



## SPATIAL RISK ASSESSMENT OF THIRD-PARTY INTERFERENCE ON PETROLEUM PIPELINES IN THE NIGER DELTA: A GIS-BASED SAFETY MANAGEMENT FRAMEWORK

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### ABSTRACT

Third-party interference (TPI) is a threat to petroleum pipeline integrity in Nigeria's Niger Delta, yet existing protection approaches are largely reactive and lack spatial predictive capability. This study develops a GIS-based Multi-Criteria Decision Analysis framework, integrating the Analytical Hierarchy Process, to assess and map the spatial variability of TPI risk along selected pipeline corridors. The analysis incorporates environmental, infrastructural, and socioeconomic factors, including land-use, population density, proximity to roads and waterways, and terrain characteristics. Results indicate that 22% of the pipeline corridor falls within high to very high-risk categories, with risk hotspots concentrated in areas characterized by high accessibility and dense human activity. Accessibility-related variables is 55% to the composite risk index, highlighting their dominant influence. Socioeconomic factors such as poverty and unemployment show spatial association with high-risk zones, their role appears complementary rather than primary. The findings demonstrate the utility of geospatial modelling in identifying spatial patterns of vulnerability and supporting targeted intervention strategies. The study provides a scalable decision-support tool for prioritizing surveillance, infrastructure protection, and community-based interventions. The study recommends the use of automated sensors, remote sensing, and routine field inspections, for pipeline segments classified as high and extremely high risk in the Spatial Risk Index. This study contributes to the growing application of GIS-MCDA approaches in infrastructure risk assessment and offers a foundation for more predictive and evidence-based pipeline security management in complex socio-environmental settings. The study concluded that TPI risk is spatially heterogeneous and strongly influenced by accessibility and human activity in the study area.

**Keywords:** Spatial Risk Assessment; Third-Party Interference; Petroleum Pipeline; GIS-Based Safety Management; Niger Delta

### INTRODUCTION

Petroleum pipelines are the most important part of the world's energy infrastructure because they offer a secure, economical, and effective way to move refined products and crude oil across great distances. Pipelines facilitate foreign exchange generation, industrial growth, and energy security in developing economies. Pipelines, which connect oil production fields in the Niger Delta to export ports along the Gulf of Guinea, are the foundation of hydrocarbon transportation in Nigeria (Li *et al.*, 2024). The strategic significance of continuing pipeline operations is highlighted by the nation's reliance on oil revenue, which makes up more than 70% of foreign earnings and a sizable chunk of GDP Nigerian National Petroleum Corporation {NNPC}, 2022). Pipeline flow disruptions, whether brought on by operational flaws, natural disasters, or human intervention, have a domino effect on the country's energy supply, income inflows, and economic stability, underscoring the necessity of effective risk management techniques to protect this vital infrastructure. Any intentional unlawful activity that jeopardises the security and integrity of pipelines, such as sabotage, illegal tapping, vandalism, and oil theft, is referred to as third-party interference (TPI). TPI is intrinsically unexpected since it is mostly opportunistic and influenced by socioeconomic and political circumstances, in contrast to technical failures, which are frequently foreseen through maintenance and engineering evaluations (National Oil Spill Detection and Response Agency {NOSDRA}, 2021). Multi-Criteria Decision Analysis (MCDA), Geographic Information Systems (GIS) offer a potent tool for spatially explicit risk assessment of linear infrastructures like pipelines (Yildirim *et al.*, 2021). To find possible risk hotspots, GIS

