climate

MDPI

Article

Geospatial Analysis of Flood Susceptibility in Nigeria's Vulnerable Coastal States: A Detailed Assessment and Mitigation Strategy Proposal

Muhammad Bello [1], Saurabh Singh [1], Suraj Kumar Singh [2], Vikas Pandey [1], Pankaj Kumar [3], Gowhar Meraj [4,*], Shruti Kanga [5,*] and Bhartendu Sajan [2]

1 Department of Civil Engineering, Suresh Gyan Vihar University, Jaipur 302017, India; gidadodougirei@gmail.com (M.B.); saurabh.singh@mygyanvihar.com (S.S.); vikas.pandey@mygyanvihar.com (V.P.)
2 Centre for Climate Change and Water Research, Suresh Gyan Vihar University, Jaipur 302017, India; suraj.kumar@mygyanvihar.com (S.K.S.); bhartendu.sajan@mygyanvihar.com (B.S.)
3 Institute for Global Environmental Strategies, Hayama 240-0115, Japan; kumar@iges.or.jp
4 Department of Ecosystem Studies, Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo 113-8654, Japan
5 Department of Geography, School of Environment and Earth Sciences, Central University, Bathinda 151401, India
* Correspondence: gowharmeraj@g.ecc.u-tokyo.ac.jp (G.M.); shruti.kanga@cup.edu.in (S.K.)

Abstract: This study employs advanced geospatial analytical techniques to evaluate the vulnerability of Nigeria's coastal states and their constituent local government areas to flood hazards, which represent a critical and escalating risk within the coastal hazard paradigm intensified by climate change phenomena. The study's objective is to utilize geospatial data to delineate and quantify the intensity and distribution of flood susceptibility, thus establishing a foundational framework for developing comprehensive disaster management strategies in response to the challenges posed by climate variability. The research uses satellite imagery and geographic information system (GIS)-based hydrological modeling to delineate regions susceptible to flooding, synthesizing topographical and hydrological data to stratify areas into discrete flood susceptibility categories. The findings indicate that the Delta coastal State of Nigeria contains extensive medium to high-risk flood zones spanning 8304.57 km^2. While the Bayelsa coastal State of Nigeria presents critical areas at high to very high flood risk, encompassing 5506.61 km^2 at high risk and 1826.88 km^2 at very high risk, this highlights the urgent necessity for immediate and strategic mitigation measures. This research highlights the critical importance of geospatial technology in shaping disaster management and enhancing community resilience against increasing flood frequencies. As Nigeria's coastal regions face escalating flood susceptibility, advanced geospatial methods are vital for assessing and mitigating these climate-induced threats, contributing to climate-resilient planning and aligning with Sustainable Development Goal 13: Climate Action. The study's geospatial approach delivers precise flood risk evaluations and guides targeted mitigation efforts, marking significant progress in managing coastal hazards in a changing climate.

Keywords: coastal hazard; climate change; geospatial analysis; disaster management; risk assessment; satellite imagery; GIS-based modeling; flood risk mapping

Citation: Bello, M.; Singh, S.; Singh, S.K.; Pandey, V.; Kumar, P.; Meraj, G.; Kanga, S.; Sajan, B. Geospatial Analysis of Flood Susceptibility in Nigeria's Vulnerable Coastal States: A Detailed Assessment and Mitigation Strategy Proposal. *Climate* **2024**, *12*, 93. https://doi.org/10.3390/cli12070093

Academic Editors: Vasiliki K. Tsoukala and Michalis K. Chondros

Received: 4 May 2024
Revised: 20 June 2024
Accepted: 25 June 2024
Published: 27 June 2024

1. Introduction

Flooding is one of Earth's worst forms of natural disaster [1]. Nigeria has seen many flood events in recent years, and due to the high level of vulnerability and lack of coping capacity of the people, extreme events caused by climate change are putting many lives and properties at risk [1,2]. This escalating challenge underscores the critical need for innovative and improved flood risk management strategies adept at navigating the complex terrain of environmental adversity [3]. Flood destructions also hit roads and cause delays to infrastructure development initiatives and political processes [4]. A flood event may result in physical damage to the building stock, essential facilities, transportation systems, utilities, and agriculture [5,6]. Flooding is linked to a multitude of infectious diseases caused by the pollution of water sources, which can result in the spread of waterborne illnesses such as cholera, dysentery, and typhoid fever [7–9] Climate change and global warming have attained a global dimension, frequently occupying the agendas of the United Nations and other international bodies [10]. The intensifying peril of global climate change, mainly attributable to anthropogenic actions, represents an escalating threat to the international community [11]. According to the Climate Change Knowledge Portal, Figure 1 shows the distribution of natural hazard occurrences in Nigeria from 1980 to 2020. Floods represent a significant threat, accounting for 33% of the incidents. With 54 recorded flood events over 40 years [12], the data emphasize the importance of prioritizing flood management strategies. These figures underscore the urgency of incorporating geospatial technologies into flood risk assessment to bolster Nigeria's preparedness and response to one of its most persistent natural hazards.

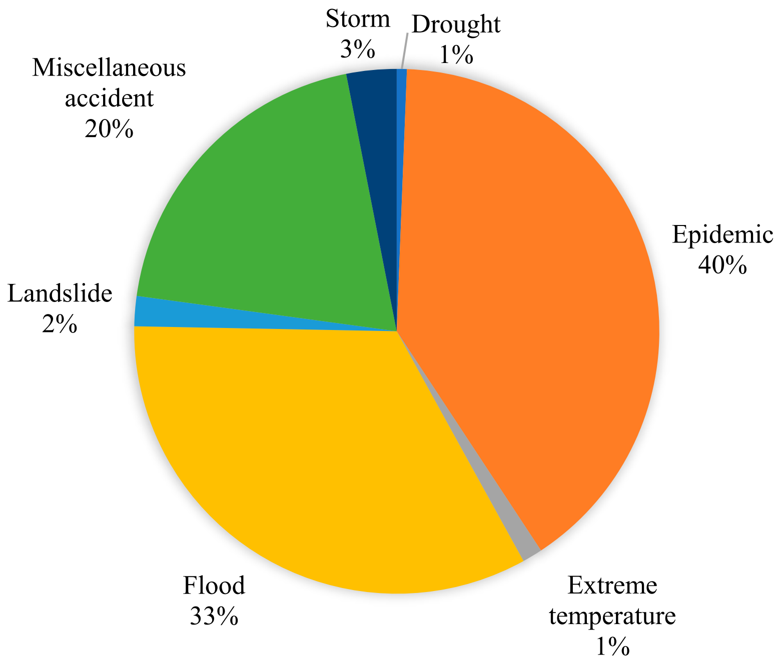

Figure 1. Average annual natural hazard occurrence from 1980 to 2020 in Nigeria.

Figure 2 shows the more profound consequences of flooding, offering a comprehensive breakdown of its severity for households regarding property loss, transportation disruption, interruption of power and water supplies, food stock depletion, and the tragic loss of lives and livelihoods. This detailed analysis serves as a critical tool for understanding the multifaceted impact of floods on communities, informing the development of nuanced disaster management strategies that address the unique challenges each affected state faces. Table 1 quantifies the extent of damage to the Bayelsa and Delta coastal states regarding property loss, transportation disruption, power and water supply interruptions, food stock losses, lives lost, and job disruptions. Through this detailed enumeration, the table sheds light on the differential vulnerabilities and the multifaceted nature of flood impacts, revealing critical areas of concern for disaster management and resilience-building efforts.

Among the ten largest countries worldwide, Nigeria is growing the most rapidly. Consequently, the population of Nigeria, currently the world's seventh largest [13], is projected to surpass that of the United States and become the third-largest country in the world shortly before 2050 [14]. The 2022 Nigeria floods are believed to be the worst floods the country has experienced in at least a decade, with a widespread impact in 33 of its 36 states, damaging homes and infrastructure, destroying farmland, and displacing people from their communities [15]. According to IFRC reports, as of 8 October 2022, about 2.8 million individuals were impacted by the flood, at least 6123 lives were lost, and more than 2500 people sustained injuries. An estimated two million people fled while others were evacuated from high-risk locations, taking just what they could carry with them and ending up in deplorable conditions with inadequate safeguards, exposing them to protection concerns. After several months, many affected people still need food, shelter, water, sanitation, and support to rebuild their livelihoods [16] The multifaceted nature of flood risk and its management in Nigeria has been the subject of extensive research, highlighting the challenges and potential pathways for more effective disaster management strategies. Nkwunonwo et al. (2016) delve into the intricacies of urban flood risk management in Lagos, Nigeria, covering a period from 1968 to 2012. Despite the considerable damage inflicted by floods, the study reveals persistent challenges arising from inadequate data, limited public awareness, and a lack of sufficient knowledge on mitigation strategies. The review evaluates the current state of understanding and proposes recommendations for future actions [17].

