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*Full Length Research*

# Mapping vulnerability and improving disaster response through inland waterways in Rivers State

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**ABSTRACT:** Flooding remains one of the most persistent environmental challenges confronting the Niger Delta region of Nigeria, where Rivers State is particularly exposed due to its low-lying topography, tidal influence, and dense riverine settlement patterns. This study aimed to map flood vulnerability and explore strategies for improving disaster response through inland waterways across selected transport corridors in Rivers State. The research employed a Geographic Information System (GIS)-based multi-criteria analysis (MCA) approach to spatially assess flood susceptibility. Data layers on elevation, slope, drainage density, land use/land cover, proximity to rivers, soil permeability, and rainfall intensity were integrated and weighted using the Analytic Hierarchy Process (AHP) to produce composite flood vulnerability maps for eight major corridors: Port Harcourt–Bonny, Port Harcourt–Nembe, Port Harcourt–Brass, Abonema Wharf–Bakana, Iwofe–Ogbakiri, Marine Base–Okrika, Akpos–Okujagu, and Abuloma–Kalio. The spatial analysis revealed significant variations in flood susceptibility across the study area. Corridors such as Port Harcourt–Bonny, Marine Base–Okrika, and Abuloma–Kalio were classified as high to very high vulnerability zones, primarily due to flat terrain, poor drainage infrastructure, and tidal inundation. In contrast, Port Harcourt–Nembe and Maccoba–Isiaka showed moderate to low vulnerability, attributed to slightly elevated topography and better natural drainage. Communities within high-risk zones such as Bakana, Okujagu, Kalio, and Okrika face recurrent inundation, infrastructure damage, livelihood disruptions, and increased exposure to waterborne and vector-borne diseases. The study concludes that GIS-based flood vulnerability mapping provides a vital decision-support tool for disaster management and spatial planning in flood-prone regions. Integrating inland waterway networks into disaster response systems can enhance mobility, evacuation efficiency, and emergency logistics during flood events. Recommendations include: (i) strengthening drainage and embankment infrastructure along critical waterways; (ii) institutionalising community-based early warning and evacuation systems; (iii) enforcing land-use regulations to prevent settlement expansion into high-risk flood zones; and (iv) incorporating real-time hydrological monitoring and GIS mapping into the Rivers State disaster management framework. These interventions, if implemented, will significantly enhance flood resilience, adaptive capacity, and sustainable development across the Niger Delta's inland waterway corridors.

**Keywords**: Disaster response, flood risk assessment, inland waterways, Geographic Information System (GIS), spatial analysis, vulnerability mapping.

## INTRODUCTION

Rivers State, located in Nigeria's Niger Delta region, is characterised by extensive inland waterways, riverine settlements, and a fragile ecological system. The state's terrain is predominantly low-lying and intersected by numerous creeks, rivers, and lagoons, making it highly susceptible to flooding, erosion, and other hydrological hazards (Okonkwo *et al*., 2015; Ogboeli *et al*., 2024a). Frequent inundation events have caused severe socio-economic disruptions, particularly among communities dependent on subsistence fishing and farming. Despite the region's exposure to recurring floods, preparedness and mitigation measures remain inadequate. According to

Elekwachi *et al*. (2021), many flood-prone riverine localities in Rivers State remain un-dredged, with blocked drainage systems and a lack of functional early warning mechanisms, leaving residents highly exposed during peak flood periods.

Spatial assessment of flood hazards in Rivers State has shown that systematic vulnerability mapping is both feasible and essential for disaster risk reduction (Ogboeli *et al*., 2024b). A study by Wizor and Mpigi (2020) employed Earth Observation and Geographic Information Systems (GIS) techniques to evaluate flood exposure in selected communities across the state. Their findings revealed that over 40% of settlements and infrastructure are located within flood-prone zones, underscoring the urgent need for a geospatially informed vulnerability framework. Such mapping provides the basis for identifying priority areas for intervention and supports effective planning for emergency response and post-disaster recovery.

Simultaneously, the inland waterways that sustain much of Rivers State's commerce and mobility face increasing environmental and operational stress. The National Inland Waterways Authority (NIWA, 2013) recently issued warnings about "fast-rising water levels across rivers and lagoons," advising communities and transport operators to adopt precautionary measures to avert disaster. Inland waterways in the Niger Delta serve as crucial arteries for transportation and connectivity among riverine settlements; however, they also constitute potential pathways for disaster escalation when unregulated or poorly maintained. A study by Nze *et al*. (2021) on the estimation of the Likelihood of Accident Occurrence on Inland Waterways Transport in Nigeria's Niger Delta identified high accident and fatality rates due to overloading, poor vessel conditions, and inadequate navigation systems. This reflects broader systemic vulnerabilities that compromise both safety and resilience during flood emergencies.

Disaster response in Rivers State's riverine areas is particularly constrained by limited accessibility. Flooding events often isolate communities, disrupt communication networks, destroy road and water transport infrastructure, and delay the arrival of relief and rescue teams (Wizor and Week, 2020; Ogboeli *et al*., 2024c). Without accurate vulnerability maps indicating the most at-risk zones, response efforts tend to be reactive and poorly coordinated. Consequently, there is a pressing need for an integrated disaster-response model that leverages existing inland waterway networks for efficient evacuation, supply distribution, and emergency communication.

Mapping vulnerability through inland waterways provides a strategic approach to enhance disaster preparedness and response. By employing GIS and remote sensing technologies, it is possible to identify critical exposure hotspots, such as densely populated riverbanks, drainage chokepoints, and transportation nodes and overlay these with navigational routes and access points. This integration enables more targeted disaster-response planning, including the pre-positioning of rescue boats, designation of emergency water-evacuation routes, and prioritisation of dredging and maintenance of strategic canals (Wizor and Week, 2020). Real-time monitoring of hydrological conditions through satellite-based early-warning systems can further strengthen community resilience and reduce response delays (Abam and Nwankwoala, 2020).

Given that many riverine communities in Rivers State depend almost entirely on water-based transportation for their livelihoods, disruptions in inland waterway networks during disaster events can effectively cut off entire populations (Mmom and Aifesehi, 2013; Ogboeli *et al*., 2024c). Strengthening the resilience of these waterways, alongside the development of vulnerability maps, therefore holds significant promise for improving both emergency preparedness and long-term adaptation to climate-induced hazards.

Flood-vulnerability mapping is now recognised as a core component of disaster risk reduction and climate adaptation. In Australia, Schwarz and Kuleshov (2022) developed a flood vulnerability index for the Hawkesbury–Nepean Catchment using an indicator-based approach that integrated elevation, slope, socio-economic status, and soil permeability. Their findings showed that low-lying, socio-economically disadvantaged areas faced the highest flood risks. This systematic, data-driven framework provides a model for Rivers State, where high-resolution hydrological data are limited, and decision-making often depends on generalised assessments.

Similarly, Suthakaran *et al*. (2022) designed an open-source, global flood-risk mapping framework that merges hazard, exposure, and vulnerability modules, especially for data-scarce regions. This model demonstrates that open-access spatial datasets and GIS tools can generate reliable, low-cost vulnerability maps. For Rivers State, adopting such a framework could help pinpoint high-risk waterway corridors, guide dredging and maintenance efforts, and improve emergency logistics planning.

However, Wu *et al*. (2019) observed that many global flood-mapping studies focus primarily on terrestrial infrastructure, often neglecting the role of inland waterways in disaster response. This oversight is significant for riverine regions like the Niger Delta, where waterways, not roads, serve as vital transport and evacuation routes.

Globally, evidence shows that inland waterway systems themselves can become points of vulnerability during disasters. In the United States, Welch *et al*. (2022) analysed the 2019 flooding of the McClellan–Kerr Arkansas River Navigation System and found that prolonged channel closures disrupted supply chains, reduced regional output, and affected employment. This case highlights how flooding of navigable waterways can create far-reaching economic and logistical impacts.

In a global review, Jović *et al*. (2025) identified 56 categories of threats to inland waterway transport, including storms, fluctuating water levels, equipment failures, and operational disruptions. These findings stress the need for disaster-management strategies that integrate both environmental and operational risks.

In South Asia, Uddin *et al*. (2017) examined two decades of inland waterway accidents in Bangladesh, using spatial regression to identify accident-prone zones linked to poor navigation infrastructure and heavy boat traffic. This underscores that waterways themselves can become high-risk zones during extreme weather events, an insight directly relevant to Rivers State, where boats and ferries are lifelines for mobility and trade.

### Objective of the study

This study seeks to bridge critical gaps in disaster-risk management by examining the intersection of spatial vulnerability mapping, inland waterway infrastructure, and disaster-response systems in Rivers State. Considering the state's recurring flood risks, fragile infrastructure, and limited institutional capacity for emergency management, a geospatially integrated framework is essential. The study will identify high-risk nodes along waterways, assess the capacity of inland water routes for emergency logistics, and develop a GIS-based decision-support model to enhance disaster-response efficiency. The findings are expected to benefit policymakers, disaster-management agencies, and riverine communities in strengthening resilience and ensuring sustainable management of inland waterways in the face of escalating hydrological hazards.

