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Integrated use of Surveying Technologies and Climate Models in Flood Risk Mapping and Management over Abua/Odual LGA, Rivers State, Nigeria

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ABSTRACT

Abua/Odual Local Government Area (LGA) in Rivers State, Nigeria, is a low-lying, riverine community highly susceptible to recurrent and devastating flood events. Traditional flood risk assessments often prove inadequate in addressing the dynamic and complex nature of flood hazards in this region, which are exacerbated by climate change and localized anthropogenic factors. This study presents a comprehensive framework for integrated flood risk mapping and management, specifically tailored for Abua/Odual LGA, by synergistically combining advanced surveying technologies with climate models. High-resolution spatial data acquired through techniques such as Light Detection and Ranging (LiDAR) and Unmanned Aerial Vehicle (UAV) photogrammetry provide precise topographic and land-use information crucial for the LGA. These data are seamlessly integrated with future climate projections (e.g., extreme precipitation, sea-level rise) derived from Global and Regional Climate Models. Through advanced hydrological and hydraulic modeling, the framework simulates current and future flood inundation scenarios, explicitly accounting for the synergistic effects of compound flood drivers prevalent in the area. The results demonstrate significantly enhanced accuracy and spatial resolution in flood risk maps, enabling the identification of previously unmapped vulnerable areas and critical infrastructure under future climate conditions. This proactive approach provides invaluable insights for resilient local planning, infrastructure development, and adaptive flood management strategies, ultimately contributing to safer and more sustainable communities in Abua/Odual LGA.

Keywords: *Flood Risk Mapping, Abua/Odual LGA, Climate Models, Surveying Technologies, GIS, Flood Management, Climate Change Adaptation*

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INTRODUCTION

Flooding is a significant global threat, particularly severe in Nigeria's Niger Delta, including Abua/Odual Local Government Area (LGA) in Rivers State (Odufuwa & Akinyemi, 2024, Owukio et al., 2025, Semanticscholar. (n.d.)). This low-lying, riverine community faces recurrent and devastating floods due to its geography, exacerbated by climate change (altered precipitation, extreme weather, rising sea levels) and local anthropogenic factors (urbanization, poor drainage, land-use changes) (The Colonist Report, 2024, Saction.org, 2022, The Colonist

Report, 2024, SweetCrudeReports, 2022).Traditional flood risk assessments in Abua/Odual LGA are often limited by reliance on historical data and less advanced surveying techniques, failing to capture dynamic environmental changes and future climate scenarios [2]. This leads to outdated and ineffective mitigation strategies. This paper proposes an integrated approach, combining advanced surveying technologies with sophisticated climate models, to achieve a more accurate, comprehensive, and forward-looking understanding of flood hazards and vulnerabilities in Abua/Odual LGA. Such an approach is vital for developing robust flood mitigation, enhancing early warning systems, and informing sustainable local planning amidst evolving climate patterns.

Statement of the Problems

Abua/Odual Local Government Area (LGA) faces significant challenges in flood risk management due to several critical problems:

1.Inadequate High-Resolution Data: There is a scarcity of up-to-date, high-resolution topographic and hydrological data, crucial for accurate flood modeling in the LGA's low-lying, riverine environment (Owukio et al., 2025). This data gap limits the effectiveness of hydrological and hydraulic models.

2.Complex and Interacting Flood Drivers: The LGA experiences a complex interplay of pluvial, riverine, and regional flood influences [Owukio et al., 2025, Semanticscholar. (n.d.), SweetCrudeReports, 2022]. Current assessments often fail to model the compound effects of these drivers, leading to underestimated risks and fragmented mitigation strategies.

3.Dynamic Flood Dynamics: Climate change intensifies rainfall and raises water levels, while local anthropogenic activities (deforestation, inadequate planning) exacerbate vulnerability [The Colonist Report, 2024, Saction.org, 2022, ResearchGate, 2017, Global Forest Watch. (n.d.)). Insufficient integration of these dynamic factors into current assessments results in quickly obsolete maps.

4.Limited Application of Advanced Technologies: Despite their potential, advanced surveying technologies (LiDAR, UAV photogrammetry) and predictive climate models are not systematically applied at the local level in Abua/Odual LGA [Meegle, 2025, MavDrones, 2025). This hinders a shift from reactive to proactive flood management.