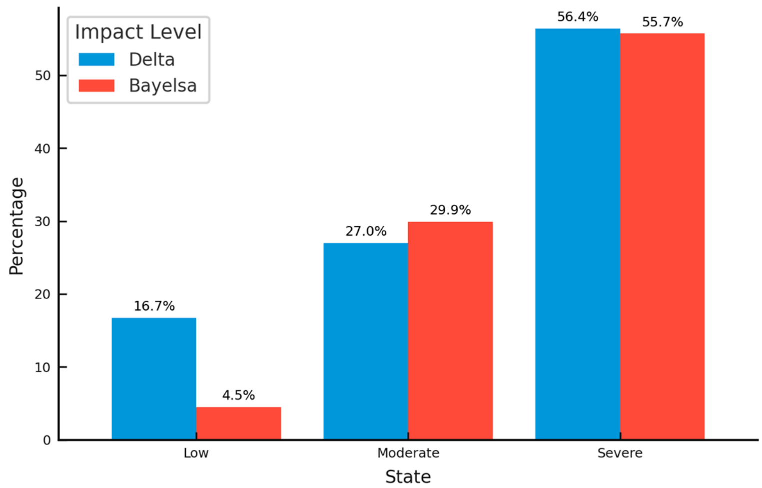

Figure 2. Detailed analysis of flood impact severity on households.

Table 1. Distribution of households showing various impacts of the floods (%).

State	Property Loss	Transport Disruption	Power Supply Interruption	Water Supply Interruption	Food Stock Loss	Lives Loss	Jobs Loss
Bayelsa	53.3	57.6	9.3	15.4	59.6	73.5	3.7
Delta	50.2	30.9	11.3	10.9	65.3	51.2	9.6

Similarly, studies have undertaken vulnerability assessments of urban dwellers in Abeokuta, Nigeria, following a significant flood event in July 2007. Employing a questionnaire survey with 248 residents, the study assesses vulnerability through exposure, susceptibility, and coping mechanisms. Findings indicate that despite 50% of respondents having experienced floods before, a staggering 66% were unprepared for the 2007 flood, with only 8% receiving any pre-warning. The predominant response to the flood was reactive, primarily due to a lack of pre-existing risk reduction measures, underscoring the pressing need for proactive disaster preparedness and management strategies in flood-prone locales. Furthering this discourse, Studies have scrutinized the public health impacts of flood disasters in Nigeria and the efficacy of existing disaster management strategies. Results have pointed out to a significant void in effective institutional frameworks capable of addressing flood emergencies, with diarrhea outbreaks signaling the health risks associated with such events [18]. The review advocates for a comprehensive approach that includes the active participation of all stakeholders, especially from the health sector, to bolster disaster management planning and mitigate health implications [18]. Nkeki et al. (2022) [18] introduce a groundbreaking approach to flood risk mapping and assessing urban infrastructural susceptibility in the Ona River Basin, Nigeria. By applying GIS and HEC-RAS methodologies, the study synergizes hydraulic and integrated models to refine predictive accuracy. The findings suggest that 48.2% of the basin is at moderate to very high flood risk, particularly in areas with dense infrastructure, offering invaluable insights for prioritizing flood management and mitigation efforts [19].

Su et al. (2024) present an innovative UAV-mounted multi-sensor system for levee inspection, integrating thermal infrared, RGB cameras, and LiDAR to enhance the efficiency and safety of structural assessments. This approach addresses traditional method limitations by offering real-time, comprehensive data acquisition. The proposed multi-level hazard detection algorithm, validated through field inspections, significantly advances levee monitoring and disaster management practices [20]. Safabakhshpachehkenari et al. (2024) assess future flood susceptibility in Japan's Ibaraki coastal region by forecasting land-use changes and their impacts by 2030 using DioVISTA 3.5.0 software. The results show increased built-up areas and grassland and urban cover variations under different urban development scenarios. The simulations predict significant residential area flooding, with the extent varying across scenarios. The findings help target future flood prevention measures [21]. Singh et al. (2023) utilized remote sensing and the Digital Shoreline Analysis System (DSAS) to evaluate shoreline changes in South Andaman from 1990 to 2023, focusing on the impact of the 2004 tsunami. Analysis of Landsat-7 and Google Earth imagery provided data on erosion and accretion rates [22]. Musa et al. (2019) further contribute to the dialogue by examining the impact of flooding on land use and land cover (LULC) along the Benue River in Adamawa State, Nigeria. Leveraging satellite imagery from different years, the study produces LULC maps through supervised classification, identifying significant alterations in farmland and vegetation. The research underscores the necessity of relocating agricultural activities away from flood-prone areas to combat food insecurity after flooding events [19]. According to the comprehensive insights provided by the Nigeria Flood Impact, Recovery and Mitigation Assessment Report 2022–2023, an overwhelming 64 percent of households grappled with the aftermath of the 2022 floods. The impacts of this calamity spanned a broad spectrum, touching upon livelihoods, housing stability, food security, and access to essential services, including health facilities and educational institutions [23]. In the 2022 floods, rural areas of the two coastal states experienced significant impact, with 74% of households affected, compared to about 40% in urban areas. Bayelsa was particularly hard-hit, with a majority of residents affected. This stark contrast highlights the region's vulnerability and the critical need for targeted flood preparedness and intervention strategies.

Despite numerous studies on flood risk, there remains a significant gap in utilizing high-resolution geospatial data for flood hazard assessment in Nigeria's coastal regions. Current methodologies often lack the integration of advanced remote sensing data and detailed topographical analysis, which are crucial for accurately predicting and managing flood susceptibility in these highly vulnerable areas. This research is particularly significant as it enhances the predictive capabilities of flood risk assessments using state-of-the-art geospatial technologies. By providing a more detailed and accurate mapping of flood-prone areas, the study aids in better planning and implementing mitigation strategies. This is vital for improving the resilience of communities, reducing the economic impact of floods, and safeguarding lives and infrastructure against future flood events. The primary objective of this study is to develop a comprehensive and adaptable flood risk assessment model that leverages high-resolution satellite imagery and GIS-based hydrological modeling. This model offers a robust tool for disaster management authorities to identify risk levels and prioritize intervention areas effectively. By doing so, it seeks to guide strategic planning and policymaking in flood management, contributing to enhanced preparedness and response strategies in Nigeria and similar settings worldwide.

2. Materials and Methods

2.1. Study Area

The geographical focus of the study encompasses two coastal states within Nigeria, namely Delta and Bayelsa, as shown in Figure 3, each selected for their pronounced vulnerability and the extensive damage they sustained during the 2022 flood events [24]. These regions, characterized by their distinct topographical and hydrological features, offer a comprehensive perspective on the varied impacts of flooding across different environmental and socio-economic contexts within the country. Delta State is situated in the southern portion of Nigeria and is distinguished by its extensive coastline along the Bight of Benin, coupled with a complex network of river systems. This configuration subjects the state to heightened flood susceptibility, particularly in areas proximate to the coastline and riverbanks, thereby necessitating a focused analysis of the challenges of managing flood susceptibility in coastal and riverine environments. Bayelsa State, located in the southern delta region, predominantly comprises riverine and low-lying plains. Its geographic makeup renders it highly susceptible to flooding, with the 2022 floods inflicting considerable damage on the region. The state's experience underscores the need to understand flood dynamics in deltaic environments, where water flows from multiple sources converge and interact.