## MATERIALS AND METHODS

This study adopts a mixed-methods research design, combining geospatial analysis, field survey, and secondary data review to map vulnerability and assess the potential of inland waterways in improving disaster response in Rivers State. The quantitative component utilises Geographic Information Systems (GIS) and Remote Sensing (RS) techniques for spatial vulnerability assessment. The research focuses on Rivers State, located in the Niger Delta region of southern Nigeria, between latitudes 4°45′N and 5°45′N and longitudes 6°30′E and 7°30′E. The state is bounded by the Atlantic Ocean to the south and is interlaced by numerous rivers, creeks, and estuaries, including the Bonny, New Calabar, and Andoni rivers. Rivers State is highly urbanised in parts (e.g., Port Harcourt) yet largely rural and riverine in many local government areas such as Andoni, Opobo–Nkoro, Degema, and Akuku-Toru. The target populations are the riverine communities within the Port Harcourt Metropolis that are impacted by floods and other kinds of disasters. The population aggregates are mustered within the jetties and loading ports within the Port Harcourt Metropolis. The choice to focus on Port Harcourt Metropolis was driven by the high volume of commuter traffic and the accessibility of water transportation, a point also highlighted by Ogboeli *et al*. (2024c). Getting around the city is often complicated, marked by heavy traffic congestion and long travel times. This research took place in flood-prone and disaster-affected areas where inland water transport plays a vital role in emergency response. Key loading jetties included in the research are located at Nembe waterside (serving Bonny, Nembe, and Brass), Maccoba, Abonnema Wharf, Iwofe, Marine Base, Akpos, and Abuloma.

### Spatial data

The geospatial datasets used in this study include:

1. Satellite Imagery: Sentinel-2 (10 m resolution) and Landsat 9 (30 m resolution) imagery for land-cover and hydrography mapping (acquired from the United States Geological Survey [USGS]).
2. Digital Elevation Model (DEM): Shuttle Radar Topography Mission (SRTM) data (30 m resolution) for elevation and slope analysis.
3. Hydrological and Administrative Data: Vector datasets on rivers, waterways, and administrative boundaries obtained from the National Inland Waterways Authority (NIWA) and the Office of the Surveyor General of the Federation (OSGOF).
4. Socio-Economic Data: Population density, settlement patterns, and poverty index data sourced from the National Population Commission and the Nigeria Bureau of Statistics.

### Non-spatial data

Non-spatial data include field observations, photographs, and semi-structured interviews with community members, boat operators, and officials from the Rivers State Emergency Management Agency (RSEMA) and NIWA.

Preprocessing of Spatial Data: Satellite imagery was corrected for geometric distortions and atmospheric effects using the Semi-Automatic Classification Plugin (SCP) in QGIS 3.28. The DEM was clipped to the Rivers State boundary, and hydrological layers were extracted to delineate river networks and floodplains.

Flood Vulnerability Mapping: Flood vulnerability was modelled using an indicator-based GIS approach, integrating multiple physical and socio-economic variables. Each indicator was normalised, weighted, and overlaid using the Weighted Overlay Analysis (WOA) tool in ArcGIS Pro. The vulnerability index (VI) was computed as:

$$VI = \sum(W_i \times X_i)$$

Where $W_i$ is the weight assigned to each factor (derived using the Analytical Hierarchy Process [AHP]), and $X_i$ is the normalised score of the variable.

Indicators considered include:

1. Physical factors: elevation, slope, drainage density, distance from rivers, and land use.
2. Socio-economic factors: population density, housing type, access to infrastructure, and proximity to inland waterways.

The resulting vulnerability map was classified into five categories: *very low, low, moderate, high,* and *very high* vulnerability zones.

### Inland waterway network analysis

Using GIS network analysis tools, inland waterways were modelled as transport routes to evaluate accessibility and connectivity between vulnerable settlements and emergency response hubs (e.g., RSEMA depots, NIWA jetties). Parameters such as waterway length, navigability, and proximity to populated areas were analysed. The analysis identified optimal evacuation routes, travel-time buffers, and potential docking or staging points for rescue operations.

### Data integration and visualisation

Spatial and non-spatial datasets were integrated within ArcGIS Pro and QGIS environments. The final outputs included: Flood Vulnerability Maps showing spatial patterns of exposure. The results were exported as georeferenced maps, shapefiles, and high-resolution cartographic outputs for use by government agencies and researchers.

### Ethical considerations

Ethical approval was obtained from the Rivers State University Research Ethics Committee. All participants provided informed consent before interviews. Community participation was voluntary, and confidentiality was ensured throughout data collection and reporting.

## RESULTS AND DISCUSSION

The Digital Elevation Model (DEM) data for coastal and riverine study areas in Rivers State and the Niger Delta reveal predominantly low-lying topography, with most regions featuring elevations below 15 meters as shown in Table 1. Across the nine profiled transects (e.g., Port Harcourt to Bonny, Nembe, Brass; Maccoba to Isiaka; Abonema-Wharf to Bakana; and others), class 1 consistently represents the lowest terrain, often including negative values indicative of areas below mean sea level,

**Table 1.** Summary of digital elevation model data set for each study area.

| No. | Range (DEM)m | Average (DEM)m |
|---|---|---|
| | Digital Elevation Model (Ph to Bonny) | |
| 1 | -0.561 – 2.948 | 1.193 |
| 2 | 2.948 - 6.458 | 4.703 |
| 3 | 6.458 – 9.967 | 8.212 |
| 4 | 9.967 – 13.477 | 11.722 |
| 5 | 13.477 – 16.987 | 15.232 |
| | Digital Elevation Model (Ph to Brass) | |
| 1 | -0.237 – 2.704 | 1.2335 |
| 2 | 2.704 – 5.646 | 4.175 |
| 3 | 5.646 – 8.589 | 7.1175 |
| 4 | 8.589 – 11.531 | 10.06 |
| 5 | 11.531 – 14.473 | 13.002 |
| | Digital Elevation Model (Abonema-Wharf to Bakana) | |
| 1 | -5.087 - -0.612 | −2.8495 |
| 2 | -0.612 – 3.862 | 1.625 |
| 3 | 3.862 – 8.338 | 6.1 |
| 4 | 8.383 – 12.813 | 10.598 |
| 5 | 12.813 – 17.28 | 15.0465 |
| | Digital Elevation Model (Marine base to Okrika) | |
| 1 | -3.880 – 0.0900 | −1.895 |
| 2 | 0.090 – 4.060 | 2.075 |
| 3 | 4.060 – 8.031 | 6.0455 |
| 4 | 8.031 – 12.001 | 10.016 |
| 5 | 12.001 – 15.972 | 13.9865 |
| | Digital Elevation Model (Abuloma to Kalio) | |
| 1 | -1.683 – 0.969 | −0.357 |
| 2 | 0.969 – 3.622 | 2.2955 |
| 3 | 3.622 – 6.275 | 4.9485 |
| 4 | 6.275 – 8.928 | 7.6015 |
| 5 | 8.928 – 11.581 | 10.2545 |
| | Digital Elevation Model (Ph to Nembe) | |
| 1 | -0.237 – 2.704 | 1.2335 |
| 2 | 2.704 – 5.646 | 4.175 |
| 3 | 5.646 – 8.589 | 7.1175 |
| 4 | 8.589 – 11.531 | 10.06 |
| 5 | 11.531 – 14.473 | 13.002 |
| | Digital Elevation Model (Maccoba to Isiaka) | |
| 1 | -3.987 - -0.652 | −2.3195 |
| 2 | -0.652 - 2.682 | 1.015 |
| 3 | 2.682 – 6.017 | 4.3495 |
| 4 | 6.017 – 9.352 | 7.6845 |
| 5 | 9.352 – 12.687 | 11.0195 |

**Table 1.** Contd.

| No. | Range (DEM)m | Average (DEM)m |
|---|---|---|
| | Digital Elevation Model (Iwofe to Ogbakiri) | |
| 1 | -3.943 – 0.041 | −1.951 |
| 2 | 0.041 – 4.026 | 2.0335 |
| 3 | 4.026 – 8.010 | 6.018 |
| 4 | 8.010 – 11.995 | 10.0025 |
| 5 | 11.995 – 15.980 | 13.9875 |
| | Digital Elevation Model (Akpos to Okujagu) | |
| 1 | -3.016 - 1.314 | −0.851 |
| 2 | 1.314 – 5.644 | 3.479 |
| 3 | 5.644 – 9.975 | 7.8095 |
| 4 | 9.975 – 14.305 | 12.14 |
| 5 | 14.305 – 18.636 | 16.4705 |

ranging from -5.087 m to approximately 3 m. Average elevations in the lowest class are typically between -2.85 m and 1.23 m, highlighting significant portions of intertidal or near-sea-level land vulnerable to flooding and inundation.

Mid-range classes (2–4) show gradual increases in elevation, with averages progressing from around 1–4 m in class 2 to 10–12 m in class 4 across most areas. Transects such as Marine Base to Okrika, Akpos to Okujagu, and Iwofe to Ogbakiri exhibit the highest upper ranges, reaching 15–18.6 m in class 5, with averages up to 16.47 m. In contrast, northern or inland-leaning routes like Port Harcourt to Bonny and Nembe maintain lower maximum elevations (up to 16.99 m), reflecting flatter coastal plains.