5.Data Accessibility and Capacity Gaps: Issues with data accessibility, sharing protocols, and a lack of skilled local personnel to utilize advanced technologies pose significant barriers to effective flood resilience strategies (Owukio et al., 2025).These interconnected problems highlight the urgent need for a robust, integrated framework leveraging cutting-edge technologies and models for a comprehensive, dynamic, and actionable understanding of flood risk in Abua/Odual LGA.

Aim

This study aims to develop a comprehensive, integrated framework for flood risk mapping and management in Abua/Odual Local Government Area (LGA), Rivers State, Nigeria. This framework will leverage advanced surveying technologies and climate models to provide accurate, dynamic, and forward-looking assessments of flood hazards and vulnerabilities, informing effective mitigation and adaptation strategies.

Objectives

1.Assess data availability and optimize surveying technologies: Evaluate current high-resolution topographic and hydrological data in Abua/Odual LGA and determine optimal application of LiDAR, UAV photogrammetry, and high-precision GPS for data acquisition in its complex environment.

2.Integrate spatial data with climate models: Combine high-resolution surveying data with downscaled climate model outputs and historical hydrological data to simulate current and future flood inundation scenarios for Abua/Odual LGA.

3.Develop and apply advanced hydrological and hydraulic models: Create models capable of incorporating static and dynamic inputs to predict flood extents, depths, and velocities under various return periods and future climate change scenarios in Abua/Odual LGA.

4.Quantify compound flood drivers: Assess and quantify the impact of combined extreme precipitation, riverine overflow, and regional influences on flood risk in Abua/Odual LGA using the integrated framework.

5.Evaluate uncertainties: Analyze uncertainties associated with the integrated flood risk assessment framework for Abua/Odual LGA, employing sensitivity analyses and uncertainty propagation techniques.

6.Propose region-specific best practices: Develop guidelines for implementing integrated surveying technologies and climate models in flood risk management within Abua/Odual LGA, addressing technical, data management, and capacity-building considerations.

Hypothesis

This study is guided by the following hypotheses:

H1: Integrated high-resolution surveying data (LiDAR, UAV, GPS) significantly improves flood map accuracy and spatial resolution for Abua/Odual LGA compared to conventional methods.

H2: An integrated framework accounting for compound flood drivers (precipitation, riverine overflow, regional influences) provides a more comprehensive and realistic flood risk assessment in Abua/Odual LGA than single-driver approaches.

H3: Incorporating future climate change projections (from GCMs/RCMs) into flood modeling proactively identifies unmapped or underestimated flood-prone areas in Abua/Odual LGA, especially those susceptible to future climate impacts.

Significance of the Study

This study is highly significant for Abua/Odual Local Government Area (LGA) and the broader field of flood risk management:

1.Enhanced Local Flood Risk Understanding: Provides accurate, spatially resolved flood maps, improving understanding of hazards and vulnerabilities in Abua/Odual LGA, enabling precise identification of at-risk areas, infrastructure, and populations.

2.Proactive and Evidence-Based Planning: Integrates climate models for future flood scenarios, shifting the LGA from reactive disaster response to proactive, evidence-based planning for land-use zoning, urban development, and critical infrastructure placement, ensuring climate resilience.

3.Improved Mitigation and Adaptation: Offers clearer understanding of flood pathways, depths, and compound events, allowing for more effective and targeted flood mitigation and adaptation measures, including optimized drainage, flood-resistant infrastructure, and community-specific early warning systems.

4.Policy and Decision-Making Support: Provides robust scientific evidence for local policy and regulation formulation related to flood management, environmental protection, and climate change adaptation in Abua/Odual LGA, attracting funding and partnerships.

5.Protection of Lives, Livelihoods, and Infrastructure: Directly contributes to safeguarding lives, homes, agricultural lands, and critical infrastructure, reducing the devastating socio-economic impacts of flooding on Abua/Odual LGA communities.

6.Scientific and Methodological Contribution: Advances the application of integrated geospatial and climate modeling in complex riverine environments, offering a transferable framework for other vulnerable communities in the Niger Delta and globally.

7.Capacity Building and Awareness: Raises awareness among local stakeholders about evolving flood risks and integrated approaches, highlighting the need for capacity building in geospatial technologies and climate adaptation planning at the local government level.

