative with acceptable knowledge and positive attitude regarding disaster preparedness among some certain students. It was concluded that disaster never happened does not mean, it cannot happen. Students can be proving useful workforce in disaster situation, therefore need to know basic strategies carried out in disaster.

A survey was conducted by Bronfman, Cisternas, Repetto and Castañeda (2019) to assessed the natural disaster preparedness (at home and work) in a multi-hazard environment; earthquake and flood. The findings showed that participants are significantly better prepared to face earthquakes than floods, which sends a serious warning

to local authorities, given that floods have caused the greatest human and material losses in the region's recent history of natural disasters. Men claimed to be more prepared than women to face floods, something that the authors attribute to the particular characteristics of the main employment sectors for men and women in the region. The sociodemographic profile of individuals with the highest levels of preparedness in an environment with multiple natural hazards are people between 30 and 59 years of age, living with their partner and school-age children.

Paganini, Borrelli, Cattani, Ragazzoni, Djalali, Careno and Ingrassia (2016) assessed the emergency department of Italian hospital towards disaster preparedness using pre-structured telephone interviews. The study reported poor knowledgebase of basic hospital disaster planning concepts by EDs' physicians-on-duty, duty staff has poor knowledge of the function and roles in the required disaster response when the hospital emergency plan is activated and did not show any relevant difference in the level of knowledge-based among different specialties of on duty staff. The study concluded that the main reason of the lack of disaster medicine knowledge for health professionals might be that disaster medicine has rarely been included in Italian medical school curriculum and continuing medical education.

Okoye and Okunrobo (2014) assessed the impact of oil spill on the physical environment (land, water) of Odu-Gboro community, Sagamu and its health implications. Using various data collection techniques and laboratory analysis, the finding of the study showed that the main cause of oil spill is vandalism; Total Petroleum Hydrocarbon (TPH) were present at the site with soil samples having the highest value compared to water. Also, health implications in the area were significant with regards to diarrhea, dermatitis, nausea, dysentery, conjunctivitis from medical records. A test of significant difference between water quality affected by oil spill and the control revealed there is a significant difference with regards to pH, EC, COD & BOD. The study recommended a follow up in the health status of the people who have been consuming the polluted water.

The effect of oil spills on fish production in the Niger Delta was examined by Osuagwu and Olaifa (2018). The study examined the effects of oil spills on fish production in the Niger Delta of Nigeria from 1981–2015 using an estimable Cobb Douglas production function. The findings suggest that oil production and spills negatively affect fish production, while farm labour has a positive effect on fish production. The study corroborated the findings in literature on the negative concomitance of oil spills and fish production and suggests a cautious

approach to oil exploration activities for a sustainable development in the region.

According to Nwilo and Badejo (2006) oil spills in the Niger Delta have been a regular occurrence, and the resultant degradation of the surrounding environment has caused significant tension between the people living in the region and the multinational oil companies operating there. It is only in the past decade that environmental groups, the Federal Government, and the foreign oil companies operating in the Niger Delta began to take steps to mitigate the impacts. Large areas of the mangrove ecosystem have also been destroyed. The mangrove forest was in the past a major source of wood for the indigenous people.

According to Bello and Olukolajo (2016) the conflict in Niger Delta has many dimensions to it and has given birth to unrepentant militant whose aim is to truncate the nation if their demands were not met. Although attempts have been made by the government at various levels as well as the multinational oil companies to address the problems emanating from the negative effect of oil and gas exploration, production and transportation in the region, the desired peace is yet to be fully realized.

Materials and Methods

A cross-sectional, mixed-methods quantitative research design was adopted for this study. The design integrated three complementary data streams that collectively addressed the objective. The cross-sectional component captured the prevailing state of pipeline integrity management practice within the Nigerian onshore sector at the point of data collection, while the historical incident analysis introduced a temporal dimension that enabled trend characterisation over a nine-year analytical window. The pipeline condition register provided a snapshot of asset-level integrity status at the operational level, calibrated against international thresholds for corrosion rate performance and inspection currency. This multi-stream design was adopted because no single data source could provide the breadth and depth of evidence required to address the research objective in an integrated manner.