Overall, the DEM summaries underscore the characteristic low-relief morphology of the Niger Delta coastal zone, with many communities situated in elevation classes below 5–8 m on average. Areas such as Maccoba to Isiaka and Abonema-Wharf to Bakana include substantial negative elevations in lower classes, reinforcing high susceptibility to sea-level rise, storm surges, and seasonal flooding. These data emphasise the environmental vulnerability of the study communities examined in the perception survey.

## Flood vulnerability assessment of the Port Harcourt–Bonny and Port Harcourt–Nembe corridors

The spatial analysis of flood vulnerability along the Port Harcourt–Bonny and Port Harcourt–Nembe corridors reveals marked variations in susceptibility within the Niger Delta's inland waterway system. The results emphasise how topography, geomorphology, and human activities interact to shape flood risk across these critical transport routes. The flood vulnerability map (Figure 1) shows that much of the Port Harcourt–Bonny corridor falls within high to very high flood-risk zones (orange–red), especially in its central and northern portions. These zones coincide with low-lying floodplains, flat terrain, and poor drainage, which typify the Niger Delta. In contrast, the southern section displays lower vulnerability (yellow–green), reflecting slightly higher elevations and more efficient drainage. This pattern aligns with the Delta's geomorphology, alluvial plains, a highwater table, and restricted natural drainage (Gambo *et al*., 2023). The clustering of high-risk areas around this corridor indicates that critical infrastructure, including roads, jetties, and industrial facilities, is repeatedly exposed to flooding. Such exposure highlights the need for comprehensive flood-control measures, including improved drainage systems, embankments, and community-based early warning systems. The results provide actionable evidence for urban and regional planning, underscoring the importance of integrating GIS-based flood assessments into land-use and infrastructure decisions. Without proactive adaptation, socio-economic impacts, such as displacement, property damage, and livelihood disruption, will likely intensify across the Port Harcourt–Bonny axis (Bello and Ogedegbe, 2015; Wizor and Week, 2020).

Conversely, the Port Harcourt–Nembe corridor (Figure 2) is dominated by low to moderate vulnerability zones (green–yellow), generally corresponding to slightly elevated terrain and effective drainage pathways. However, its northern fringe displays high to very high susceptibility (orange–red), particularly in tidal lowlands where fluvial–marine interactions intensify inundation risks. While the Port Harcourt–Nembe jetty itself lies within a low-risk zone, adjacent northern settlements experience recurrent flooding, infrastructure damage, and public-health hazards from stagnant water and vector-borne diseases (Ozegin and Ilugbo, 2025). The Brass–Nembe corridor, a major fishing and trade hub, faces economic losses during persistent flood events. To mitigate these impacts, a dual-response strategy is essential: structural interventions (embankments, drainage expansion, shoreline stabilisation) and non-structural measures (land-use control, early-warning dissemination, and strategic resettlement) (Wizor and Week, 2020).

## Flood vulnerability assessment of the Port Harcourt–Brass and Maccoba–Isiaka corridors

The flood vulnerability map of the Port Harcourt–Brass (Figure 3) corridor shows a landscape predominantly characterised by low to moderate flood susceptibility, represented in green and light-yellow tones. These zones indicate relatively safer areas, likely associated with slightly elevated terrain and improved drainage systems. However, the northern fringe exhibits scattered orange and red patches, representing high to very high flood vulnerability. This spatial variation reflects the geomorphological dynamics of the Niger Delta, where low elevation, tidal influence, and weak natural drainage amplify flood exposure (Iyalla, 2001). While the Port Harcourt–Brass jetty lies in a low-risk zone, the surrounding northern

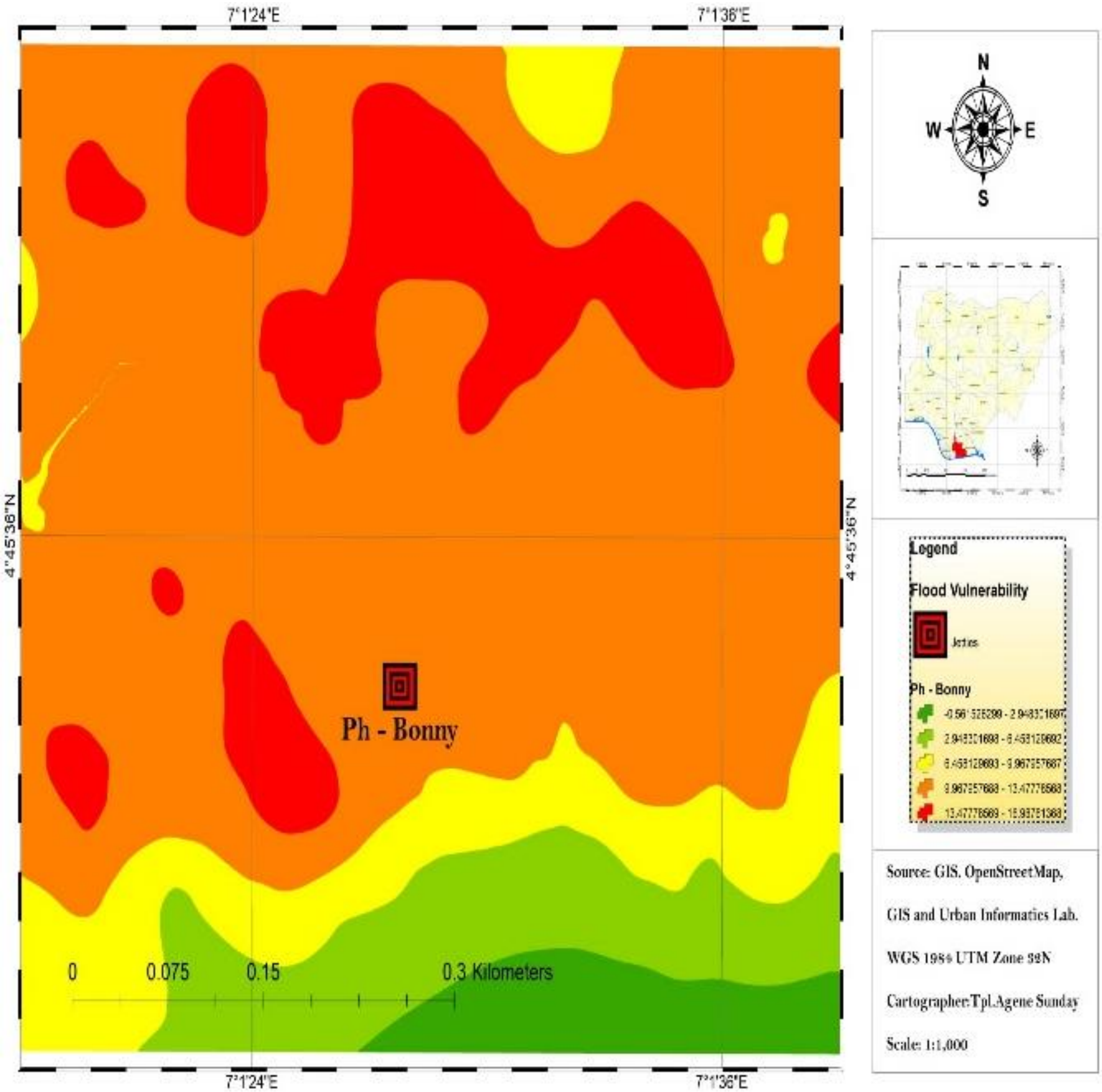


**Figure 1.** Digital elevation model of Port Harcourt to Bonny.

settlements are more prone to periodic inundation. Communities in these zones face infrastructure damage, transport disruptions, and increased public health threats, particularly from stagnant floodwaters and waterborne diseases (Samuel et al., 2017). Recurrent flooding along the Brass axis also poses substantial socio-economic challenges. The area serves as a major hub for fishing, inland trade, and oil logistics, and persistent inundation threatens these activities by reducing mobility, damaging waterfront infrastructure, and affecting community stability. Hence, the Port Harcourt–Brass corridor requires targeted flood-mitigation measures, including shoreline reinforcement, drainage improvement, and the establishment of early-warning mechanisms to safeguard vulnerable communities.