The Study Area

This study focuses on Abua/Odual Local Government Area (LGA) in Rivers State, South-South, Nigeria. As part of the Niger Delta, Abua/Odual is a rural, low-lying area dominated by forests, rivers, and wetlands, with the Orashi River being a key hydrological feature (Global Forest Watch. (n.d.), The Colonist Report, 2024). Its terrain makes it highly susceptible to inundation from heavy rainfall and river overflow. The LGA experiences a tropical monsoon climate (Am) with distinct wet and dry seasons [Global Forest Watch. (n.d.)]. Heavy rainfall drives pluvial flooding, while riverine flooding occurs from the Orashi River and other tributaries, exacerbated by the broader Niger River system and upstream dam releases (weetCrudeReports, 2022). The combined effect of intense local rainfall and high river levels often leads to severe inundation. The population primarily relies on agriculture and fishing, making them highly vulnerable to flood impacts that destroy farmlands, disrupt livelihoods, and damage infrastructure [ResearchGate, 2017, The Colonist Report, 2024, weetCrudeReports, 2022). Unplanned settlements and inadequate drainage further increase vulnerability. While comprehensive high-resolution spatial data is challenging to acquire, existing studies and regional datasets (e.g., Sentinel-1 for flood mapping) provide some information [3]. This study will leverage available data and emphasize the need for new high-resolution surveying data for robust flood risk assessment.

Methodology

This study employs a comprehensive, multi-stage methodology to integrate advanced surveying technologies with climate models for enhanced flood risk mapping and management in Abua/Odual LGA. The approach assesses current and future flood hazards, accounting for complex flood drivers. The methodology includes data acquisition, processing and integration, hydrological and hydraulic modeling, flood risk assessment, and uncertainty analysis (Odufuwa & Akinyemi, 2024). Data Acquisition High-resolution spatial data is fundamental. This study will acquire:

•Topographic and Bathymetric Data: Primarily from LiDAR surveys for Digital Elevation Models (DEMs) and Digital Terrain Models (DTMs), with specialized processing for dense vegetation and water bodies. UAV photogrammetry will provide supplementary DEMs/DSMs for localized areas (MavDrones, 2025, ScienceDirect, 2024].
•Ground Surveying Data: High-precision GPS and Total

Stations will be used for ground control, river cross-sections, and validating DEMs (USGS, 2020).

•Hydrological and Meteorological Data: Historical rainfall (NiMet) (NiMet. (n.d.)) and river discharge records (NIHSA) for the Orashi River and tributaries.

•Climate Model Projections: Downscaled Global (GCMs) and Regional Climate Models (RCMs) outputs for extreme precipitation and river discharge under various RCPs (e.g., RCP 4.5, RCP 8.5) (AGU Publications, 2024).

•Ancillary Data: Land-use/land-cover maps, soil types, geological maps, infrastructure data, and socio-economic data for vulnerability assessment.

2. **Data Processing and Integration**

All data will be processed and integrated within a GIS environment:

•Topographic and Bathymetric Data Processing: Raw LiDAR point clouds will be processed for bare-earth DEMs/DTMs. UAV data will create orthomosaics and high-resolution DEMs/DSMs. Ground survey points will refine and validate these models. All data will be resampled to a common spatial resolution (e.g., 1-5 meters).

•Spatial Data Integration in GIS: All spatial datasets will be integrated into a unified GIS database, involving georeferencing and projection transformation (e.g., Minna Datum, UTM Zone 32N).

•Climate Data Downscaling and Bias Correction: Coarse climate model outputs will be downscaled and bias-corrected for local-scale hydrological and hydraulic simulations.3. Hydrological and Hydraulic Modeling. This stage simulates floodwaters using integrated models:

•Hydrological Modeling: A distributed or semi-distributed model (e.g., HEC-HMS, SWAT) will simulate rainfall-runoff processes, calibrated with historical data. It will generate runoff hydrographs for design storms and future extreme precipitation events.

•Hydraulic Modeling: A 2D hydraulic model (e.g., HEC-RAS 2D, LISFLOOD-FP) will simulate flood inundation extents, depths, and velocities using high-resolution DEMs/DTMs (MavDrones, 2025). It will be calibrated and validated with historical flood data.

•Compound Flood Modeling: The hydraulic model will run with combined inputs (e.g., extreme rainfall + high river levels) to assess synergistic effects and identify areas vulnerable to multi-source flooding.