Results and Discussion

Causes, Impacts, and Trend Drivers of Unplanned Leaks on Ageing

Figure 1, reveal that corrosion and external damage are perceived as the most significant causes of unplanned pipeline leaks, highlighting their continued role as the primary threats to pipeline integrity. The overwhelming

consensus among respondents suggests that corrosion remains a persistent challenge despite advances in inspection and maintenance technologies. Human error and material failure were also identified as important contributors to leak incidents, underscoring the multifaceted nature of pipeline failures and the need for integrated integrity management strategies. The consequences of unplanned leaks were viewed as severe across environmental, economic, health and safety, and reputational dimensions. Respondents rated reputational impact slightly higher than other consequences, indicating growing awareness of the broader business implications of pipeline incidents, including regulatory scrutiny, stakeholder confidence, and social licence to operate. The close ranking of environmental, economic, and health and safety impacts further demonstrates that leak events are perceived as multidimensional risks requiring holistic management approaches.

The study also found that respondents perceive unplanned leaks as an ongoing and significant challenge, with corrosion and ageing infrastructure identified as the principal drivers of this trend. These findings support the argument that asset ageing and cumulative degradation continue to increase operational risks across pipeline networks. While external factors such as climate change and urbanisation were acknowledged as contributing factors, they were considered less influential than direct infrastructure-related causes, suggesting a stronger industry focus on immediate operational threats. Regarding the effectiveness of current management strategies, respondents generally recognised the value of existing integrity management practices but expressed reservations about their overall adequacy. The findings suggest that current approaches have not fully mitigated the risks associated with corrosion and ageing assets, indicating the need for more proactive, technology-driven, and risk-based management frameworks. This perception points to opportunities for strengthening inspection regimes, predictive maintenance programmes, and real-time monitoring systems.

Overall, the results highlight the critical importance of addressing corrosion, ageing infrastructure, and operational vulnerabilities through enhanced surveillance technologies, improved maintenance practices, and more comprehensive integrity management systems. Such measures are essential for reducing leak occurrences, improving operational reliability, and minimizing the environmental, economic, and reputational impacts associated with pipeline failures.