enables the integration of several geographical information, such as topography, land-use, transportation networks, settlement patterns, and socioeconomic indicators. These factors can be systematically weighted according to their respective contributions to vulnerability using MCDA techniques, especially the Analytical Hierarchy Process (AHP) (Saaty, 2008). Pipeline safety management can be made proactive rather than reactive by merging GIS and AHP to create a Spatial Risk Index (SRI) that ranks pipeline segments for surveillance, preventive measures, and community involvement. Although GIS-MCDA techniques are widely acknowledged for their efficacy, their use in pipeline TPI in Nigeria is still restricted. The majority of current research concentrates on qualitative evaluations of vandalism drivers, post-incident analysis, or descriptive mapping (Anejionu *et al.*, 2023; Adewumi *et al.*, 2022). According to Anejionu *et al.* (2023), TPI has surpassed corrosion, ageing, and operational problems in frequency and severity as the primary cause of pipeline collapse in Nigeria. In addition to causing infrastructure damage, these acts also interfere with operations, lower production output, contaminate the environment, and create difficult security issues. Crucially, TPI also has socio-political repercussions since populations impacted by spills frequently participate in protests, legal actions, or other types of conflict, which makes management plans more difficult to implement and raises operational risks. TPI has significant negative effects on Nigeria's economy. Every year, hundreds of pipeline leaks cause unscheduled shutdowns, revenue shortfalls, and millions of dollars' worth of lost crude oil (NNPC, 2022). The hefty expenses of emergency repairs, environmental cleanup, and extra security expenditures exacerbate these losses. In

addition to direct financial losses, TPI can result in higher insurance premiums, a greater perception of risk among investors, and possible regulatory fines for oil corporations (Eke & Nwankwo, 2021). Unexpected production disruptions jeopardise national energy security, impact foreign exchange profits, and further destabilise local supply chains. Furthermore, TPI erodes investor trust in the industry by deterring long-term capital inflows required for infrastructure growth and modernisation, resulting in a vicious cycle of underinvestment and heightened vulnerability. In the Niger Delta, an area with vast wetlands, creeks, and mangrove ecosystems, pipeline interference frequently leads to oil spills that have long-lasting environmental effects (United Nations Environment Programme {UNEP}, 2020).

Freshwater resources are impacted, soil fertility is disturbed, and agricultural productivity is drastically decreased due to oil pollution, endangering the main sources of income for nearby people who rely on farming and fishing. The delicate Niger Delta ecology is further destabilised by long-term exposure to hydrocarbons, which has been connected to ecological degradation, biodiversity loss, and the spread of exotic plant and animal species (Kadafa, 2021). Cumulative environmental deterioration has resulted from the persistence of TPI-induced spills, with some impacted sites going decades without remediation. In addition to impeding sustainable development, these environmental effects also contribute to public health issues, such as respiratory disorders and water-borne illnesses among the local populace (United Nations Development Programme {UNDP}, 2023).

Degradation of the environment and disruption of the economy are intimately linked to the social consequences of pipeline tampering. The productivity of farmlands and fisheries resources, which are the main sources of revenue for nearby people, is decreased by oil spills caused by TPI. According to Adekola *et al.* (2021), this intensifies poverty and increases youth restlessness, resulting in a vicious cycle whereby economic hardship encourages additional pipeline damage. Due to decades of marginalisation and the meagre economic benefits of oil money, some communities view oil pipelines as exploitable resources rather than national assets. Pipeline management is made more difficult by social unrest, disputes between local residents and oil firms, and protests. This emphasises the need to include socioeconomic factors in risk assessment frameworks in order to foresee human-driven hazards. According to research by Obida *et al.* (2020), TPI shows distinct spatial patterns that are influenced by socioeconomic conditions, human accessibility, settlement density, and proximity to transportation networks. Because they are easier to reach and have less surveillance obstacles, pipelines that cross heavily inhabited areas, major roadways, or navigable rivers are more often targeted (Onuoha & Oyewole, 2022).