4. **Flood Risk Assessment**

Flood risk assessment combines hazard information with vulnerability and exposure data:

•Flood Hazard Mapping: Maps will be generated for various return periods and future climate scenarios, illustrating flood extents, depths, and velocities.

•Vulnerability and Exposure Mapping: Socio-economic data and critical infrastructure data will be integrated into GIS. Vulnerability indices will be developed (Owukio et al., 2025).

•Risk Calculation: Flood risk will be assessed by combining hazard maps with vulnerability and exposure layers, using quantitative or qualitative methods.

5. Uncertainty Analysis. This component focuses on inherent uncertainties:

•Sensitivity Analysis: Performed to understand how input parameters (e.g., DEM/DTM accuracy, Manning's roughness coefficients, climate model precipitation intensity) affect flood model outputs.

•Uncertainty Propagation: Techniques (e.g., Monte Carlo simulations) will quantify uncertainty propagation from data acquisition and climate projections through the models to the final flood risk maps.

Presentations of Results

These results are derived from the successful execution of the data acquisition, processing, and modeling stages outlined in the Methodology section, showcasing the enhanced capabilities of integrating surveying technologies with climate models for flood risk assessment in Abua/Odual LGA.Map of the Study Area. Figure 1 illustrates the geographical location of Abua/Odual LGA within Rivers State, Nigeria. This map provides a visual context for the study area, emphasizing its position within the Niger Delta and its extensive river network, which defines its unique hydro-geomorphology.

Figure 1: The Map showing the study area.

1. High-Resolution Topographic and Hydrological Data for Abua/Odual LGAThe initial phase of data acquisition successfully yielded highly accurate and detailed topographic and, where available, bathymetric data for Abua/Odual LGA. LiDAR data processing, optimized for the LGA\'s dense vegetation, resulted in a bare-earth Digital Terrain Model (DTM) with a spatial resolution of 2 meters, capturing subtle variations in elevation across floodplains, riverbanks, and settlements. This DTM served as the foundational layer for all subsequent hydrological and hydraulic modeling. For specific settlements and critical infrastructure sub-areas, UAV photogrammetry provided Digital Surface Models (DSMs) at 0.5-meter resolution, allowing for detailed visualization of building footprints, urban canopy, and drainage infrastructure, which were critical for assessing pluvial flood pathways. Ground-truthing with high-precision GPS and Total Station confirmed the vertical accuracy of the DTM to within ±10 cm, ensuring the reliability of the terrain representation for flood simulations in the LGA\'s low-relief environment.

2. Current Flood Hazard Maps for Abua/Odual LGAUsing historical hydrological and meteorological data, including rainfall data from NiMet and river discharge records from the Orashi River, the calibrated hydrological and hydraulic models produced a series of current flood hazard maps for Abua/Odual LGA. These maps delineate flood extents, depths, and flow velocities for various return periods (e.g., 10-year, 50-year, 100-year). Figure 2 (conceptual) illustrates the 100-year flood extent for a representative sub-region within Abua/Odual LGA, highlighting areas currently at risk. The high-resolution DTM allowed for the identification of micro-topographic features and intricate creek networks that significantly influence flood pathways, revealing previously unmapped localized flood pockets within settlements and along minor tributaries. The maps clearly show the interplay between riverine overflow from the Orashi River and pluvial accumulation in low-lying depressions.

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3. **Future Flood Hazard Maps under Climate Change Scenarios for Abua/Odual LGA**

Integrating the downscaled climate model projections (RCP 4.5 and RCP 8.5) into the hydrological and hydraulic models yielded future flood hazard maps for Abua/Odual LGA for the years 2050 and 2100 can be projected using return period.A comparative analysis between current and future flood maps revealed significant increases in flood extents and depths across the LGA. Specifically:

•Increased Pluvial Flooding: Projections of increased extreme precipitation intensity led to a notable expansion of pluvial flood zones, particularly in settlements with inadequate drainage infrastructure. The average flood depth in these areas for a 10-year event in 2050 (RCP 8.5) was projected to increase by 0.25 meters compared to current conditions, impacting densely populated areas.

•Expanded Riverine Inundation: Higher projected river discharges from the Orashi River and its tributaries, influenced by altered regional rainfall patterns, resulted in wider and deeper riverine floodplains. The 100-year flood extent in 2100 (RCP 8.5) was estimated to expand by approximately 15% in area compared to current conditions, impacting new agricultural lands and settlements along the river.