The Maccoba–Isiaka (Figure 4) area presents a landscape largely dominated by low flood vulnerability zones (green), suggesting comparatively reduced exposure to inundation. This condition likely stems from moderate elevation, vegetation cover, and effective local

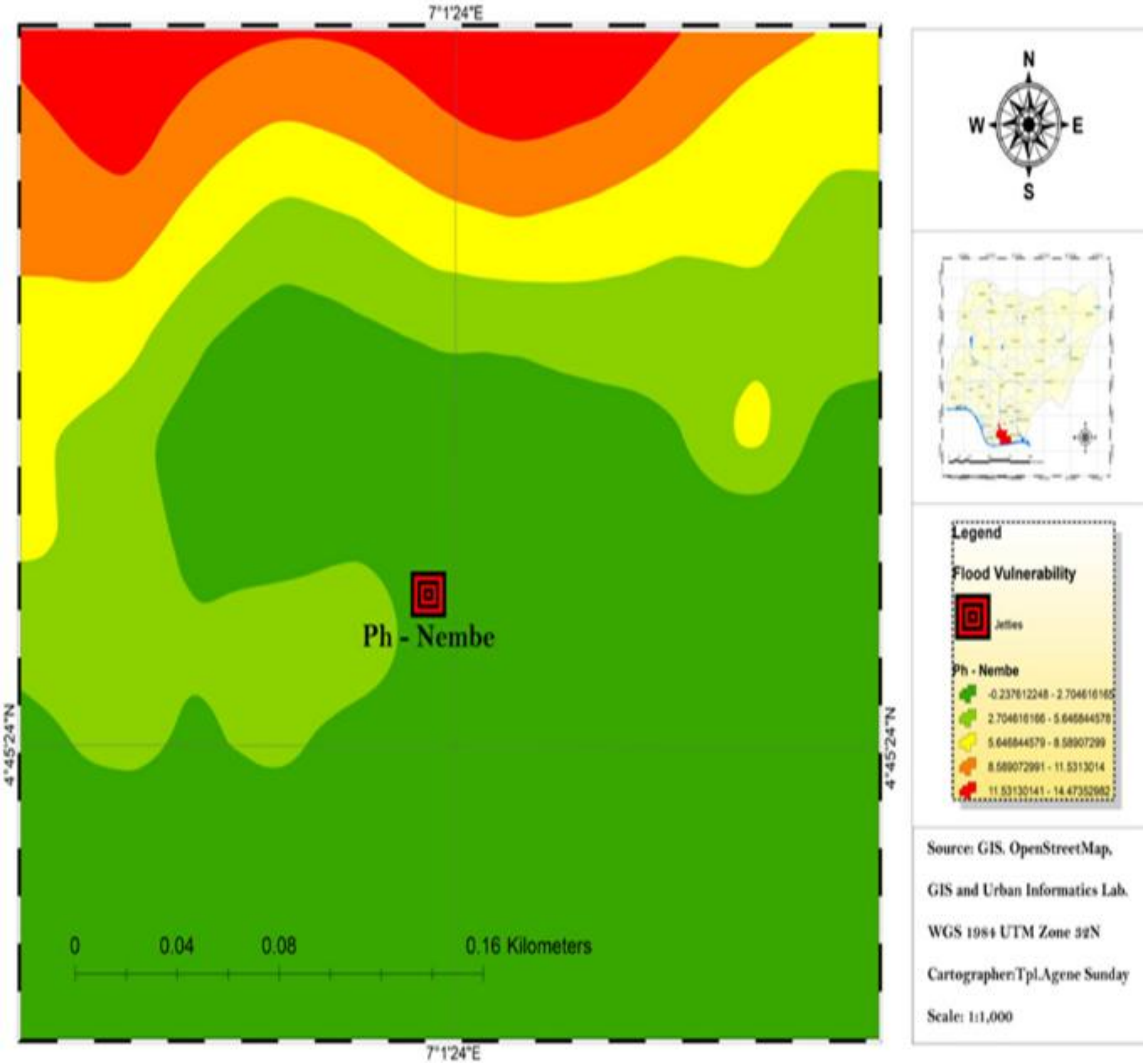


**Figure 2.** Digital elevation model of Port Harcourt to Nembe.

drainage. Nonetheless, pockets of moderate to high vulnerability (yellow to orange) are observed across the western and northeastern edges, signifying localised depressions and restricted water flow. A more concerning pattern appears along the southwestern boundary, where concentrated red zones denote high-risk flood hotspots.

These areas are particularly exposed to storm surges, intense rainfall, or sea-level fluctuations, making nearby settlements and infrastructure susceptible to flood-related damage (Adelekan, 2010). Although the overall risk in Maccoba–Isiaka remains lower than in other Niger Delta locations, the existence of these vulnerable clusters highlights the need for proactive management. Under conditions of prolonged rainfall or poor land-use practices, these high-risk patches could experience significant property loss, livelihood disruption, and socio-economic instability. Continuous monitoring through GIS-based flood mapping, coupled with local adaptation strategies, will be essential for mitigating these emerging threats.

## Flood vulnerability assessment of the Abonnema Wharf–Bakana and Iwofe–Ogbakiri corridors

The flood vulnerability map of the Abonnema Wharf–Bakana corridor (Figure 5) reveals a landscape dominated

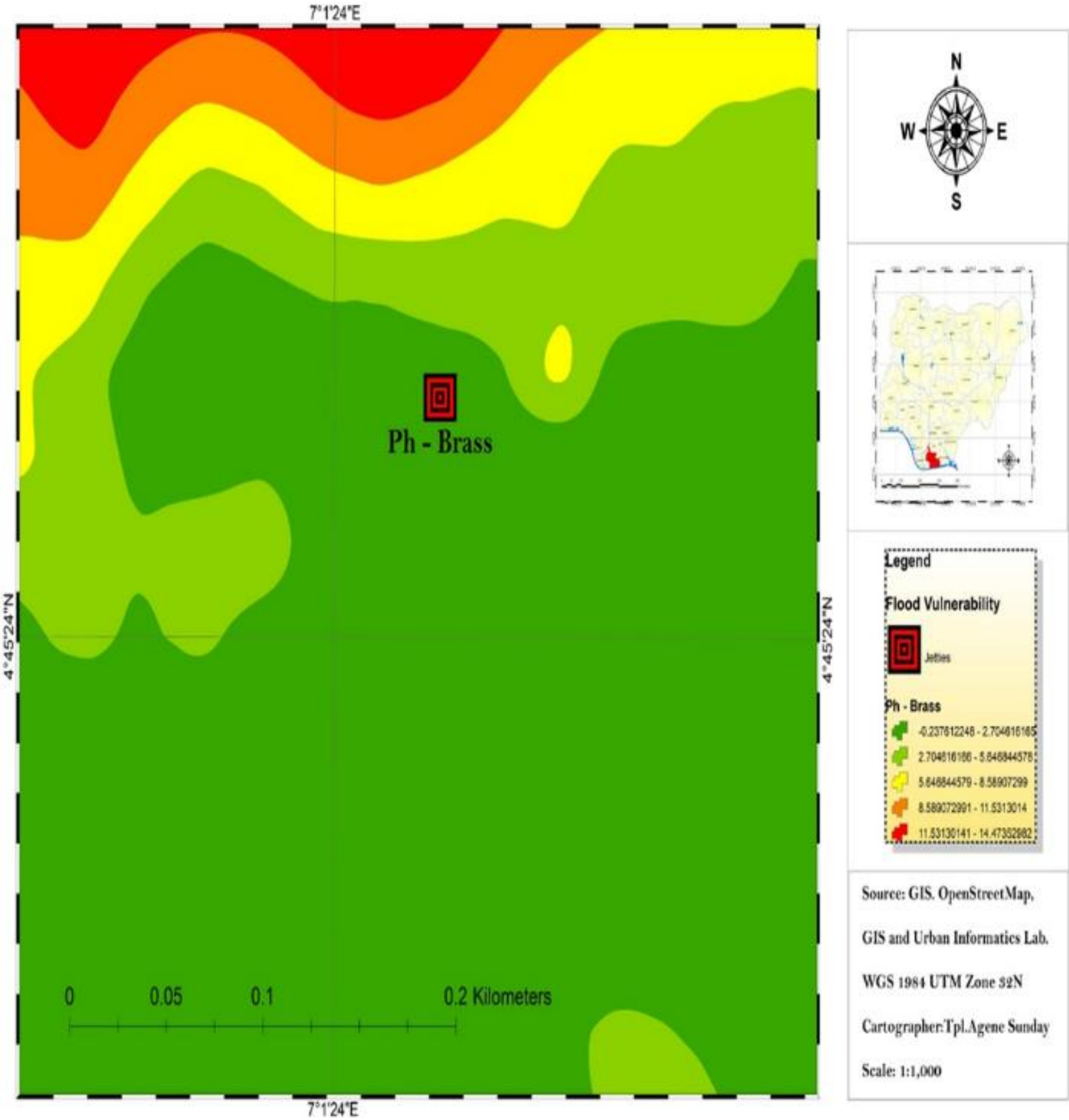


**Figure 3.** Digital elevation model of Port Harcourt to Brass.

by moderate to high flood susceptibility, represented in yellow and orange zones. Several red patches across the eastern sector indicate very high vulnerability, while limited green areas mark isolated low-risk zones. This spatial pattern reflects the geomorphological and hydrological characteristics of the Niger Delta, where low elevation, tidal incursions, and intense rainfall contribute to widespread inundation (Barroca *et al*., 2006). Communities along this corridor, particularly Bakana and its adjoining riverine settlements, face severe socio-economic and health challenges due to recurrent flooding. Repeated inundations disrupt fishing and farming, the main sources of livelihood, and threaten critical infrastructure such as jetties, schools, and local access roads. Beyond economic disruption, stagnant floodwaters foster vector-borne diseases and water-related epidemics,