Conversely, interference rates are frequently lower in distant or inaccessible pipeline segments. The spatial clustering of events indicates that physical, environmental, and socioeconomic factors structurally determine TPI rather than it being random. In order to move pipeline safety management from a reactive to a proactive paradigm, it is essential to comprehend these geographical patterns. This will allow operators to prioritise high-risk locations and deploy resources effectively. TPI in the Niger Delta is mostly caused by socioeconomic factors, namely poverty, unemployment, and youth marginalisation. Local communities are more likely to engage in illicit tapping due to high unemployment rates, and criminal networks involved in oil theft are sustained by a lack of alternative sources of income (UNDP, 2023). Destructive acts are further motivated by historical

frustrations over the unequal distribution of oil income (Onuoha & Oyewole, 2022). Zones of elevated risk can be identified since these socioeconomic determinants are frequently spatially clustered. Therefore, in order to precisely identify the causes of TPI and guide focused mitigation actions, a thorough risk assessment framework must incorporate both environmental and socioeconomic factors. In Nigeria, pipeline safety management is still primarily reactive, emphasising emergency response procedures, widespread security patrols, and post-incident repairs (Eke & Nwankwo, 2021). Military patrols and community-based surveillance are examples of expensive security measures that frequently fail to stop recurrent events. Furthermore, these methods hardly ever use spatial intelligence, which makes it difficult to predict high-risk areas before TPI happens (Adewumi *et al.*, 2022). The necessity for integrated, predictive frameworks that can guide proactive decision-making is highlighted by the fact that operators must deal with ongoing vulnerabilities, ineffective resource allocation, and limited preventive capacity.

Previous studies have investigated pipeline vandalism using qualitative approaches, incident mapping, and socioeconomic analyses. However, there is still a notable gap in the integration of advanced spatial modelling techniques that systematically combine environmental, infrastructural, and socioeconomic variables within a predictive framework. In particular, the use of Geographic Information System based Multi-Criteria Decision Analysis for proactive risk assessment of Transnational Pipeline Interference in Nigeria remains underdeveloped. This study seeks to bridge this gap by developing a GIS-MCDA framework grounded in the Analytical Hierarchy Process (AHP) to conduct a spatial assessment of TPI risk along pipeline corridors in the Niger Delta. Specifically, the study addresses the following research questions: What are the key spatial determinants influencing TPI risk in the Niger Delta? How high-risk zones are spatially distributed along pipeline corridors? To what extent do accessibility and socioeconomic factors contribute to the observed patterns of TPI risk?

## MATERIALS AND METHODS

### Study Area Description

The study is conducted in the Niger Delta region of Nigeria, one of the most hydrocarbon-rich and environmentally sensitive regions globally. The area spans approximately 70,000 km<sup>2</sup> and comprises nine oil-producing states, including Rivers State, Bayelsa State, and Delta State. Characterized by dense mangrove forests, swampy terrain, and extensive river networks, the region hosts a complex network of petroleum pipelines that are highly vulnerable to third-party interference (TPI). Socioeconomic challenges such as unemployment, poverty, and informal settlements further exacerbate pipeline vulnerability.

### Design and Source of Data

This study employs a GIS-based multi-criteria decision-making (MCDM) framework integrated with the Analytical Hierarchy Process (AHP) to assess and map TPI risk. It involves identifying key risk factors, processing and standardizing spatial data, assigning weights using AHP, and combining the criteria through spatial overlay to produce a risk map, followed by validation and sensitivity analysis to ensure reliability. Spatial datasets were obtained from multiple sources, including pipeline network data from oil companies and regulatory agencies, land use/land cover (LULC) maps derived from satellite imagery such as Landsat and Sentinel, Digital Elevation Model (DEM) data for terrain analysis, road and settlement datasets from national geospatial

repositories, and hydrological data capturing rivers and creeks. Also, socioeconomic indicators were derived from population density datasets, poverty and unemployment statistics, and historical records of pipeline vandalism incidents to capture the human and economic factors influencing TPI risk.