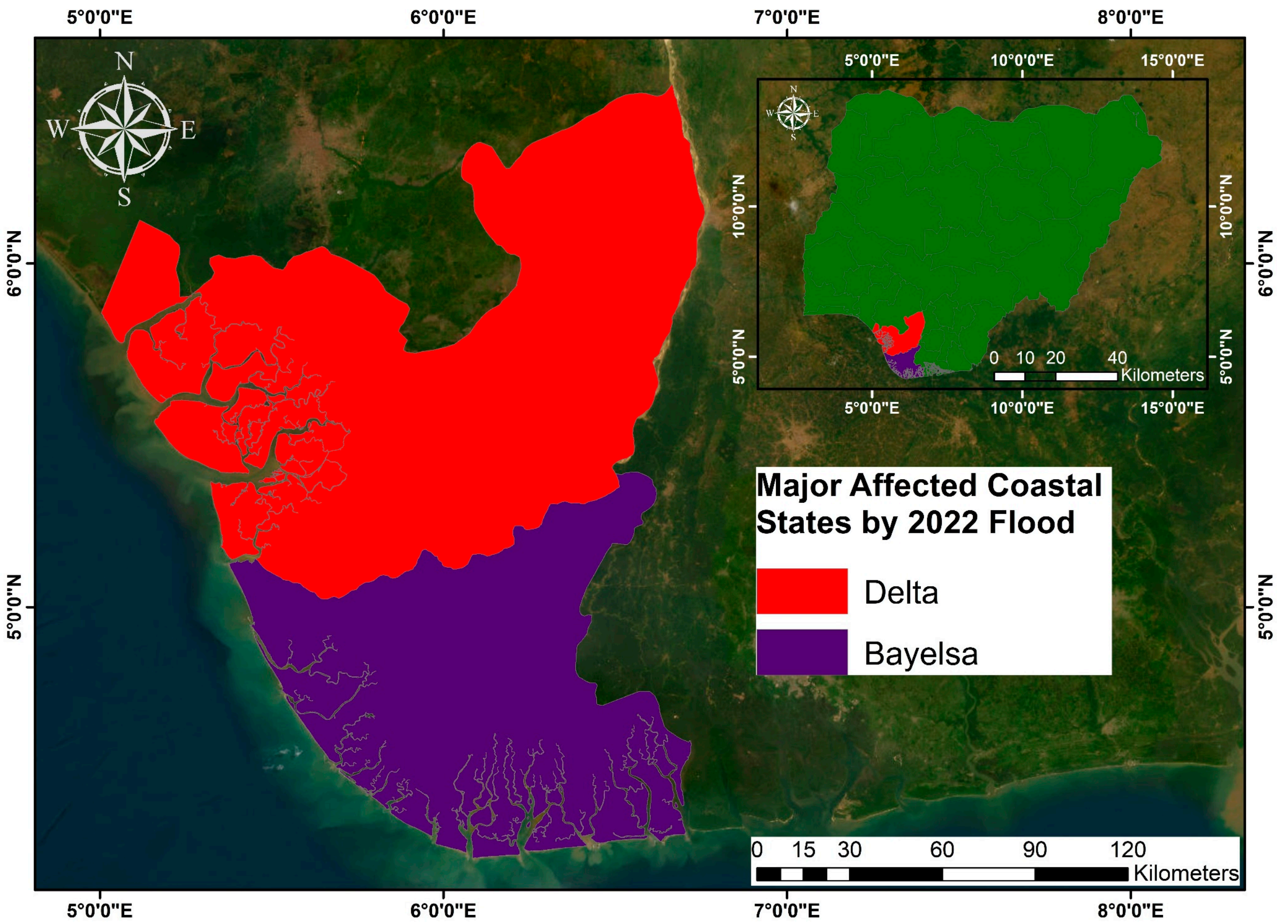

Figure 3. Extent of the 2022 flood impact on the coastal states of Delta and Bayelsa.

The selection of these states provides a diversified yet coherent framework for assessing flood risk and management in Nigeria. By analyzing these varied geographic contexts, this study aims to generate insights that are not only relevant to the specific states under consideration but also applicable to other regions facing similar flood-related challenges. Through this approach, the research seeks to contribute to the development of effective, context-sensitive strategies for flood risk management and disaster preparedness in Nigeria and comparable settings globally.

2.2. Methodology for Flood Susceptibility Assessment Using Google Earth Engine

This section elaborates on the systematic approach employed to assess flood susceptibility in Nigeria's vulnerable coastal states using Google Earth Engine (GEE). The methodology integrates several geospatial data analyses and modeling techniques to thoroughly understand flood dynamics within the study area. Key processes include the use of the Joint Research Centre (JRC) Global Surface Water dataset, processed at a 30 m resolution, to identify permanent water bodies by detecting areas where water was present for at least 80% of the observable period from 2015 to 2020. The distance from these water bodies is measured using a fast distance transform method at the same resolution, providing foundational data for flood risk assessment based on proximity. Elevation and topography are analyzed using Shuttle Radar Topography Mission (SRTM) data at a 30 m resolution to classify terrain vulnerability, particularly in lower elevations near water bodies. Vegetation health and surface moisture are evaluated using NDVI and NDWI indices derived from 2022 Landsat 8 imagery, also at a 30 m resolution, to identify areas at increased flood risk. These indices form a composite susceptibility that delineates areas into varying risk levels from very low to very high, which are then visualized on the final flood risk maps generated at a detailed 30 m resolution. This comprehensive mapping and assessment process is visually organized in a flowchart (Figure 4), which succinctly illustrates the data collection, processing methods, and output integration, ensuring clarity and actionable insights for disaster management and planning.

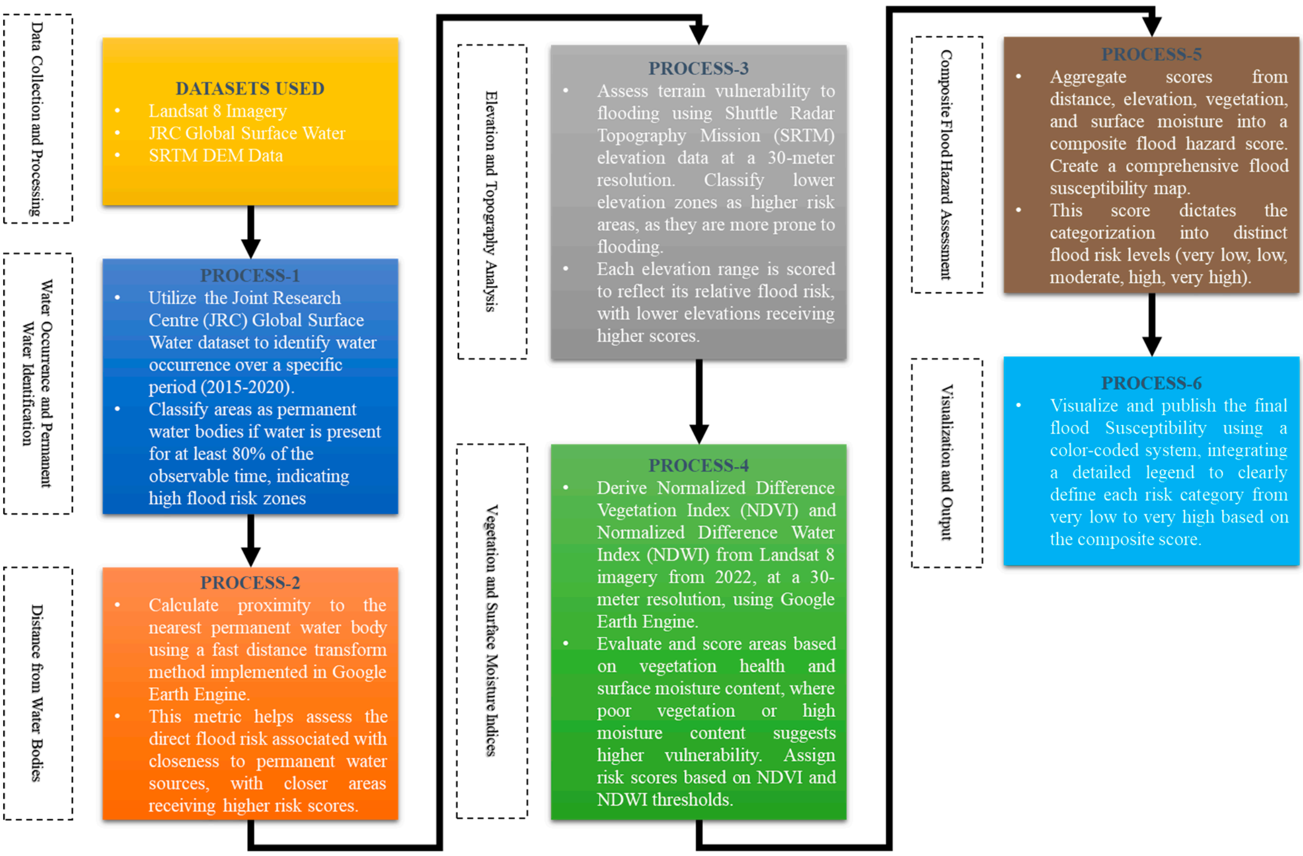

Figure 4. Flowchart diagram showing the methodology for flood hazard score risk map.