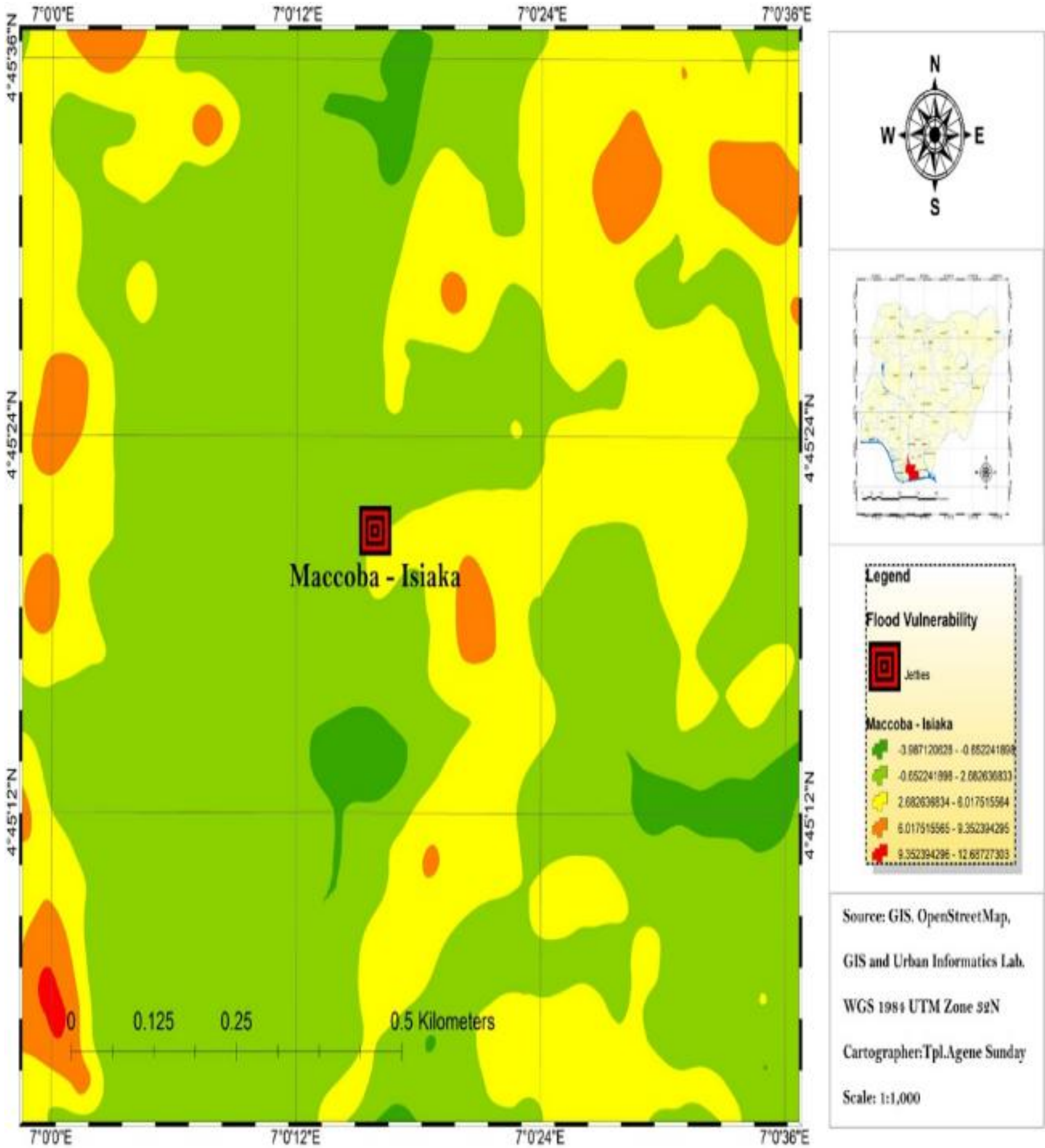


**Figure 4.** Digital elevation model of Maccoba to Isaka.

including malaria and cholera outbreaks (Uyigue and Agho, 2007). Without targeted adaptation, these communities remain at risk of property loss, displacement, and livelihood instability. Embedding GIS-based flood mapping into local and regional development planning offers a framework for identifying hotspots, prioritising interventions, and strengthening infrastructure and community resilience (Wizor and Week, 2020).

The Iwofe–Ogbakiri (Figure 6) corridor exhibits a similar pattern, with moderate to high flood susceptibility

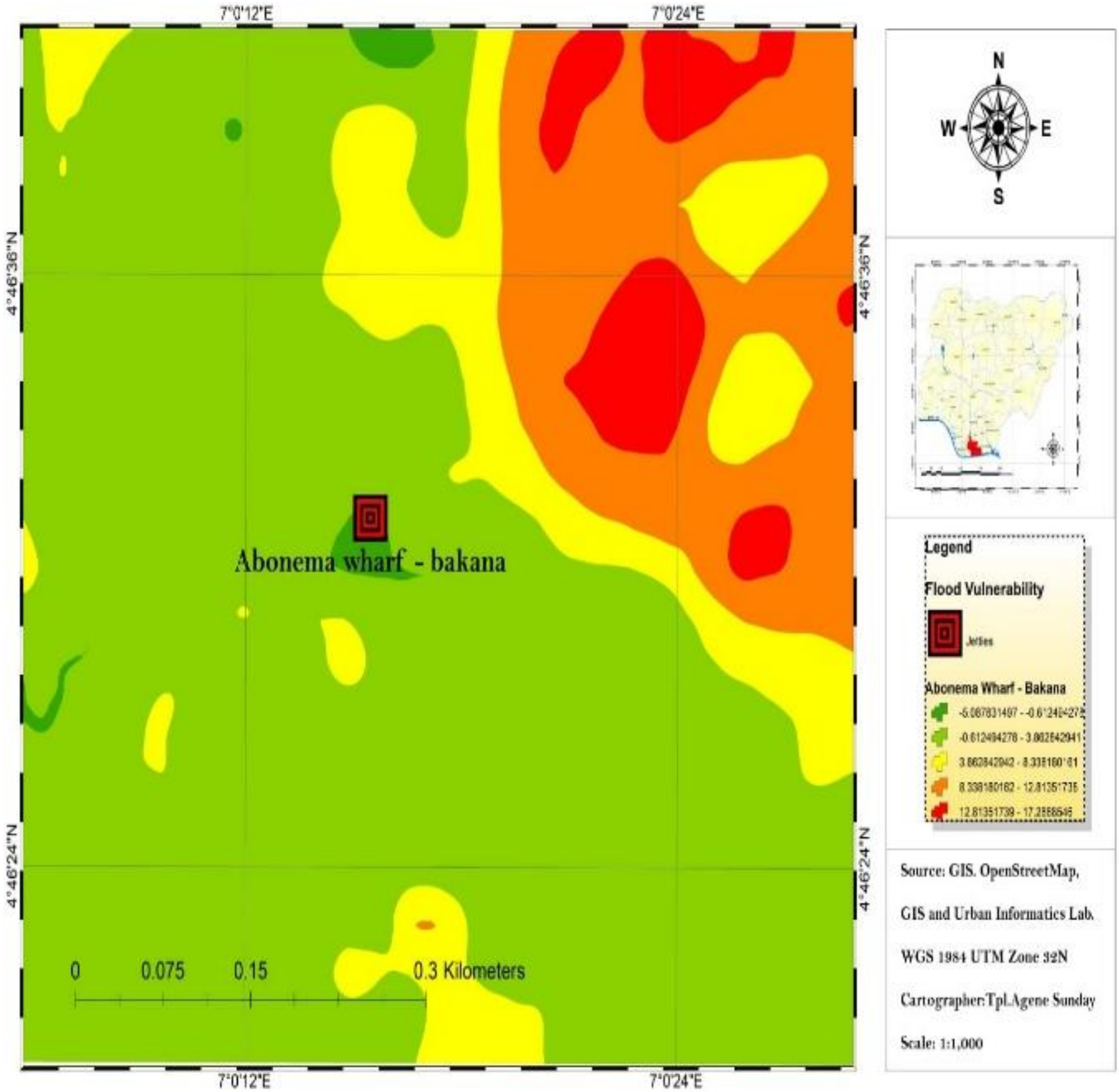


**Figure 5.** Digital elevation model of Abonema wharf to Bakana.

dominating much of the area. Extensive yellow and orange zones reflect exposure linked to flat terrain, poor drainage, and a high groundwater table, all characteristic of the Niger Delta (Uyigue and Agho, 2007). Scattered red patches identify localised extreme-risk areas where both settlements and infrastructure face acute flood threats. Limited green patches denote lower-risk zones, typically located on slightly higher ground or along natural drainage channels. Flooding within this corridor poses major risks to transportation networks, housing, and agricultural land, leading to mobility constraints, food insecurity, and settlement instability. Furthermore, persistent inundation creates favourable conditions for waterborne diseases, including cholera and typhoid, which disproportionately affect vulnerable populations (Barroca *et al*., 2006). Mitigating these risks requires integrated flood management measures, including improved drainage infrastructure, riverbank protection, and stricter land-use planning. The application of GIS-based flood vulnerability mapping in this study provides a critical decision-support