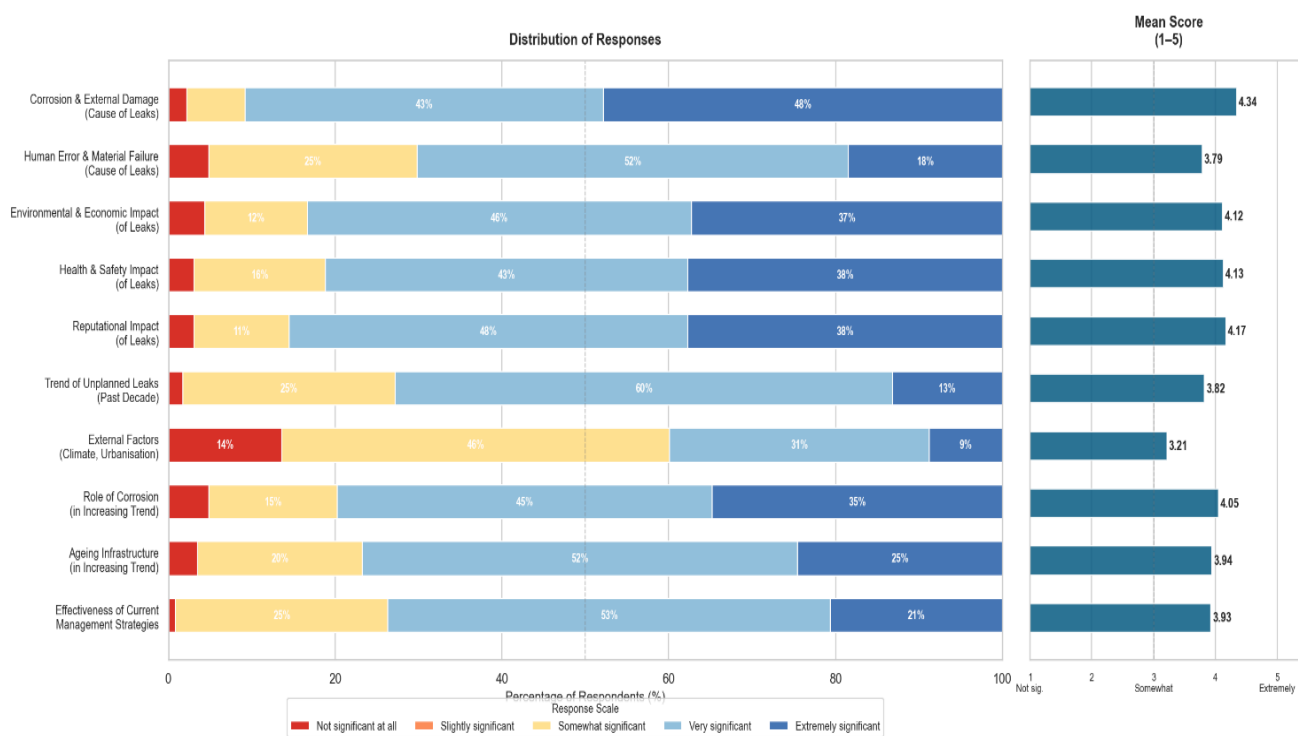


Figure 1: Perceived Significance of Causes, Impacts, and Trend Drivers of Unplanned Leaks on Ageing Pipelines (n=229)

Frequency of pipeline spills

Figure 2 indicates that pipeline spill incidents remain widespread across the Nigerian oil and gas sector, with over 90% of respondents reporting at least one spill incident within the three years preceding the survey. A substantial proportion of organisations also reported experiencing multiple spill events, suggesting that pipeline failures are not isolated occurrences but a persistent operational challenge. The consistency between respondents' experiences and official incident records further strengthens the reliability of the findings and confirms the continued prevalence of spill incidents across the industry. The high frequency of reported spills points to underlying structural weaknesses in pipeline integrity management, including inadequate maintenance practices, insufficient inspection activities, and ineffective corrosion control measures. The results also suggest that ageing infrastructure, combined with operational and environmental stressors, continues to increase the vulnerability of pipeline systems to failure.

Furthermore, the persistence of crude oil theft, vandalism, and other forms of third-party interference exacerbates the problem by introducing additional sources of pipeline damage beyond normal deterioration processes.

Importantly, the findings demonstrate that spill incidents occur across different categories of organisations, indicating that the challenge is systemic rather than limited to specific operators or pipeline segments. This suggests that company-level interventions alone may be insufficient to achieve significant reductions in spill frequency. Instead, there is a need for coordinated industry-wide efforts, including stronger regulatory oversight, standardized integrity management practices, enhanced monitoring technologies, and greater investment in preventive maintenance and surveillance systems. Such measures are essential for improving pipeline reliability and reducing the environmental, economic, and operational consequences of spill incidents in Nigeria.