2.2.1. Geospatial Data Collection and Processing

Data collection and processing were performed using Google Earth Engine (GEE) to handle various datasets, enabling the dynamic geospatial analysis necessary for comprehensive flood hazard assessment.

2.2.2. Water Occurrence and Permanent Water Identification

The JRC Global Surface Water dataset was utilized to map the occurrence of water bodies across the study area. Areas where water was present for at least 80% of the observable period between 2015 and 2020 were identified and classified as permanent water bodies using the expression var permanent = water.gt (80). This classification was crucial for identifying regions at higher risk of flooding, as permanent water bodies are critical contributors to flood dynamics. The choice of these specific years ensures a contemporary understanding of water body dynamics essential for accurate flood risk assessment.

2.2.3. Distance from Water Bodies

The proximity of geographic areas to the nearest permanent water bodies was calculated using a fast distance transform method. This proximity measure provided a foundational layer for assessing flood risk, given that closeness to water bodies is a critical factor in flood susceptibility. The calculation was performed with the code var distance = permanent.fastDistanceTransform().divide(30).clip(roi), which standardized the distance measurement, making it a pivotal component in the risk analysis framework.

2.2.4. Elevation and Topography Analysis

Elevation data from the SRTM were processed to assess the terrain's vulnerability to flooding. Areas with lower elevations are generally more susceptible to flooding due to water accumulation during flood events. Elevation data were categorized and scored to reflect varying degrees of flood risk, with lower elevations assigned higher risk scores, as demonstrated in the expression var elevScore = elevation. where (elevation.lte(5),5).

2.2.5. Vegetation and Surface Moisture Indices

The Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI) were derived from Landsat 8 imagery to assess vegetation health and surface moisture, respectively, for the year 2022. These indices are critical flood risk indicators, with poor vegetation or high moisture content suggesting higher vulnerability. Areas with undesirable vegetation health or significant moisture were assigned higher risk scores, as outlined by the code var vegScore = ndvi.where(ndvi.lte(0.2),5). Utilizing data from a specific recent year minimizes the impact of annual climatic variation and ensures the relevance of the vegetation and moisture assessments in current flood risk evaluations.

2.2.6. Composite Flood Susceptibility Assessment

Scores from distance to water, elevation, vegetation health, and surface moisture were aggregated to create a composite flood hazard score. This integrated approach allowed for delineating areas at varying risk levels from very low to very high, providing a nuanced view of flood vulnerability across the study area. This was achieved through the code var floodHazard = distanceScore.add(topoScore). add(vegScore).add(wetScore).add(elevScore), which combines individual risk factors into a comprehensive flood susceptibility map.

2.2.7. Visualization and Output

To enhance the interpretability of our flood susceptibility maps for decision-making, the maps are rendered using a color-coded schema that delineates various risk categories from very low to very high. Each risk category is associated with a specific color range, facilitating the immediate visual recognition of risk areas. A comprehensive legend explaining this color-coding system is now prominently featured within Figure 5 and alongside the map displays. This update ensures that stakeholders with varying levels of technical expertise can easily access and interpret the maps. The integration of a clear legend and distinct color-coding not only improves the usability of these visual data in strategic planning and risk management but also addresses the need for clarity in communicating complex geospatial information. These enhancements aim to make the flood risk maps more actionable and informative, thereby significantly increasing their utility in practical applications.

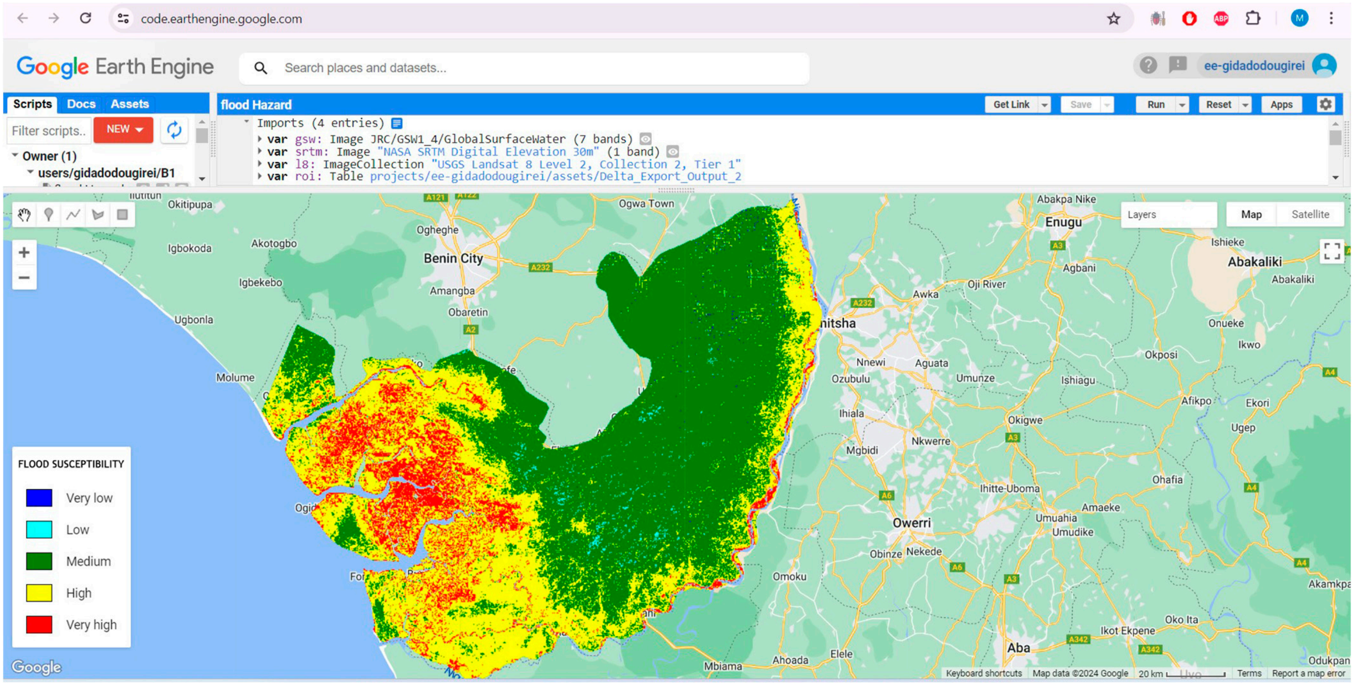

Figure 5. Google Earth Engine visualization of flood susceptibility map.

3. Results

3.1. Delta State Flood Risk Assessment

This section provides a detailed flood hazard assessment for Delta State, Nigeria and explored through the "Flood hazard score risk map of local coastal government area of Delta State" in Figure 6. The assessment comprehensively evaluates the terrain categorized by varying levels of flood risk, offering clear visualizations ranging from the most vulnerable to the least affected areas. The maps highlight different regions within Delta State according to their susceptibility to flooding, with risk levels spanning from very low to very high. This segmentation underscores the imperative for strategic flood risk management tailored to the state's diverse geographical landscape. The assessment serves as a foundation for prioritizing mitigation strategies and directing resource allocation to bolster resilience and preparedness efforts across Delta State.

Figure 6 shows the flood hazard score risk maps for various local government areas within Delta State, delineating the array of flood susceptibility. Figure 6a shows Burutu, where the risk levels are color-coded from blue for very low risk to red for very high risk. Figure 6b focuses on Warri North, highlighted extensively in red to indicate very high flood susceptibility. Figure 6c covers Warri South West, with significant red patches denoting areas at greatest flood risk. Each map includes tools like a compass rose and a scale bar that help contextualize the geographic spread of risks. The precise visual categorization aids stakeholders in effective disaster management and risk mitigation planning. The comprehensive flood susceptibility assessment for coastal Delta state, Nigeria, is shown in Figure 7. The distribution of flood susceptibility levels in the coastal Delta region is shown in Figure 8.