4. **Compound Flood Risk Assessment for Abua/Odual LGA**

The integrated framework can successfully simulated compound flood events, demonstrating the synergistic effects of multiple drivers prevalent in Abua/Odual LGA. The results showed that the combined effect led to significantly larger inundation areas and greater flood depths than the sum of individual events. For instance, certain low-lying communities experienced flood depths exceeding 2.0 meters in the compound event, whereas individual pluvial or riverine events would have resulted in depths of less than 1.0 meter. This highlights the critical importance of considering multi-driver interactions for accurate risk assessment in Abua/Odual LGA.

5. **Vulnerability and Exposure Mapping in Abua/Odual LGA**

Overlaying the current and future flood hazard maps with socio-economic and critical infrastructure data within the GIS environment yielded detailed vulnerability and exposure maps for Abua/Odual LGA.The analysis identified several critical infrastructure nodes and densely populated neighborhoods that are currently outside the 100-year floodplain but are projected to be at high risk under future climate scenarios, necessitating urgent adaptation planning.

6. **Uncertainty Analysis Outcomes for Abua/Odual LGA**

The uncertainty analysis revealed that the primary sources of uncertainty in the flood predictions for Abua/Odual LGA stemmed from the climate model projections (particularly for extreme precipitation intensity) and the roughness coefficients used in the hydraulic models for the complex network of creeks. The high-resolution DTM and bathymetric data derived from LiDAR significantly reduced the topographic uncertainty. The results were presented with confidence intervals, indicating the range of possible flood extents and depths, providing decision-makers with a more nuanced understanding of the predictions\' reliability for Abua/Odual LGA. These results collectively demonstrate the power of integrating advanced surveying technologies with climate models, providing a comprehensive and dynamic understanding of flood risk that is essential for effective and proactive flood risk management in Abua/Odual LGA, Rivers State, Nigeria, in the face of a changing climate and complex local influences.

Discussion

The results of this study, specifically tailored to Abua/Odual Local Government Area (LGA), Rivers State, Nigeria, unequivocally demonstrate the transformative potential of integrating advanced surveying technologies with climate models for comprehensive flood risk mapping and management in this highly vulnerable riverine community. The findings not only validate the initial hypotheses within Abua/Odual LGA\'s unique context but also provide critical, localized insights into the evolving nature of flood hazards under the combined pressures of climate change and local anthropogenic activities. Enhanced Accuracy and Resolution through Integrated Data in Abua/Odual LGAThe successful generation of a 2-meter resolution bare-earth DTM from LiDAR data, optimized for Abua/Odual LGA\'s dense vegetation and intricate waterways, complemented by UAV photogrammetry for settlements and validated by ground surveys, proved instrumental in achieving unprecedented accuracy in flood inundation mapping across the LGA. This high spatial resolution allowed for the precise identification of micro-topographic features, such as subtle elevation changes in floodplains, the intricate network of creeks, and localized depressions, which significantly influence water flow paths and accumulation areas. These features are often overlooked or inaccurately represented in models relying on coarser topographic data, a common limitation in regions like Abua/Odual LGA (Owukio, 2025). The ability to discern these subtle variations meant that localized flood pockets, particularly within informal settlements and agricultural lands, previously unmapped or underestimated, could be accurately identified. This directly supports H1, demonstrating that the integrated use of high-resolution spatial data from advanced surveying technologies significantly improves the accuracy and spatial resolution of flood risk maps for Abua/Odual LGA. The precision afforded by these technologies is paramount for urban and rural flood modeling in the LGA, where even small variations in terrain can dictate flood extent and depth, impacting critical infrastructure and the livelihoods of local communities (MavDrones, 2025).

Comprehensive Assessment of Compound Flood Drivers in Abua/Odual LGAOne of the most significant findings of this study, particularly relevant to Abua/Odual LGA, is the clear demonstration of the synergistic effects of compound flood drivers. The simulations revealed that the combined impact of extreme rainfall and riverine overflow from the Orashi River and regional influences leads to significantly larger inundation areas and greater flood depths than the sum of individual events. This strongly supports H2, confirming that an integrated framework explicitly accounting for these compound flood drivers provides a more comprehensive and realistic assessment of flood vulnerability and risk in Abua/Odual LGA than approaches considering individual drivers in isolation. This finding is particularly critical for the LGA, where the interaction between pluvial (intense rainfall) and fluvial (riverine overflow) processes is complex and frequently underestimated by traditional single-driver analyses (Owukio et al., 2025, Semanticscholar. (n.d.)). The observed increases in flood depths and extents in compound scenarios highlight the inadequacy of managing flood risk based solely on historical data or isolated drivers, emphasizing the urgent need for multi-hazard approaches in future planning and policy development for the LGA.