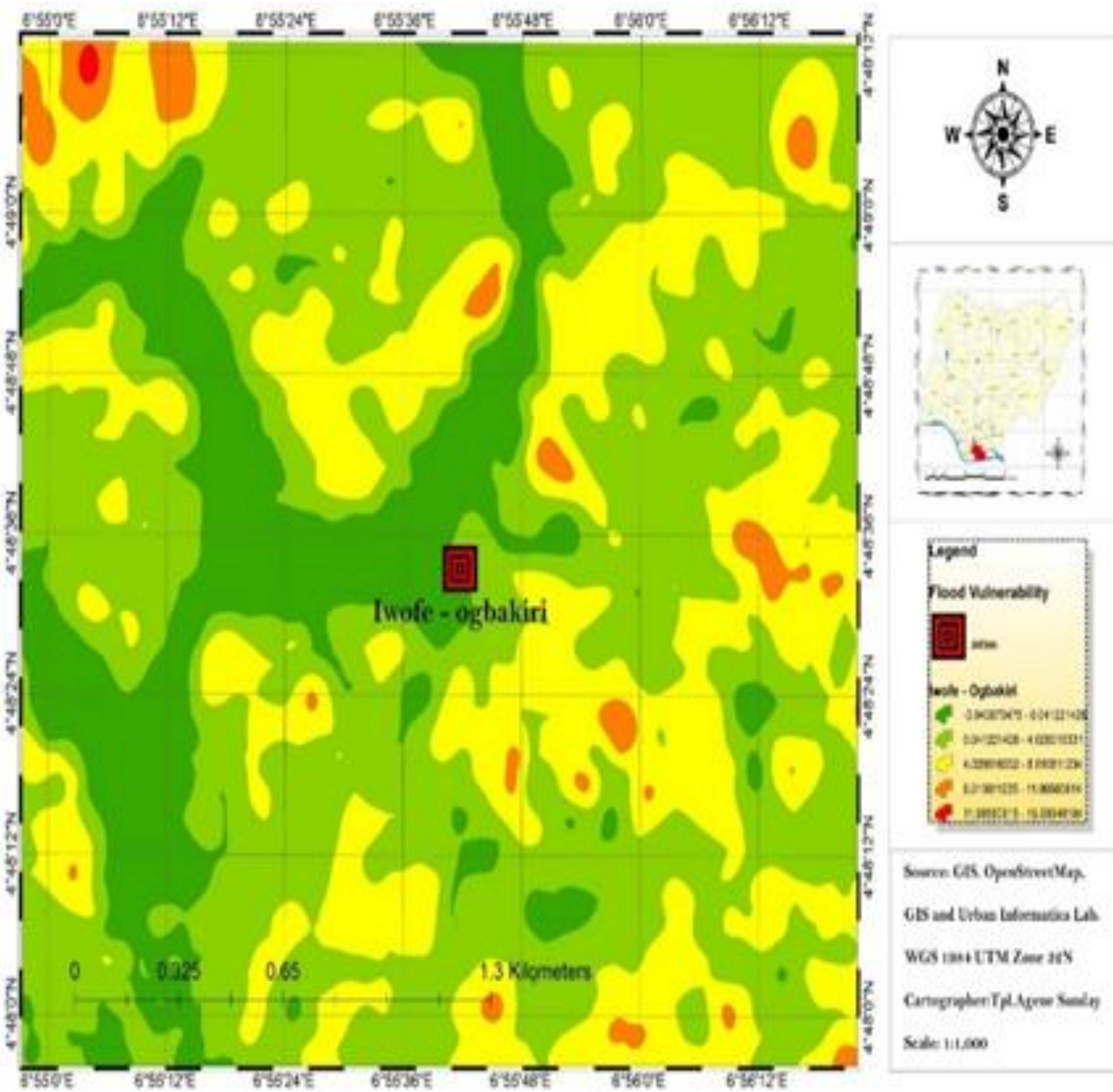


**Figure 6.** Digital elevation model of Iwofe to Ogbakiri.

tool for identifying hazard zones and informing disaster risk reduction (DRR) strategies across Rivers State (Ozegin and Ilugbo, 2025).

### Flood vulnerability assessment of the Marine Base–Okrika and Akpos–Okujagu corridors

The flood vulnerability map of the Marine Base–Okrika (Figure 7) corridor shows a landscape largely dominated by moderate to very high flood risk zones, represented by yellow, orange, and red shades. These zones cover most of the area, reflecting the coastal and estuarine nature of Okrika, where low elevation, tidal surges, and heavy rainfall interact to amplify flood susceptibility (Iyalla, 2001). In contrast, green patches, indicating low-risk zones, are sparse and likely correspond to slightly elevated areas or sites benefiting from artificial drainage systems. The socio-economic implications are profound. Flooding frequently disrupts mobility infrastructure, particularly roads, bridges, and jetties, which are vital for commuting, commerce, and inter-island connectivity. The recurring inundations also jeopardise fishing, trading, and other livelihood activities, while posing risks to oil and gas installations along the corridor (Bello and Ogedegbe, 2015). Furthermore, stagnant floodwaters create breeding grounds for vector-

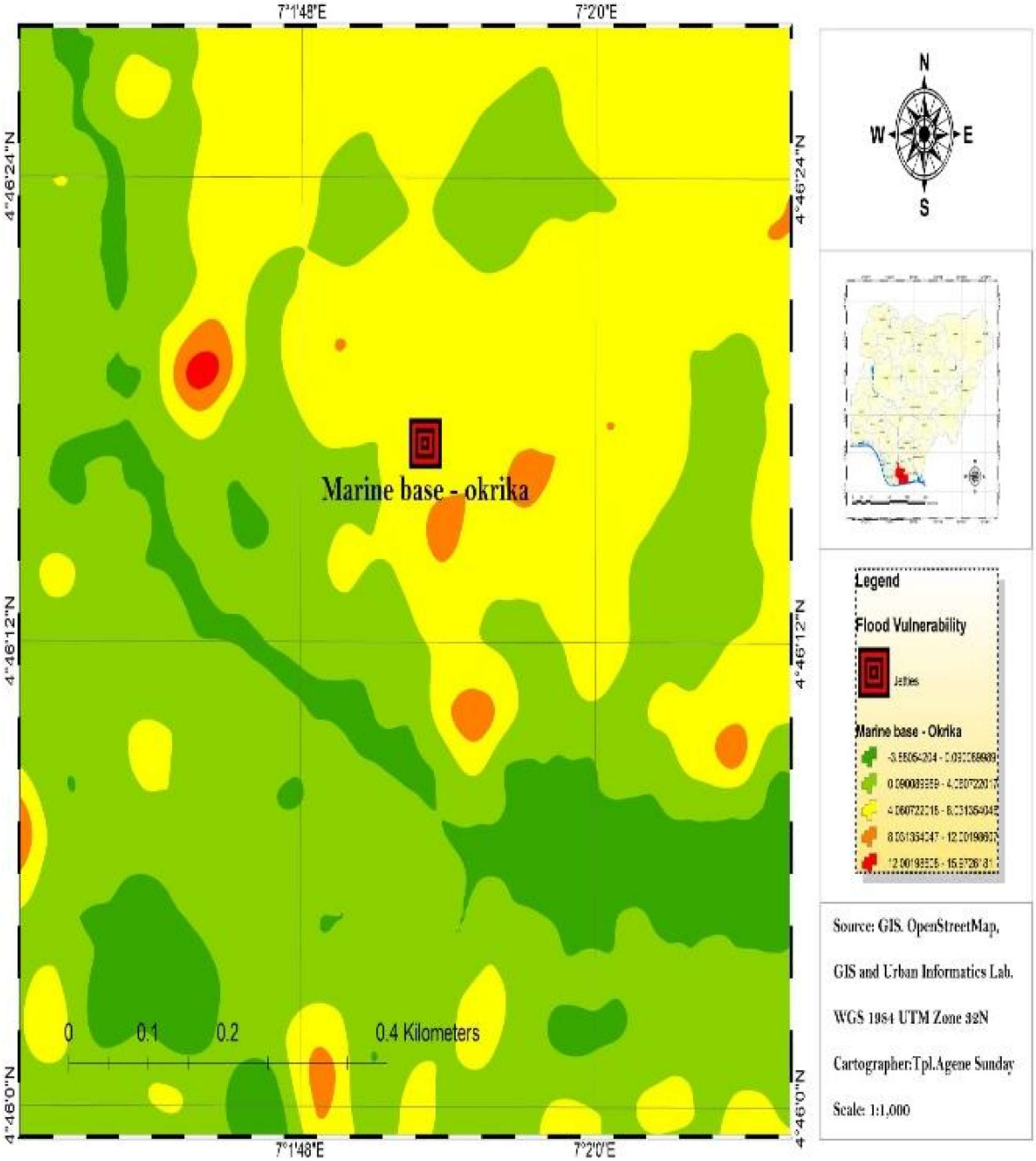


**Figure 7.** Digital elevation model of Marine base to Okrika.

and waterborne diseases, including malaria and cholera. The spatial distribution of flood risk underscores the urgency of proactive flood management. Recommended measures include shoreline protection, construction of effective drainage networks, and enforcement of land-use regulations to minimise exposure. The GIS-based vulnerability mapping used in this study provides a scientific framework for prioritising high-risk zones, guiding resource allocation, and enhancing disaster risk reduction (DRR) and climate resilience strategies in coastal settlements (Wizor and Week, 2020).