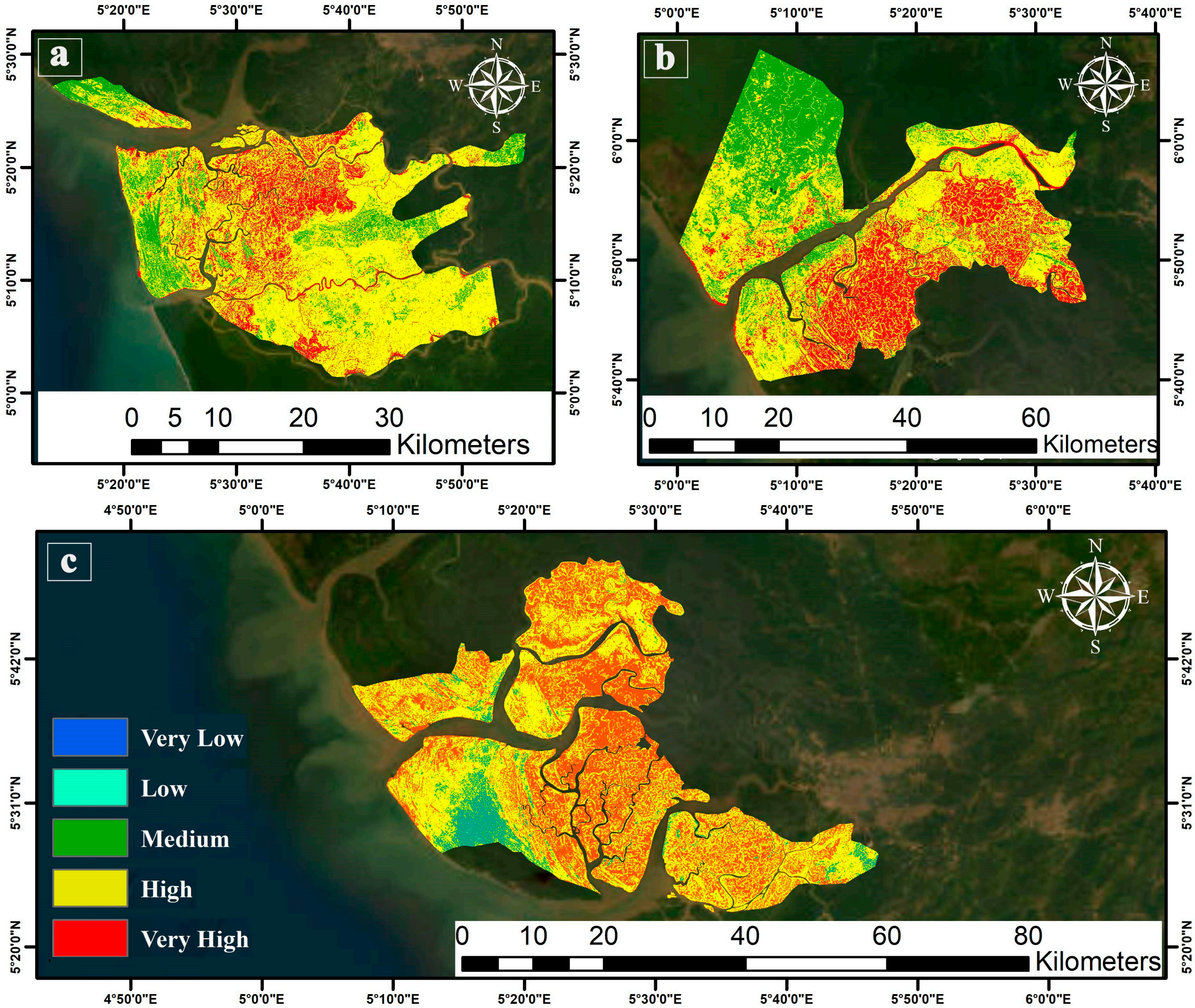

Figure 6. Flood susceptibility map of local coastal government area of Delta State. (**a**) Flood susceptibility map of Burutu; (**b**) flood hazard score risk map of Warri North; (**c**) flood hazard score risk map of Warri South West.

The map divides coastal Delta State, Nigeria, into regions with varying flood susceptibility. High-risk areas cover a substantial 5905.62 km^2, indicating the regions most likely to experience significant flooding. Medium-risk areas, which face less-severe but still noteworthy flooding, span 8304.57 km^2 of Delta State. In contrast, low-risk areas, susceptible to infrequent or minor flooding, cover 259.87 km^2. The very high-risk areas, most prone to catastrophic flooding, encompass 1983.21 km^2. Areas with very low risk, least expected to be affected by flooding, are minimal, covering only 10.37 km^2. This detailed distribution is crucial for policymakers, urban planners, and disaster management professionals, guiding strategic planning to enhance flood resilience and emergency responses across the diverse landscape of Delta State.

The quantitative distribution of flood hazard risk levels in the coastal Delta region provides a detailed statistical analysis of the extent of areas under different risk categories. This quantitative breakdown aids in prioritizing areas for intervention and resource allocation, allowing stakeholders to focus on regions with the highest need for flood mitigation and preparedness strategies. The visualization and accompanying data are essential for implementing targeted flood risk management initiatives, fostering a proactive approach to enhancing community resilience against flood hazards.

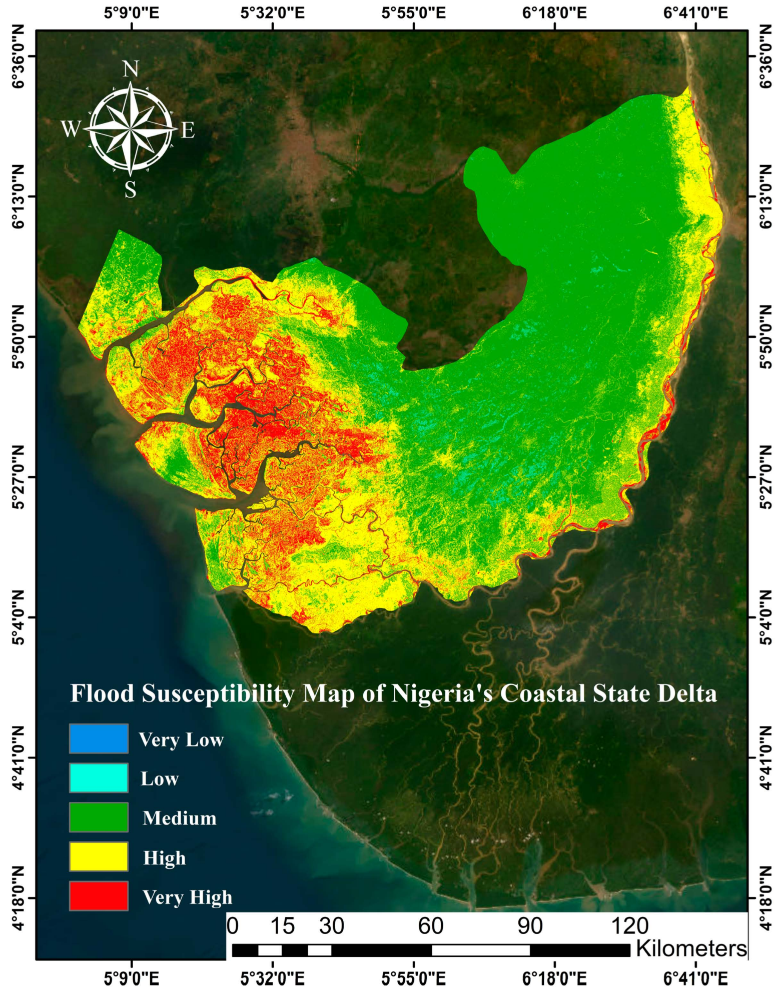

Figure 7. Comprehensive flood susceptibility assessment for coastal Delta State, Nigeria.