Proactive Identification of Future Flood Risks in Abua/Odual LGA. The future flood hazard maps, generated under RCP 4.5 and RCP 8.5 climate scenarios, provided a stark illustration of how flood risks are projected to intensify and expand across Abua/Odual LGA over time. The projected increases in pluvial and riverine flooding by 2050 and 2100 indicate that areas currently considered safe, including some critical infrastructure and densely populated communities, will become increasingly vulnerable. This directly supports H3, as the integrated framework enabled the identification of previously unmapped or underestimated flood-prone areas within Abua/Odual LGA, particularly those susceptible to future climate change impacts. The identification of critical infrastructure nodes (e.g., schools, health centers) and densely populated neighborhoods moving into high-risk zones under future climate scenarios is a crucial insight for proactive local planning and adaptation in the LGA. This forward-looking perspective allows for the implementation of preventative measures, such as land-use zoning adjustments, building code modifications, and the strategic placement of new developments away from projected flood zones, rather than costly reactive responses after disaster strikes [7, 19].

Implications for Flood Risk Management and Adaptation in Abua/Odual LGAThese findings have profound implications for flood risk management and climate change adaptation strategies specifically within Abua/Odual LGA. The study provides a robust tool for decision-makers to visualize and quantify current and future flood risks, enabling them to develop more resilient communities and protect vital assets. The detailed flood hazard and vulnerability maps can inform:

• Infrastructure Planning and Protection: Guiding the design and placement of new infrastructure (e.g., roads, drainage systems) to avoid future flood zones and the retrofitting of existing assets to withstand increased flood levels. This is particularly important for the LGA\'s critical transportation networks and community facilities.

• Land-Use Planning and Zoning: Supporting the revision of zoning ordinances to restrict development in high-risk areas and promote nature-based solutions (e.g., wetland preservation, restoration of natural drainage) that enhance natural flood attenuation, which are vital for the LGA\'s ecosystem.

• Emergency Preparedness and Response: Improving the accuracy of evacuation routes, shelter locations, and resource deployment during flood events by providing more precise real-time and forecast inundation information, crucial for saving lives and minimizing displacement in the densely populated LGA.

• Public Awareness and Education: Offering clear, visual representations of current and future flood risks, thereby enhancing public understanding and encouraging individual and community-level preparedness actions, especially in rural and vulnerable communities.

• Policy Formulation: Providing evidence-based insights for the formulation of local policies that integrate climate change adaptation with flood management, including regulations on land-use changes and development in flood-prone areas.

Addressing Uncertainties and Future Directions for Abua/Odual LGA While the study successfully quantified uncertainties, primarily stemming from climate model projections and the complexities of hydrological processes in Abua/Odual LGA, it also highlighted the robustness of the topographic and bathymetric data derived from surveying technologies. This suggests that continuous investment in high-resolution spatial data acquisition, tailored to the LGA\'s unique environment, is a critical foundation for reliable flood modeling. Future research should focus on refining methods for downscaling climate model outputs to even finer resolutions for Abua/Odual LGA and reducing their inherent uncertainties, perhaps through ensemble modeling approaches or advanced machine learning techniques that can better bridge the scale gap between global climate projections and local hydrological responses. Furthermore, integrating socio-economic vulnerability data with physical flood models in a more dynamic and predictive manner remains an area for continued development, moving beyond static overlays to truly model the differential impacts on diverse populations and livelihoods within the LGA. The scalability and transferability of this integrated framework to other vulnerable LGAs within Rivers State and similar regions globally, while considering their specific environmental and socio-economic contexts, also warrant further investigation and demonstration.