TPI risk factors were grouped into three major categories: environmental factors (elevation, slope, and land cover type such as forest, wetland, and built-up areas), infrastructural factors (distance to pipelines, proximity to roads, and distance to settlements), and socioeconomic factors (population density, poverty index, and historical vandalism hotspots), with each variable selected based on its established theoretical and empirical relevance to TPI occurrence. All spatial datasets were projected to a common coordinate system (e.g., UTM WGS84 Zone 32N), and preprocessing involved rasterization of vector datasets, resampling to a uniform spatial resolution (e.g., 30 m), conducting buffer analysis to derive proximity measures (such as distance to pipelines, roads, and settlements), and normalization of continuous variables to ensure consistency and comparability across all criteria. To ensure comparability, all criteria were standardized to a common scale (e.g., 0–1 or 1–5) using a fuzzy membership function or linear scaling approach, where higher values were assigned to areas with greater susceptibility to TPI and lower values to less vulnerable areas. The resulting TPI risk index was classified into five categories very low, low, moderate, high, and very high risk using

natural breaks (Jenks) or quantile classification methods to delineate distinct risk levels across the study area. The spatial distribution of high-risk zones along pipeline corridors was analyzed using buffer zone analysis (e.g., 500 m and 1 km), hotspot analysis with the Getis-Ord Gi statistic, and cluster analysis to identify areas of concentrated TPI risk. All data used in this study were obtained from publicly available sources or authorized institutions. Sensitive infrastructure data were handled with confidentiality to prevent misuse. The analysis was conducted using Geographic Information System (GIS) software such as ArcGIS and QGIS for spatial processing and mapping, Microsoft Excel for Analytical Hierarchy Process (AHP) computations, and statistical tools such as SPSS and R for validation and sensitivity analysis.

**RESULTS AND DISCUSSION**

The results of the GIS-based multi-criteria risk assessment of third-party interference (TPI) along the chosen pipeline path in the Niger Delta are shown and explained in this section. The findings are arranged to show the spatial distribution of each risk factor, the composite Spatial Risk Index (SRI) that derives from the Analytical Hierarchy Process (AHP), and the relative importance of each element. The focus is on finding regional patterns of vulnerability and elucidating the ways in which environmental, infrastructural, and socioeconomic factors combine to affect pipeline exposure to TPI. See Figure 1-7 for details explanation