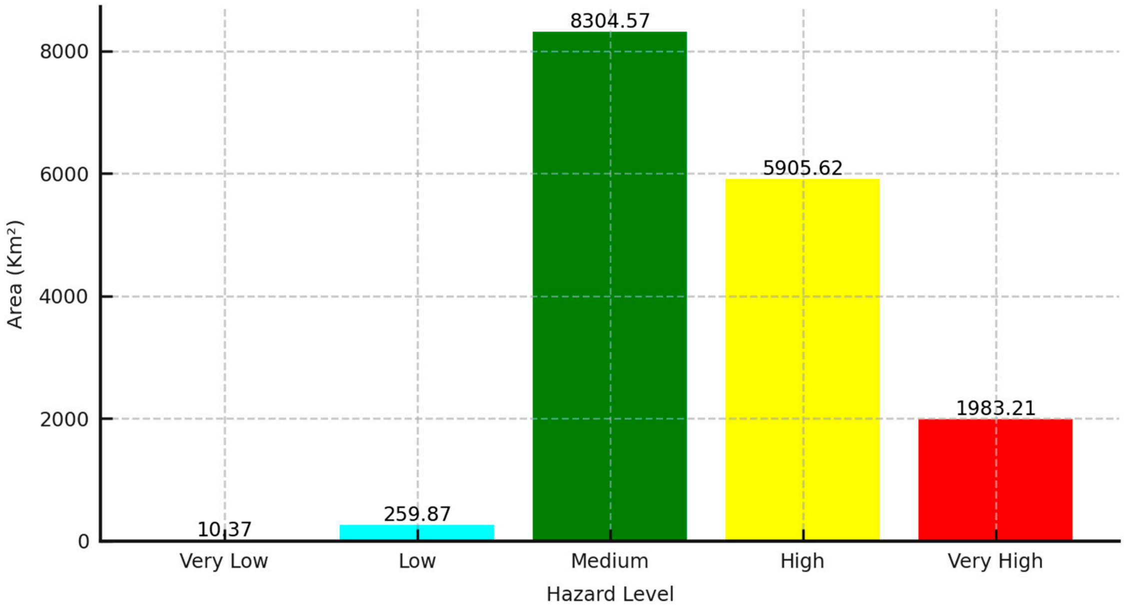

Figure 8. Quantitative distribution of flood susceptibility levels in the coastal Delta region.

3.2. Bayelsa State Flood Risk Assessment

Figure 9 provides an exhaustive depiction of the flood hazard score risk across three designated local government areas within Bayelsa State, Nigeria, detailing the spectrum of flood susceptibility present. The mappings include Figure 9a Southern Ijaw, displaying zones with flood susceptibility ranging from very low to very high; Figure 9b Ekeremor, exhibiting a broad spectrum of flood risk intensities; and Figure 9c Brass, with areas color-coded to denote varying degrees of flood risk from minimal to severe. Each map employs a chromatic scale transitioning from blue to red, a methodological choice that enhances the communication of the urgency related to each flood hazard level. This strategic use of color is an indispensable tool for facilitating effective strategic planning and mitigation efforts to manage disaster risks. Additionally, the visualizations underscore the heterogeneous and varied levels of flood vulnerability throughout the state, providing critical data that support making informed decisions and prioritizing flood prevention strategies. Figure 10 shows the comprehensive flood susceptibility map of Bayelsa State, Nigeria. Quantitative The distribution of flood susceptibility map levels in the coastal Bayelsa region is shown in Figure 11.

The map provides a meticulous assessment of flood risk across Bayelsa State, categorizing the territory into distinct zones according to varying degrees of flood risk. The analysis reveals extensive regions of high risk, covering 5506.61 km^2, and very high risk, encompassing 1826.88 km^2, which are notably prone to flooding. These areas are interspersed with significant medium-risk zones spanning 2260.84 km^2. In contrast, areas categorized as low risk and very low risk are comparatively minor, measuring 27.24 km^2 and 0.45 km^2, respectively. This strategic categorization is crucial for developing customized flood mitigation and emergency response strategies within Bayelsa State, focusing attention and resources on the areas that most urgently require intervention.

The combined flood risk assessments for Delta and Bayelsa States provide a detailed understanding of the spatial distribution of flood hazards, which is crucial for effective disaster management and urban planning. In Delta State, the analysis identifies extensive high-risk areas (5905.62 km^2) and very high-risk areas (1983.21 km^2), primarily along riverbanks and coastal regions vulnerable to flooding, alongside medium-risk areas (8304.57 km^2), which include regions less frequently affected but significant in their potential impacts on infrastructure. Bayelsa State shows a similar pattern of vulnerability, with significant areas classified as high risk (5506.61 km^2) and very high risk (1826.88 km^2) due to its deltaic and low-lying geographical features, interspersed with medium-risk zones (2260.84 km^2). The detailed assessments are pivotal in guiding flood mitigation strategies and resource allocation, ensuring areas with the highest risk receive immediate attention for infrastructure development, community preparedness, and resilience-building initiatives. This strategic utilization of advanced remote sensing data and GIS-based hydrological modeling is vital for reducing the socio-economic impacts of flooding and enhancing the resilience of these vulnerable communities, providing a robust foundation for policymakers and disaster management professionals to prioritize flood defense constructions, improve drainage systems, and organize community training for emergency responses. By integrating these assessments into regional planning frameworks, both states can better manage their flood susceptibility and aim for sustainable development, minimizing the adverse impacts of future flood events and enhancing overall community safety and resilience.

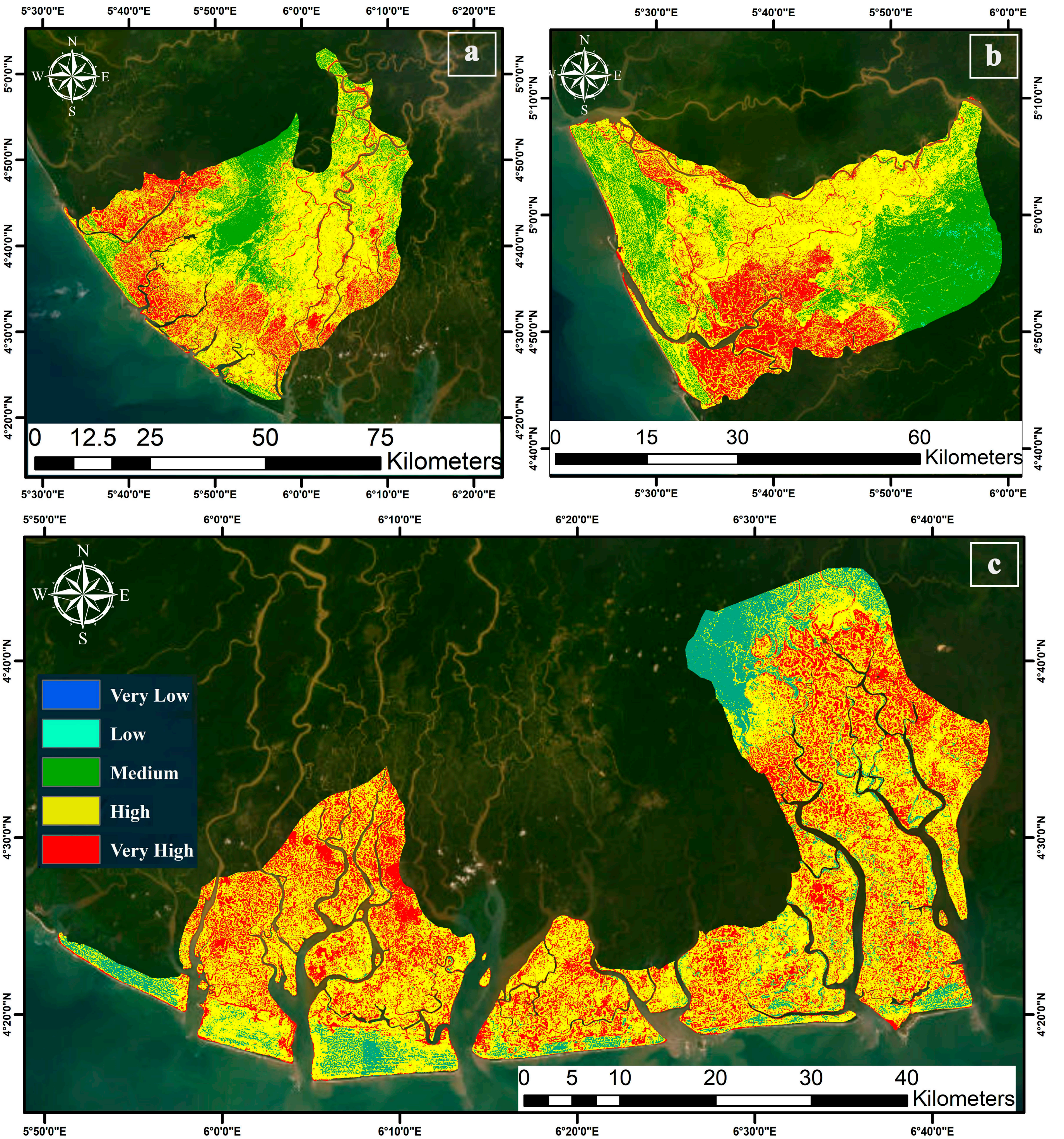

Figure 9. Flood susceptibility map of local coastal government area of Bayelsa State. (**a**) Flood susceptibility map of Southern Ijaw; (**b**) flood susceptibility map of Ekeremor; (**c**) flood susceptibility map of Brass.