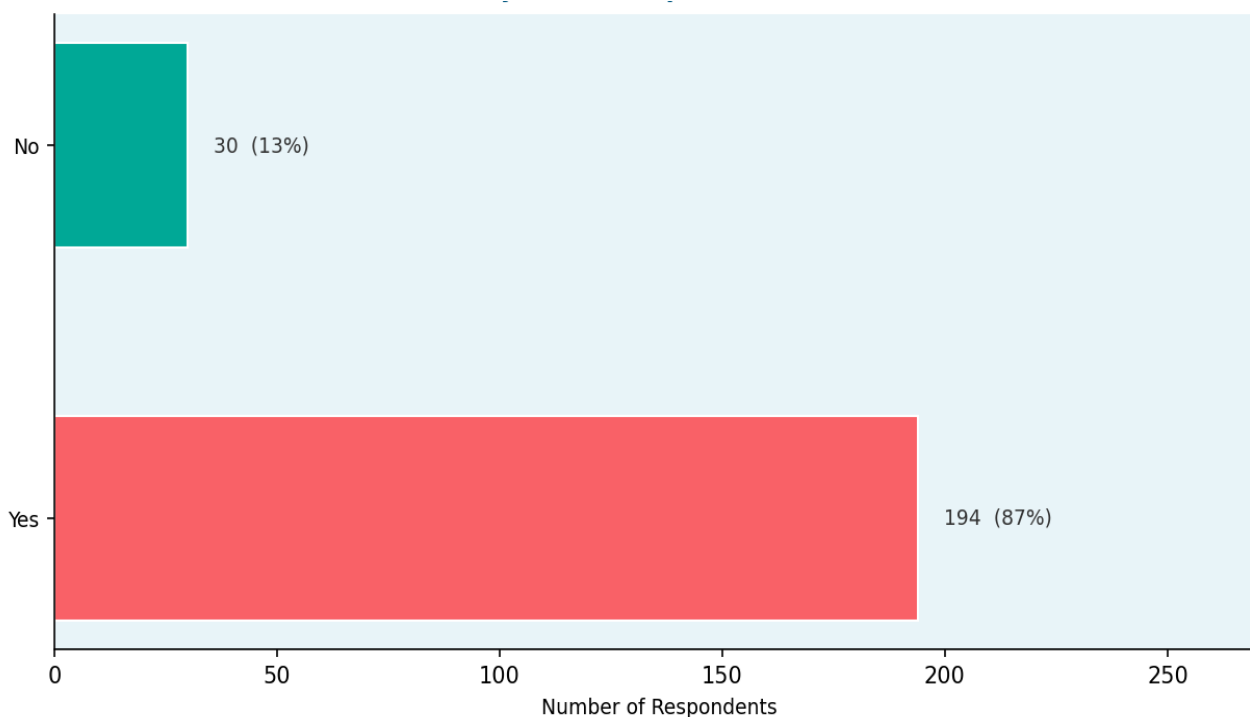


Figure 2: Frequency of pipeline spills reported by respondents in the past three years (n = 229)

Conclusions

This paper examined the challenges, opportunities, and adoption trends associated with advanced pipeline surveillance technologies and infrastructure security in Nigeria's oil and gas sector. The findings reveal that pipeline integrity and infrastructure security remain significant concerns, with corrosion, external damage, ageing infrastructure, and human-related factors identified as the principal drivers of unplanned leaks and pipeline failures. It further found that spill incidents remain prevalent across the sector, indicating that existing integrity management and surveillance practices have not been sufficiently effective in eliminating leak occurrences. Importantly, the study highlights that pipeline failures in Nigeria are largely systemic rather than operator-specific. The paper concludes that the effective protection of Nigeria's pipeline infrastructure will depend on the accelerated adoption of advanced surveillance technologies, strengthened regulatory oversight, improved maintenance practices, and greater investment in digital monitoring solutions.

1. Operators should expand inline inspection coverage and deploy advanced monitoring technologies, including SCADA systems, leak detection tools, and drone surveillance, to improve early fault detection and pipeline reliability.
2. Pipeline operators and regulators should develop standardized integrity databases to

centralize inspection, operational, and incident data, enabling informed decision-making and sector-wide risk assessment.

3. Regulatory agencies should implement updated pipeline integrity standards, mandatory ageing-asset assessments, and stricter compliance measures to ensure safe and sustainable pipeline operations.
4. Community engagement and surveillance programmes should be integrated into integrity management strategies to improve leak reporting, reduce vandalism, and strengthen operators' social licence to operate.
5. Collaboration among industry, regulators, and universities should be strengthened to develop local expertise, advance pipeline integrity research, and support innovation in monitoring and risk management practices.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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