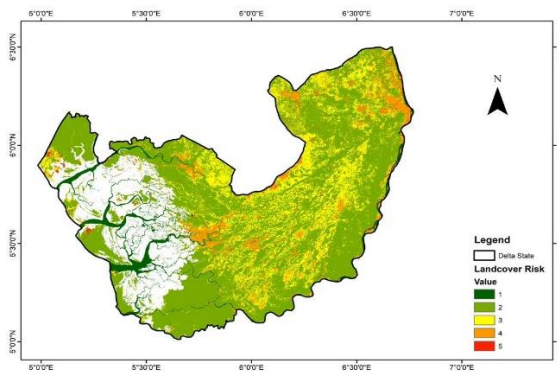


Figure 1: Land Cover Risk

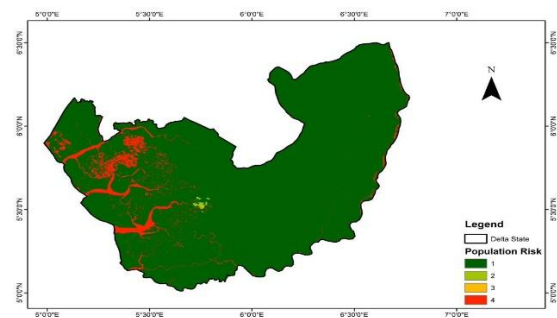


Figure 2: Population Risk

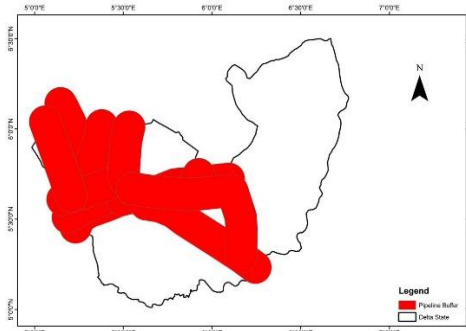


Figure 3: Pipeline Buffer

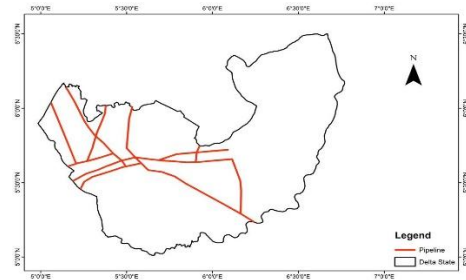


Figure 4: Pipeline

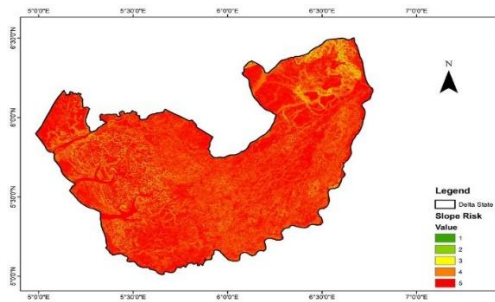


Figure 5: Slope Risk

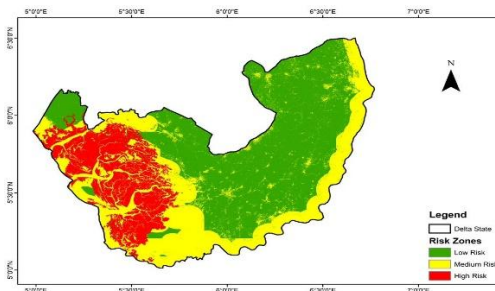


Figure 6: Risk Zone

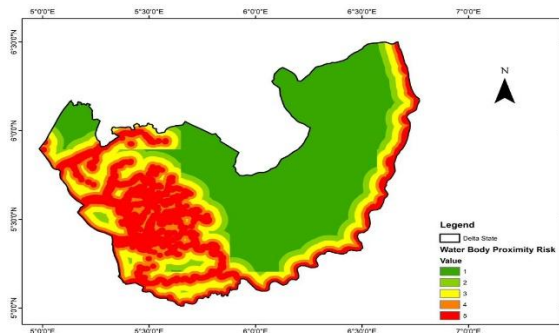


Figure 7: Water Body Proximity Risk

The study's findings demonstrate that third-party interference (TPI) risk along Niger Delta oil pipeline corridors is spatially structured and non-random. The substantial clustering of high-risk zones indicates that pipeline interference arises from particular spatial configurations rather than being an incidental or uniformly distributed event. The basic logic of the GIS-based MCDA paradigm, which posits that interference is most likely to occur where pipes are highly accessible and where human activity is intense, is validated by this spatial concentration. The idea that TPI is caused by recognisable spatial conditions rather than chance is supported by the alignment of high-risk clusters with areas of concentrated settlement, infrastructure connection, and land-use pressure.

Figure 1 presents the spatial distribution of land cover types and their associated risk levels for third-party interference (TPI) along pipeline corridors. The map indicates that areas classified as built-up land, degraded vegetation, and zones with intensive human activity exhibit higher risk levels, while forested and less accessible areas tend to show comparatively lower risk. This spatial variation reflects the influence of land use patterns on pipeline vulnerability, as areas with greater human presence and land-use intensity are more likely to experience interference. When linked to the overall findings of the study, Figure 1 supports the GIS-MCDA results by confirming that land cover is a significant environmental factor contributing to TPI risk. It aligns with the buffer analysis and hotspot patterns, which show that high-risk zones often coincide with densely populated and infrastructure linked areas. Furthermore, the observations are consistent with earlier studies, including those by Okoli (2013) and Orinya (2015), which highlighted that built-up and accessible land use categories are strongly associated with increased vulnerability to pipeline vandalism. Overall, Figure 1 reinforces that land cover patterns play a critical role in shaping the spatial distribution of TPI risk, with higher risks concentrated in areas of intensified human modification of the landscape.