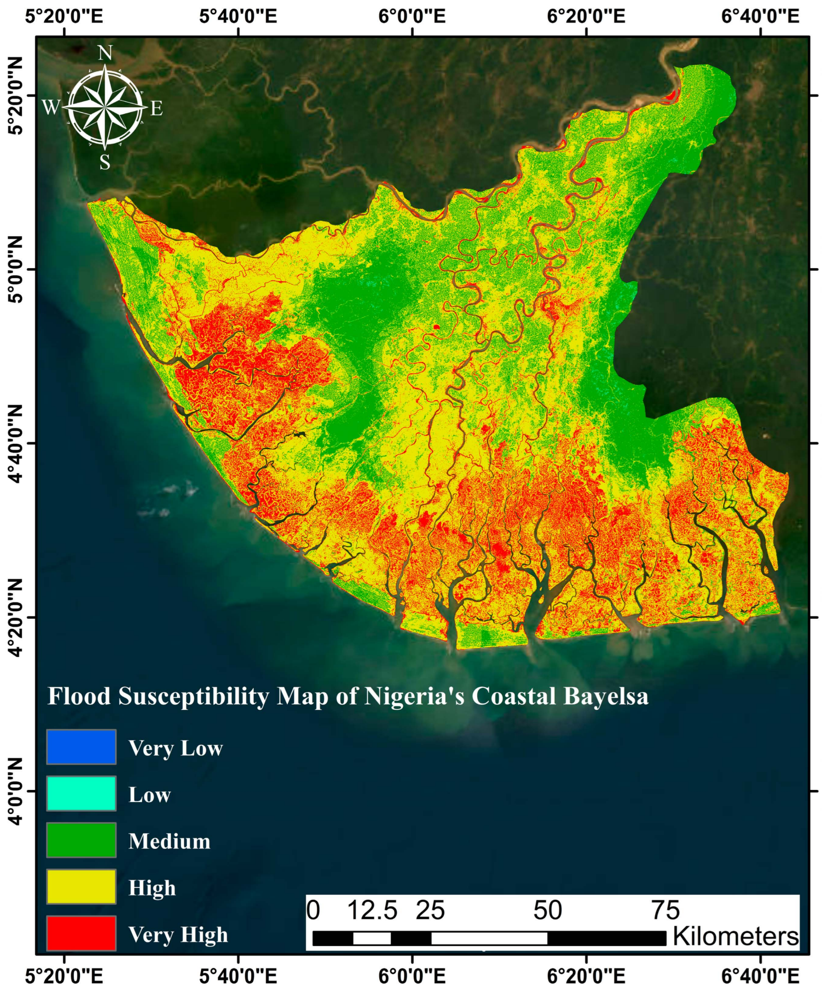

Figure 10. Comprehensive flood susceptibility map of Bayelsa State, Nigeria.

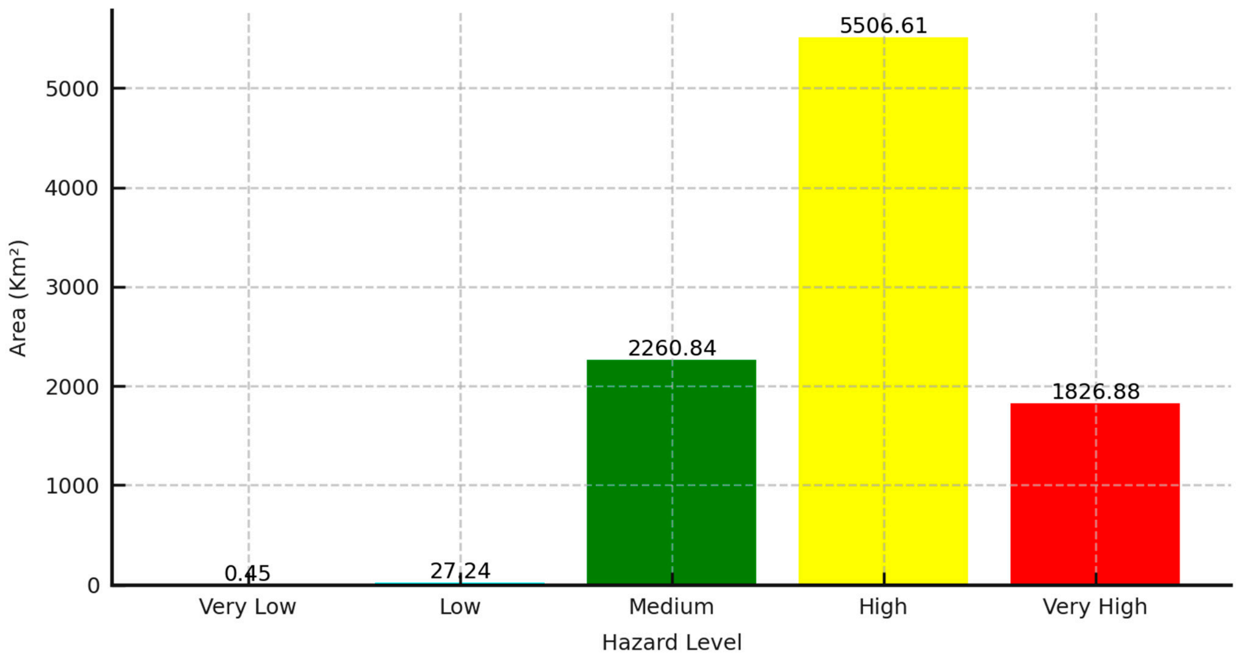

Figure 11. Quantitative distribution of flood susceptibility map levels in the coastal Bayelsa region.

4. Discussion

The multilayered geospatial analysis presented in the Section 3 provides a nuanced understanding of flood susceptibility across the local government areas in Delta and Bayelsa States, with a keen focus on regions such as Burutu, Warri North, Warri South West in Delta State, and Southern Ijaw, Ekeremor, and Brass in Bayelsa State. The vivid differentiation of flood risk levels from very low to very high aids in visualizing and prioritizing intervention efforts, which is crucial for disaster management and strategic planning. In Delta State, identifying substantial high-risk zones covering 5905.62 km^2 and medium-risk areas spreading across 8304.57 km^2 calls for a proactive approach towards flood mitigation. The mapping of these risks provides a vital tool for policymakers and urban planners to direct resources efficiently and tailor response strategies effectively, especially considering the vast and varied landscape of the state. With its 5506.61 km^2 high-risk and 1826.88 km^2 very high-risk flood zones, Bayelsa State presents an even more urgent scenario for mitigation and emergency response strategies. Moreover, the results underscore the potential of geospatial analysis for demarcating flood-prone regions and furnishing actionable insights that can inform and refine disaster management policies, aligning with the objectives of Sustainable Development Goal 13: Climate Action. The public perception data, indicating significant discrepancies between the governmental flood mitigation efforts and community viewpoints, highlight a communication gap that needs to be bridged. The application of geospatial analysis in this context underscores its indispensable role in disaster management and a significant stride towards precise flood risk assessment and the facilitation of targeted interventions [25,26]. This aligns with SDG 13: Climate Action, emphasizing the urgent need for adaptive planning and resilience-building strategies to mitigate climate threats [27]. The nuanced understanding of flood risk distribution gained through this study provides a robust foundation for prioritizing mitigation strategies, particularly in the highlighted states where urgent intervention is required [28,29]. Nigeria's position as one of the fastest-growing countries globally, with projections suggesting it will become the third-largest country before 2050, underscores the imperative for advanced methodologies in efficiently assessing and mitigating flood susceptibility [30]. The devastating impacts of recurring floods on lives, livelihoods, and infrastructure are causing critical gaps in Nigeria's disaster preparedness and response mechanisms [31]. Through its methodological rigor and comprehensive analysis, this study contributes valuable insights toward addressing these gaps, offering a model that integrates physical and societal risk dimensions to inform disaster management strategies [32]. The geospatial approach adopted in this research not only enhances our understanding of flood susceptibility but also facilitates the development of nuanced strategies for disaster management [33]. This is particularly pertinent in the face of Nigeria's rapid urbanization and environmental changes, which exacerbate vulnerability to flooding as seen in many other regions of the World as well [34,35]. The effects of climate change need to be assessed, and new technologies offer such possibilities, enhancing our capacity to predict and manage natural hazards more effectively. Innovative geospatial tools and climate models allow for the real-time analysis of risk factors and adaptation strategies, allowing authorities to implement more targeted and effective responses to the increasing threats posed by climate change. This capability is crucial for improving the accuracy of flood risk predictions and optimizing resource allocation for flood defense and community resilience programs. As climate patterns continue to shift, these technological advancements will be vital in shaping adaptive, long-term strategies for flood risk management, directly contributing to the sustainability and safety of vulnerable regions.