The Akpos–Okujagu (Figure 8) corridor exhibits wide-

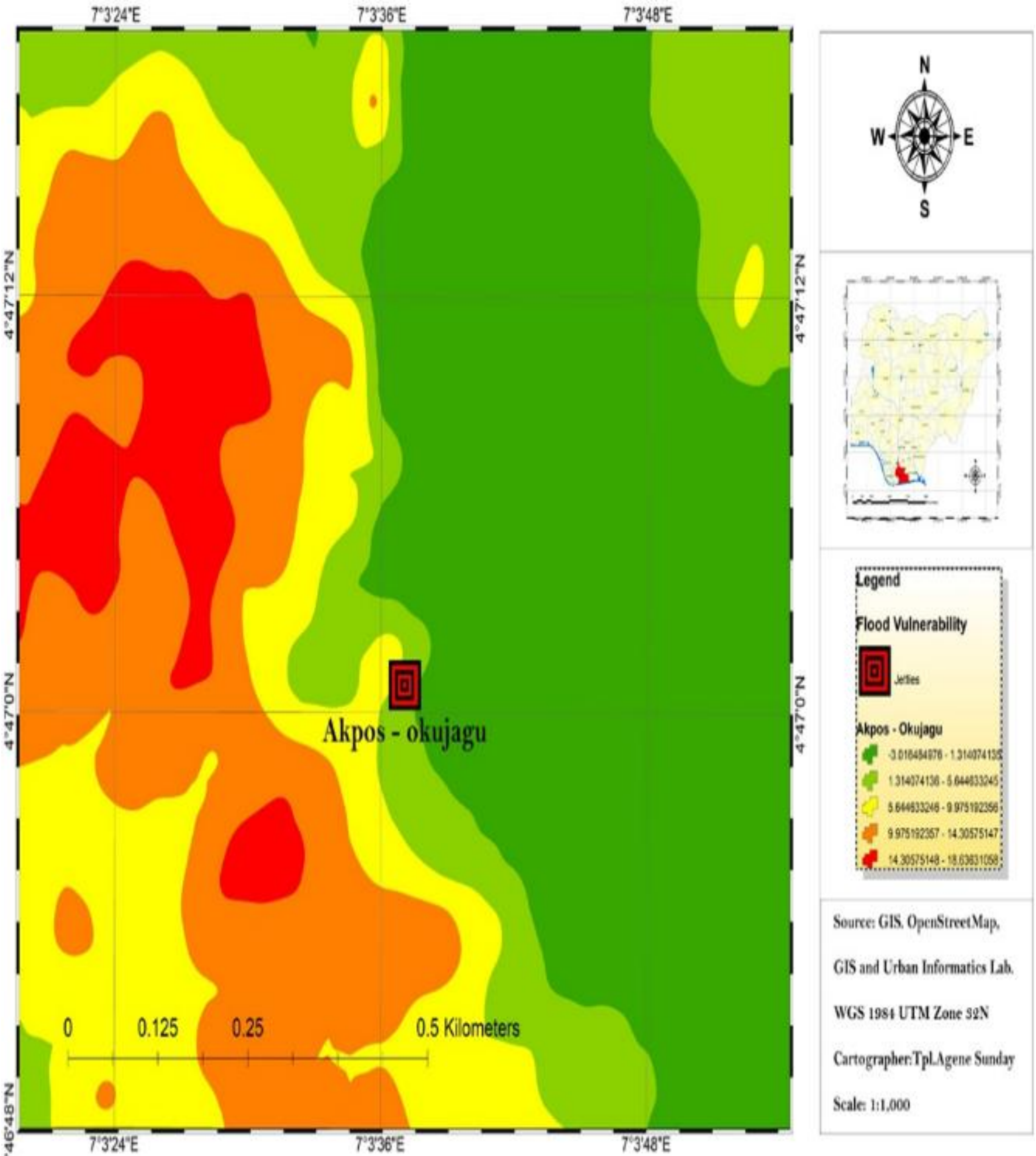


**Figure 8.** Digital elevation model of Akpos to Okujagu.

spread moderate to high flood vulnerability, as reflected by extensive yellow and orange zones. These zones indicate significant exposure linked to swampy terrain, tidal effects, and inadequate drainage, which typify the Niger Delta (Barroca *et al*., 2006). Red patches concentrated in the western section represent very high-risk areas, typically located within low-lying depressions and river channels, while green zones in the eastern areas denote relatively safer terrain. Flooding along this corridor poses multiple challenges. Persistent inundation undermines housing stability, transport access, and local livelihoods, particularly fishing and small-scale agriculture. It also

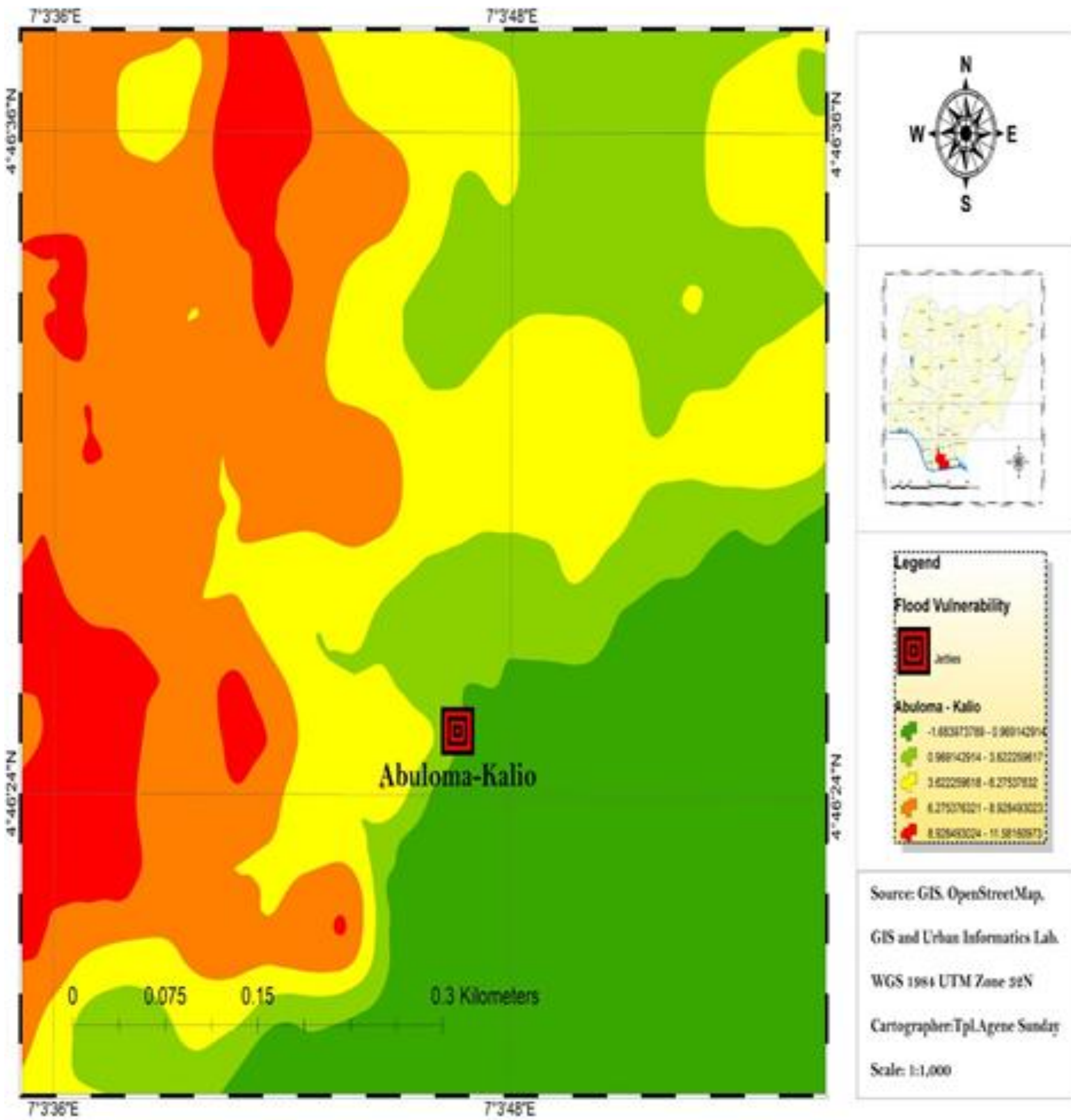


**Figure 9.** Digital elevation model of Abuloma to Kalio.

degrades soil fertility and contaminates drinking water sources, triggering cholera, malaria, and other waterborne diseases (Eze & Igwe, 2020). Addressing these challenges requires community-driven flood risk management, incorporating drainage improvement, shoreline reinforcement, early warning systems, and regulated land-use practices. The GIS-based approach adopted here offers a practical and evidence-based tool for identifying flood hotspots, directing mitigation actions, and building adaptive capacity across the Akpos–Okujagu axis (Wizor and Week, 2020).