Figure 2 illustrates the spatial distribution of population density and its corresponding contribution to third-party interference (TPI) risk along pipeline corridors. The map reveals that areas with higher population concentrations are associated with elevated risk levels, while sparsely populated regions exhibit comparatively lower risk. This pattern indicates that population density is a critical socioeconomic driver of TPI, as densely populated areas tend to have increased human activity, greater accessibility, and higher pressure on land and resources surrounding pipeline infrastructure.

This supports the GIS-MCDA results by confirming that socioeconomic variables significantly influence TPI risk distribution. The clustering of high population density zones overlaps with identified high-risk areas from the spatial overlay and hotspot analyses, reinforcing the argument that TPI is not randomly distributed but concentrated in areas of intense human presence. This observation is consistent with earlier studies by Okoli (2013) and Edoumiekumo (2017), which highlighted population pressure as a key factor driving oil-related crimes and pipeline vandalism. Overall, Figure 2 demonstrates that population density is a major determinant of spatial risk, complementing environmental and infrastructural factors in explaining the observed pattern of TPI across the study area.

Figure 3 illustrates buffer zones around pipeline corridors that delineate proximity-based exposure to third-party interference (TPI). The spatial pattern shows that areas closer to pipelines fall within higher-risk zones, particularly where

settlements, road networks, and land-use activities intersect with these buffers. This observed gradient of risk aligns with the study's broader GIS-MCDA results, which identified proximity to infrastructure and human activity as key drivers of TPI risk. For example, Okoli (2013) and Orinya (2015) both emphasized that areas with greater accessibility such as those near roads and settlements are more susceptible to pipeline interference. The buffer analysis in Figure 3 therefore reinforces these findings by visually and quantitatively demonstrating that risk increases with decreasing distance to pipeline corridors.

Figure 4 presents the spatial distribution and alignment of petroleum pipeline corridors across the study area, serving as the foundational layer for the entire TPI risk assessment. The figure highlights the linear infrastructure network that traverses various land use types, settlement zones, and environmental settings. Notably, many pipeline segments pass through or near densely populated areas, accessible road networks, and regions of intensive land-use activity, which increases their exposure to third-party interference. When linked to the study's overall findings, Figure 4 provides the spatial context for the buffer analysis, land cover risk, and population risk layers. The proximity of pipelines to high-density settlements and built-up areas observed in Figures 1 and 2 explains the clustering of high-risk zones identified in the GIS-MCDA model. This spatial alignment supports the study's conclusion that TPI risk is strongly influenced by accessibility and human activity patterns rather than being randomly distributed. Furthermore, the pipeline layout shown in Figure 4 reinforces earlier research findings, including those by Adewumi *et al* (2023), which emphasized that pipeline vulnerability is heightened in areas where infrastructure intersects with populated and easily accessible environments. Overall, Figure 4 underscores the structural exposure of pipeline networks and their susceptibility to interference within high-risk spatial contexts.

Figure 5 presents the spatial variation of slope across the study area and its implication for third-party interference (TPI) risk along petroleum pipeline corridors. The map reveals a clear gradient in which low-slope (flat or gently undulating) areas are associated with higher risk levels, while steeper slope regions exhibit comparatively lower risk. This pattern reflects the role of terrain in influencing accessibility, mobility, and human settlement patterns. Flat terrains are generally easier to access, develop, and traverse, thereby facilitating increased human activity, informal land use, and proximity to pipeline infrastructure all of which elevate the likelihood of interference.

From a spatial analysis perspective, the slope risk layer functions as an important environmental constraint within the GIS-MCDA framework. When overlaid with other risk layers such as land cover, population density, and pipeline proximity, low-slope areas tend to coincide with zones of intensive human presence and infrastructural connectivity. This overlap explains the clustering of high-risk zones observed in the composite TPI risk map and hotspot analysis. In contrast, areas with steep slopes often correspond to less accessible terrains, reduced settlement density, and limited infrastructural development, which collectively reduce exposure to pipeline interference.