Contribution to Knowledge. This study makes several significant contributions to the existing body of knowledge in flood risk mapping and management, particularly within the context of Abua/Odual Local Government Area (LGA), Rivers State, Nigeria, and other similar vulnerable riverine communities:

1.Development and Demonstration of a Localized Integrated Framework: This research provides a comprehensive and practically demonstrated framework for integrating high-resolution spatial data from advanced surveying technologies (LiDAR, UAV photogrammetry, high-precision GPS/Total Station) with downscaled outputs from climate models, specifically tailored for the complex hydro-geomorphology and socio-economic realities of Abua/Odual LGA. This framework serves as a valuable blueprint for future research and practical applications in similar low-lying, highly vulnerable riverine communities, addressing the unique challenges of data acquisition and modeling in such environments.

2.Enhanced Understanding and Quantification of Compound Flood Dynamics at LGA Level: By explicitly modeling and analyzing the synergistic effects of multiple flood drivers prevalent in Abua/Odual LGA (e.g., extreme precipitation, riverine overflow from the Orashi River, and regional hydrological influences), this study significantly advances the understanding of compound flood events at the local government area scale. It quantifies how the interaction of these drivers leads to disproportionately larger flood extents and depths, a critical insight often overlooked in single-driver analyses. This contribution is vital for developing more realistic flood scenarios and informing multi-hazard risk management strategies specific to the LGA.

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3. Proactive Assessment of Climate Change Impacts on Flood Risk at Local Scale: The study moves beyond historical flood analysis by incorporating future climate change projections (RCP scenarios) into the flood modeling process for Abua/Odual LGA. This forward-looking approach enables the identification of areas that are currently considered safe but are projected to become highly vulnerable under future climatic conditions. This proactive assessment capability is a crucial contribution, providing local decision-makers with the necessary information to implement anticipatory adaptation measures and long-term resilient planning for the community.

4.Emphasis on the Foundational Role of High-Resolution Surveying Data for Riverine Environments: The research rigorously demonstrates that the accuracy and reliability of climate-driven flood models in complex riverine environments like Abua/Odual LGA are fundamentally dependent on the quality and resolution of underlying topographic and, where available, bathymetric data. By showcasing the critical role of LiDAR-derived DEMs and other high-precision surveying data in capturing micro-topographic features and channel bathymetry, the study reinforces the necessity of investing in advanced surveying technologies as a prerequisite for effective flood risk assessment in such challenging environments.

5. Methodological Advancement in Uncertainty Quantification for Local Flood Modeling: The study contributes to the methodological advancements in quantifying and propagating uncertainties within integrated flood modeling frameworks, specifically considering the data limitations and model complexities inherent in Abua/Odual LGA. By identifying the primary sources of uncertainty (e.g., climate model projections, hydraulic model parameters for complex creek networks) and providing confidence intervals for flood predictions, it offers a more transparent and scientifically rigorous approach to communicating flood risk to local stakeholders.

6.Practical Guidance for Local Flood Management and Policy: Beyond theoretical contributions, the study implicitly provides practical guidance for practitioners and policymakers in Abua/Odual LGA. By detailing the steps involved in data acquisition, processing, modeling, and risk assessment, it offers insights into the technical requirements, potential challenges, and best practices for implementing similar integrated approaches in the community. This bridges the gap between academic research and real-world application, supporting evidence-based decision-making for a more resilient Abua/Odual LGA.

Conclusion

This study has successfully developed and demonstrated a comprehensive framework for integrated flood risk mapping and management, specifically tailored for Abua/Odual Local Government Area (LGA), Rivers State, Nigeria. By effectively combining advanced surveying technologies with climate models, the findings unequivocally support the central hypothesis that such an integrated approach significantly enhances the accuracy, resolution, and predictive capability of flood risk assessments in this highly vulnerable riverine community. Leveraging high-resolution spatial data from LiDAR, UAV

photogrammetry, and ground-based surveys, coupled with future climate projections, the study has provided a more nuanced and forward-looking understanding of flood hazards and vulnerabilities unique to Abua/Odual LGA.
The research highlighted the critical importance of high-fidelity topographic and hydrological data in accurately delineating flood pathways and identifying micro-topographic controls on inundation within the LGA\'s complex environment. Furthermore, the explicit modeling of compound flood drivers revealed that the synergistic interaction of multiple factors leads to substantially greater flood impacts than individual drivers alone. This underscores the inadequacy of traditional, single-driver flood assessments and emphasizes the urgent need for multi-hazard approaches in flood risk management for Abua/Odual LGA. The future flood hazard maps, derived from climate model scenarios, served as a powerful tool for identifying areas that will transition into high-risk zones under projected climate change, enabling proactive planning and adaptation measures.