**Flood vulnerability assessment of Abuloma–Kalio corridors**

The Abuloma–Kalio flood vulnerability map (Figure 9) displays a landscape dominated by moderate to high flood susceptibility, reflected in extensive yellow and orange zones. Red patches, concentrated around river channels and tidal depressions, mark very high-risk areas where storm surges, tidal inundation, and poor drainage converge to amplify flood exposure. In contrast, green zones indicate relatively safer areas, typically on slightly elevated terrain or in locations with drainage infrastructure (Barroca *et al*., 2006). Flooding along this axis poses major socio-economic threats, disrupting transportation, housing, and livelihoods such as fishing, trading, and small-scale farming. The proximity of Abuloma to oil and industrial installations also raises concerns over potential economic and environmental impacts during severe flood events. Furthermore, stagnant floodwaters foster vector- and waterborne diseases, worsening public health vulnerabilities (Iyalla, 2001). These patterns highlight the urgency of integrated flood management through drainage enhancement, shoreline protection, and effective land-use enforcement. The GIS-based vulnerability assessment presented here offers a vital, data-driven foundation for policy formulation, infrastructure planning, and risk-sensitive development, strengthening resilience across coastal and riverine communities of Rivers State (Wizor and Week, 2020).

## Conclusion

This study shows that using GIS to map flood vulnerability is a powerful way to understand and manage disaster risks along the inland waterways of Rivers State, Nigeria. The spatial analysis revealed clear differences in how much various waterways are at risk, with routes such as Port Harcourt–Bonny, Marine Base–Okrika, Port Harcourt–Nembe, Abonema Wharf–Bakana, and Abuloma–Kalio showing some of the highest levels of exposure. Much of the state's riverine and coastal landscape falls within moderate to very high flood-risk zones because of low-lying terrain, poor drainage, tidal water movement, and human activities common in the Niger Delta. Heavily built-up areas like Port Harcourt–Bonny and Marine Base–Okrika face greater risk, while slightly elevated areas such as Maccoba–Isiaka and parts of Port Harcourt–Nembe are less vulnerable. Communities close to tidal channels and estuaries, including Bakana, Kalio, and Okujagu, often experience repeated flooding, echoing broader findings that the Niger Delta is one of the most flood-prone and environmentally sensitive regions in sub-Saharan Africa.

The findings also stress the importance of including inland waterway routes in disaster-response plans, since many at-risk communities can only be reached by boat. Improving waterway infrastructure, through dredging, protecting embankments, and establishing emergency routes, would make evacuation and response more effective during severe floods. The GIS-based maps created in this study offer practical support for policymakers and disaster-management teams by helping them pinpoint high-risk areas, prioritize interventions, allocate resources more wisely, and strengthen early warning systems. Ultimately, building flood resilience in Rivers State will require a combination of better technology, stronger infrastructure, and active community involvement to support long-term adaptation in a region where water shapes both daily life and disaster risk.

## Recommendations

This study highlights several important steps that can help reduce flood risks and improve disaster response across the inland waterways of Rivers State.

1. Government agencies such as NEMA, RSEMA, and NIWA should use GIS-based flood maps when planning development to ensure safer and smarter decisions.
2. High-risk corridors like Port Harcourt–Bonny, Marine Base–Okrika, and Abuloma–Kalio urgently need better drainage, routine desilting, levees, and stronger shoreline protection.
3. Because many communities can only be reached by water, improving disaster response through well-placed rescue stations, clear boat routes, and floating relief hubs will make emergency access faster and safer.
4. Communities should also be supported with early warning systems, mobile alerts, radio messages, and basic training to help them respond quickly.
5. Finally, enforcing land-use rules, restoring wetlands, and protecting mangroves and forests will reduce flood impacts while keeping the environment healthy.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## REFERENCES


Abam, T. K. S., & Nwankwoala, H. O. (2020). Hydrogeology of eastern Niger Delta: A review. *Journal of Water Resource and Protection*, *12*(9), 741-777.

Adelekan, I. O. (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. *Environment and Urbanization*, *22*(2), 433-450.

Barroca, B., Bernardara, P., Mouchel, J. M., & Hubert, G. (2006). Indicators for identification of urban flooding vulnerability. *Natural Hazards and Earth System Sciences*, *6*(4), 553-561.

Bello, I. E., & Ogedegbe, S. O. (2015). Geospatial analysis of flood problems in Jimeta Riverine community of Adamawa State, Nigeria. *Journal of Environment and Earth*, *5*(12), 32-45.

Elekwachi, W., Phil-Eze, P. O., Etuk, E. A., Wizor, C. H., & Onyishi, C. J. (2021). Spatiotemporal characteristics of wetlands ecosystem in the Niger Delta region. *Journal of Geoscience and Environment Protection*, *9*(12), 244-264.

Gambo, J., binti Roslan, S. N. A., Shafri, H. Z. M., Ya, N. N. C., Yusuf, Y. A., & Ang, Y. (2024). Unveiling and modelling the flood risk and multidimensional poverty determinants using geospatial multi-criteria approach: Evidence from Jigawa, Nigeria. *International Journal of Disaster Risk Reduction*, *106*, 104400.

Iyalla, T. M. (2001). Environmental and hydrogeological mapping; A requirement for the Niger Delta development planning. *Technical paper presented at the Nigerian Society of Engineers' Techincal Session, Port Harcourt, April 12th*.

Jović, M., Duhme, W., Specht, P., & Delmeire, N. (2025). Resilience of Inland Waterway Transport: Towards a Practice-Oriented Repository of Common Threats and Hazards. In *Transport Research Arena Conference* (pp. 240-245). Cham: Springer Nature Switzerland.

Mmom, P. C., & Aifesehi, P. E. (2013). Vulnerability and resilience of niger delta coastal communities to flooding. *IOSR Journal of Humanities and Social Science*, *10*(6), 27-33.

National Inland Waterways Authority (NIWA) (2013). *Harnessing the potentials of inland waterways transport in Nigeria*. NWA Bulletin, Lokoja, 1, 4-8.

Nze, N. J., Ibe C. C., Emenike, G. C., & Nze, I.C. (2021). Estimation of the Likelihood of Accident Occurrence on Inland Waterways Transport in Nigeria's Niger Delta. *Journal of Multidisciplinary Engineering Science and Technology, 8*(11), 14787-14789.

Ogboeli G. P. N., Chilaka, S. N., & Dan, I. C. (2024a). River basin network channel and flood menace control in greater Port Harcourt, Rivers State. *Global Scientific Journal,* 12(12), 47-53

Ogboeli G. P. N., Chilaka, S. N., Abam, T. K. S., Onwuteka, J. N. (2024b). Spatial map flood vulnerability matrix of communities in the greater Port Harcourt. *International Journal Multidisciplinary Research in Science, Engineering and Technology*, *7*(11), 16416-16431.

Ogboeli, G. P., Brown, I., & Onuegbu, W. (2024c). Evincing the Social and Economic Impact of Inland Waterways Transportation in the Development of the Port Harcourt metropolis. *International Journal of Hydrology,* 8(1), 27-35.

Okonkwo, C. N. P., Kumar, L., & Taylor, S. (2015). The Niger Delta wetland ecosystem: What threatens it and why should we protect it? *African Journal of Environmental Science and Technology*, *9*(5), 451-463.

Ozegin, K. O., & Ilugbo, S. O. (2025). Evaluation of potentially susceptible flooding areasleveraging geospatial technology with multicriteria decision analysis in Edo State, Nigeria. *Natural Hazards Research, 5*(1), 109-133.

Samuel, K. J., Yakubu, S., Ologunorisa, T. E., & Kola-Olusanya, A. (2017). A post-disaster assessment of riverine communities impacted by a severe flooding event. *Ghana Journal of Geography, 9*(1), 17-41.

Schwarz, I., & Kuleshov, Y. (2022). Flood vulnerability assessment and mapping: a case study for australia's Hawkesbury-Nepean catchment. *Remote Sensing*, *14*(19), 4894.

Suthakaran, S., Jayakody, S., Subasinghe, S., Seneviratne, N., & Alahakoon, R. (2022). Mapping the flood risk exposure using open-source geospatial tools and techniques: A case of Gampaha Divisional Secretariat Division, Sri Lanka. *Journal of Geoscience and Environment Protection*, *10*(10), 18-31.

Uddin, M. I., Islam, M. R., Awal, Z. I., & Newaz, K. M. S. (2017). An analysis of accidents in the inland waterways of Bangladesh: Lessons from a decade (2005-2015). *Procedia Engineering*, *194*, 291-297.

Uyigue, E., & Agho, M. (2007). *Coping with climate change and environmental degradation in the Niger Delta of southern Nigeria*. A Publication of the Community Research and Development Centre, Nigeria. Pp. 1-30.

Welch, K., Lambert, L. H., Lambert, D. M., & Kenkel, P. (2022). Flood-induced disruption of an inland waterway transportation system and regional economic impacts. *Water*, *14*(5), 753.

Wizor, C. H., & Mpigi, G. L. (2020). Geospatial mapping of urban flood-prone areas in Port Harcourt metropolis: Implications for effective urban physical planning in Nigeria. *World Journal of Innovative Research*, *8*(1), 17-25.

Wizor, C. H., & Week, D. A. (2020). Geospatial mapping and assessment of flood-prone communities in the core Niger Delta, Nigeria. *Asian Journal of Advanced Research and Reports*, *9*(3), 6-20.

Wu, Y., Peng, F., Peng, Y., Kong, X., Liang, H., & Li, Q. (2019). Dynamic 3D simulation of flood risk based on the integration of spatio-temporal GIS and hydrodynamic models. *ISPRS International Journal of Geo-Information*, *8*(11), 520.