The findings from Figure 5 are consistent with the broader results of the study, which emphasize that TPI risk is not randomly distributed but is shaped by a combination of environmental and anthropogenic factors. The influence of slope complements other determinants such as proximity to settlements and roads, reinforcing the argument that accessibility is a key driver of risk. This aligns with previous

research by Adewumi *et al.* (2023), which similarly identified terrain accessibility as a contributing factor to pipeline vulnerability. Overall, Figure 5 provides strong empirical evidence that terrain characteristics, particularly slope, play a significant role in shaping the spatial distribution of TPI risk. When integrated with infrastructural and socioeconomic variables, slope helps explain why certain areas emerge as persistent high-risk zones, thereby supporting the robustness of the GIS-based MCDA framework used in this study.

Figure 6 represents the final composite third-party interference (TPI) risk zonation map generated from the GIS-based Multi-Criteria Decision Analysis (MCDA) framework using the Analytical Hierarchy Process (AHP). It integrates multiple standardized and weighted criteria comprising environmental (e.g., slope, land cover), infrastructural (e.g., distance to pipelines, roads, and settlements), and socioeconomic variables (e.g., population density, poverty, and historical vandalism) to produce a continuous risk surface subsequently classified into discrete categories ranging from very low to very high risk. The spatial distribution shown in the map reveals a pronounced clustering of high and very high-risk zones along major pipeline corridors, particularly in areas characterized by dense human settlements, extensive road networks, and intensive land-use activities. These high-risk zones are predominantly located in low-lying, flat terrains with high accessibility, confirming that proximity and ease of access are key determinants of TPI vulnerability. In contrast, very low and low-risk zones are typically found in remote, sparsely populated, and less accessible areas, often associated with steeper slopes, limited infrastructural connectivity, and minimal human disturbance.

When interpreted in relation to the preceding thematic layers (Figures 1–5), Figure 6 demonstrates a strong spatial correspondence between individual risk factors and the final integrated risk output. High-risk zones align with built-up land cover areas (Figure 1), regions of high population density (Figure 2), pipeline corridors and their buffer zones (Figure 3 and Figure 4), and low-slope terrains (Figure 5). This consistency indicates that the overlay and weighting process effectively captured the combined influence of multiple determinants, reinforcing the internal validity of the GIS–MCDA model. The observed spatial clustering further validates the study's core assumption that TPI risk is not randomly distributed but is structurally determined by the interaction of environmental accessibility, infrastructural proximity, and socioeconomic pressures. These findings are consistent with earlier empirical studies by Ahmed *et al.* (2025). From a practical standpoint, Figure 6 provides a decision-support tool for identifying priority intervention zones, enabling stakeholders to allocate surveillance resources, enhance monitoring strategies, and implement targeted risk mitigation measures. High-risk zones highlighted in the map can guide the deployment of security infrastructure, community engagement programs, and preventive maintenance strategies along vulnerable pipeline segments.

Figure 7 presents the spatial distribution of risk associated with proximity to water bodies, including rivers, creeks, and wetlands, in relation to third-party interference (TPI) along petroleum pipeline corridors. The map indicates that areas located closer to water bodies exhibit higher risk levels compared to locations farther away. This pattern reflects the unique environmental and socioeconomic characteristics of the Niger Delta, where waterways serve as major transportation routes and support fishing, trade, and settlement activities, thereby increasing human accessibility around pipeline infrastructure.

The proximity to water bodies enhances vulnerability to TPI for several reasons. First, waterways provide alternative access routes that are often less regulated than road networks, facilitating movement in otherwise remote areas. Second, settlements and economic activities are frequently concentrated along riverbanks and creeks, increasing population pressure in these zones. Third, the swampy and fragmented terrain associated with water bodies often complicates monitoring and surveillance, creating opportunities for undetected interference. As a result, pipeline segments located near rivers and creeks are more exposed to human interaction and potential vandalism.