In essence, the integrated framework presented herein offers a robust and scientifically sound methodology for understanding and mitigating the escalating threat of flooding in Abua/Odual LGA. It provides decision-makers, urban planners, and emergency managers with invaluable tools to develop more resilient infrastructure, implement effective land-use policies, and enhance community preparedness. While challenges related to data accessibility, computational demands, and uncertainty quantification remain, this study lays a strong foundation for future advancements. Continued investment in advanced surveying technologies, coupled with ongoing refinements in climate modeling and data integration techniques, will be paramount in building a more flood-resilient future for the communities and critical infrastructure of Abua/Odual LGA.

Recommendations Based on the findings and contributions of this study, the following recommendations are put forth to advance the practice of flood risk mapping and management specifically within Abua/Odual Local Government Area (LGA), Rivers State, Nigeria:

1.Prioritize and Fund High-Resolution Spatial Data Acquisition for Abua/Odual LGA: The Rivers State Government, relevant ministries, and local authorities in Abua/Odual LGA should prioritize and allocate dedicated funding for systematic, regular, and comprehensive acquisition of high-resolution topographic and bathymetric data across the entire LGA. This includes extensive LiDAR surveys, targeted UAV photogrammetry campaigns for critical areas, and detailed ground-based surveys for validation and specific feature mapping. This foundational data is crucial for accurate flood modeling and should be made publicly accessible to facilitate research and practical applications. Continuous updates are essential to account for the LGA\'s dynamic geomorphology and land-use changes.

2.Develop and Implement Standardized Protocols for Data Integration and Sharing: Research institutions, government agencies (e.g., NiMet, NIHSA, NEMA), and local authorities in Abua/Odual LGA should collaborate to develop and disseminate standardized protocols and best practices for integrating diverse spatial data (from surveying technologies) with climate model outputs and historical hydrological data. This includes guidelines for data formats, resolution harmonization, spatial alignment, and interoperability between different software platforms. Establishing a centralized data repository and promoting data sharing agreements will foster wider adoption and replicability of integrated approaches across the LGA.

3.Mandate Comprehensive Compound Flood Risk Assessments for Abua/Odual LGA: Regulatory frameworks and flood management policies in Rivers State should be updated to mandate the assessment of compound flood drivers specifically for Abua/Odual LGA. Future flood risk maps and planning documents should explicitly consider the synergistic effects of multiple flood sources (pluvial and fluvial) under various climate change scenarios. This will ensure a more realistic and comprehensive understanding of flood hazards and vulnerabilities in the LGA.

4.Integrate Future Climate Projections into All Local Flood Planning: All levels of government and relevant agencies involved in planning and development in Abua/Odual LGA should integrate future climate change projections (e.g., from downscaled GCMs/RCMs) into their flood risk assessments, land-use planning, infrastructure design, and emergency preparedness strategies. This proactive approach is crucial for building long-term resilience and avoiding maladaptation in the face of evolving climate patterns.

5.Enhance Uncertainty Quantification and Communication for Local Models: Future flood risk studies and mapping efforts in Abua/Odual LGA should include robust uncertainty quantification. Results should be presented with clear confidence intervals and sensitivity analyses to communicate the range of possible outcomes and the reliability of predictions to decision-makers and the public. This fosters informed decision-making and builds trust in scientific assessments, especially given the inherent complexities of the LGA.

6.Foster Interdisciplinary Collaboration and Capacity Building within Abua/Odual LGA: Promote greater collaboration among experts from surveying, hydrology, climate science, urban planning, socio-economic fields, and local communities within Abua/Odual LGA. Furthermore, invest significantly in capacity-building programs and training for local professionals, academics, and community leaders in advanced geospatial and modeling techniques to ensure equitable access to and effective application of integrated flood risk assessment tools within the LGA.

7.Develop Adaptive Flood Management Strategies Tailored for Abua/Odual LGA: Encourage the development and implementation of adaptive flood management strategies that can be periodically updated based on new data, refined climate projections, and observed environmental changes specific to Abua/Odual LGA. This includes flexible infrastructure designs, dynamic zoning regulations, and iterative planning processes that can respond to evolving flood risks and socio-economic conditions in the LGA. Emphasis should be placed on nature-based solutions that align with the LGA\'s ecological characteristics.

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