When linked to the overall findings of the study, Figure 7 complements other spatial layers such as population density, land use, and pipeline proximity by highlighting the hydrological dimension of TPI risk. High-risk zones identified in the composite risk map (Figure 6) often coincide with areas close to water bodies, reinforcing the notion that multiple environmental and infrastructural factors interact to shape vulnerability patterns. This spatial overlap confirms that risk is not determined by a single factor but emerges from the convergence of accessibility, human activity, and environmental context.

The findings illustrated in Figure 7 are also consistent with previous studies by Ozor *et al.* (2025) which emphasized that riverine and wetland areas in the Niger Delta are particularly prone to pipeline vandalism due to their accessibility and the concentration of economic activities along waterways. Similarly, the work of Edoumiekumo (2017) supports the observation that environmental settings characterized by water-based transportation networks tend to experience higher levels of oil-related crimes. It demonstrates that proximity to water bodies is a significant environmental factor influencing TPI risk distribution. It reinforces the study's central conclusion that pipeline interference in the Niger Delta is spatially structured, with high-risk zones emerging in areas where hydrological features, human settlements, and infrastructural elements converge.

This result is consistent with Ebegbulem's (2021) criticism of exclusively securitized responses to pipeline vandalism in the Niger Delta, which prioritizes militarization and enforcement at the expense of underlying socioeconomic factors. The study's findings support the idea that security-focused actions by themselves are unlikely to yield long-term results. As a result, the Spatial Risk Index (SRI) map should not be used exclusively to guide security personnel. Instead, it needs to function as a tactical manual for focusing on non-coercive measures, such as enhanced Corporate Social Responsibility (CSR) programs, alternative livelihood initiatives, and inclusive stakeholder engagement procedures. The risk map provides a more comprehensive foundation for intervention by fusing spatial intelligence with socioeconomic factors, supporting plans that blend development-oriented tactics with focused security measures. In the Niger Delta, such integrated interventions are more likely to treat the underlying causes of TPI as well as its symptoms, improving community–infrastructure relations and pipeline security over time.

## CONCLUSION

This study highlights the use of GIS, MCDA, and AHP for assessing third-party interference (TPI) risk along pipelines in the Niger Delta, showing that risk varies spatially and is influenced by socioeconomic, land-use, accessibility, and topographical factors. High-risk areas are generally located in densely populated, socioeconomically disadvantaged regions with strong road and river connectivity. The Spatial Risk Index map provides a structured spatial representation that

supports decision-making for pipeline security. The consistency between individual factor maps, expert-derived weights, and the composite output suggests methodological coherence. However, the performance of the model should be interpreted cautiously, as it depends on data quality, resolution, and underlying assumptions. The framework's applicability to other regions is not automatic and may require recalibration of weights and inclusion of local context-specific variables. Validation with local data is also necessary to ensure reliability. Therefore, the model should be viewed as a decision-support tool rather than a definitive predictive system. Its effectiveness is context-dependent and subject to refinement. Overall, it promotes a proactive, risk-informed approach to pipeline management under suitable local conditions.

### RECOMMENDATIONS

The following recommendations are put out to improve pipeline security and lessen third-party interference (TPI) in the Niger Delta in light of the study's findings: TO:

- i. Prioritised risk-based monitoring, that include the use of automated sensors, remote sensing, and routine field inspections, for pipeline segments classified as high and extremely high risk in the Spatial Risk Index (SRI).
- ii. Managing agricultural operations and settlement encroachment along pipeline rights-of-way by working with local authorities and urban planners to integrate land-use planning with pipeline security.
- iii. Putting socioeconomic mitigation techniques into practice in vulnerable communities along pipeline corridors, such as initiatives for livelihood diversification, youth employment, and poverty reduction.
- iv. Infrastructure management and controlled access, using physical barriers, checkpoints, and coordinated monitoring, along highways and rivers that overlap pipeline corridors.

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