5. Conclusions

In conclusion, this comprehensive study employing geospatial technology to assess flood susceptibility in Nigeria's coastal states, particularly Delta and Bayelsa, offers crucial insights into managing and mitigating climate-induced flooding in these vulnerable areas. The 2022 flooding events highlighted the acute vulnerability of these regions, where over 2.8 million people were affected, and substantial infrastructural, agricultural, and residential damages were recorded. This underscores the urgency of enhanced flood risk management in areas prone to annual flooding due to their flat, low-lying deltaic geographies. Integrating remote sensing data with GIS-based hydrological modeling elucidates flood risk severity and spatial distribution, identifying significant high-risk zones across 8304.57 km^2 in Delta State and extensive territories in Bayelsa State. These findings are pivotal for informing disaster management policies and enhancing community resilience against escalating climate events. They also align with the Sustainable Development Goals, particularly SDG 13: Climate Action, highlighting the role of advanced geospatial analysis in improving disaster preparedness and strategic response strategies. This study's detailed risk categorization and mapping are invaluable for strategic resource allocation and planning to bolster flood resilience across Nigeria's diverse landscapes. This research supports efforts to mitigate the impacts of climate change but also enhances policymaking for disaster risk management and climate resilience. Furthermore, the insights offered are essential for future research and policy frameworks within Nigeria and other regions facing similar climatic threats. Ultimately, this study marks a significant contribution to the academic discourse on disaster management and climate risk mitigation, emphasizing the transformative potential of geospatial technologies in developing informed, evidence-based strategies for flood risk management. As we continue to confront the complexities of climate change, the ongoing evolution of comprehensive, interdisciplinary methodologies is crucial for building resilient communities capable of withstanding and adapting to these challenges.

Author Contributions: Conceptualization, S.S., B.S., G.M. and M.B.; methodology, S.S., M.B., S.K.S. and B.S.; software, M.B.; validation, G.M., S.K. and S.K.S.; formal analysis, S.K.; investigation, S.S.; resources, V.P.; data curation, G.M.; writing—original draft preparation, M.B.; writing—review and editing, G.M.; visualization, M.B.; supervision, G.M., S.S., S.K.S. and V.P. project administration, P.K. and S.K.S.; funding acquisition, P.K. and S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data shall be available from the corresponding authors upon reasonable request.

Acknowledgments: We greatly appreciate the insightful suggestions provided by the two anonymous reviewers during the peer review process of this manuscript. Their input has significantly enhanced the quality of this work. Gowhar Meraj acknowledges the support of Japan Society for the Promotion of Science for JSPS KAKENHI (Grant Number 23KF0024).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Echendu, A.J. The impact of flooding on Nigeria's sustainable development goals (SDGs). *Ecosyst. Health Sustain.* **2020**, *6*, 1791735. [CrossRef]
2. Komolafe, A.A.; Adegboyega, S.A.A.; Akinluyi, F.O. A Review of Flood Risk Analysis in Nigeria. *Am. J. Environ. Sci.* **2015**, *11*, 157–166. [CrossRef]
3. Ouma, Y.O.; Tateishi, R. Urban Flood Vulnerability and Risk Mapping Using Integrated Multi-Parametric AHP and GIS: Methodological Overview and Case Study Assessment. *Water* **2014**, *6*, 1515–1545. [CrossRef]
4. Glago, F.J.; Glago, F.J. Flood Disaster Hazards; Causes, Impacts and Management: A State-of-the-Art Review. In *Natural Hazards—Impacts, Adjustments and Resilience*; IntechOpen: London, UK, 2021. [CrossRef]
5. Sun, Q.; Mann, J.; Skidmore, M. The Impacts of Flooding and Business Activity and Employment: A Spatial Perspective on Small Business. *Water Econ. Policy* **2022**, *8*, 2140003. [CrossRef]
6. Fayaz, M.; Meraj, G.; Khader, S.A.; Farooq, M.; Kanga, S.; Singh, S.K.; Kumar, P.; Sahu, N. Management of Landslides in a Rural–Urban Transition Zone Using Machine Learning Algorithms—A Case Study of a National Highway (NH-44), India, in the Rugged Himalayan Terrains. *Land* **2022**, *11*, 884. [CrossRef]
7. Nichols, G.; Lake, I.; Heaviside, C. Climate Change and Water-Related Infectious Diseases. *Atmosphere* **2018**, *9*, 385. [CrossRef]
8. Shafii, N.Z.; Saudi, A.S.M.; Pang, J.C.; Abu, I.F.; Sapawe, N.; Kamarudin, M.K.A.; Mohamad, M.H.N. Association of Flood Risk Patterns with Waterborne Bacterial Diseases in Malaysia. *Water* **2023**, *15*, 2121. [CrossRef]

9. Lee, J.; Perera, D.; Glickman, T.; Taing, L. Water-related disasters and their health impacts: A global review. *Prog. Disaster Sci.* **2020**, *8*, 100123. [CrossRef]
10. Chen, X.M.; Sharma, A.; Liu, H. The Impact of Climate Change on Environmental Sustainability and Human Mortality. *Environments* **2023**, *10*, 165. [CrossRef]
11. Warner, D.; Krakauer, N.Y.; Allafta, H.; Opp, C. Climate Change Paradox: The Least Responsible for It Encounters the Most of Its Implications. *Climate* **2024**, *12*, 38. [CrossRef]
12. Umar, N.; Gray, A. Flooding in Nigeria: A review of its occurrence and impacts and approaches to modelling flood data. *Int. J. Environ. Stud.* **2023**, *80*, 540–561. [CrossRef]
13. Pew Research Center. The Countries Projected to Gain and Lose the Most People by 2100. Available online: https://www.pewresearch.org/short-reads/2019/07/10/for-world-population-day-a-look-at-the-countries-with-the-biggest-projected-gains-and-losses-by-2100/ (accessed on 14 March 2024).
14. United Nations. World Population Projected to Reach 9.8 Billion in 2050, and 11.2 Billion in 2100. Available online: https://www.un.org/en/desa/world-population-projected-reach-98-billion-2050-and-112-billion-2100 (accessed on 11 March 2024).
15. ReliefWeb. Nigeria: Floods—Operation Update #2 (MDRNG034)—Nigeria. Available online: https://reliefweb.int/report/nigeria/nigeria-floods-operation-update-2-mdrng034 (accessed on 9 March 2024).
16. ReliefWeb. Nigeria: Floods—6 Months Operation Update (MDRNG034)—Nigeria. Available online: https://reliefweb.int/report/nigeria/nigeria-floods-6-months-operation-update-mdrng034 (accessed on 11 March 2024).
17. Nkwunonwo, U.C.; Whitworth, M.; Baily, B. Review article: A review and critical analysis of the efforts towards urban flood risk management in the Lagos region of Nigeria. *Nat. Hazards Earth Syst. Sci.* **2016**, *16*, 349–369. [CrossRef]
18. Nkeki, F.N.; Bello, E.I.; Agbaje, I.G. Flood risk mapping and urban infrastructural susceptibility assessment using a GIS and analytic hierarchical raster fusion approach in the Ona River Basin, Nigeria. *Int. J. Disaster Risk Reduct.* **2022**, *77*, 103097. [CrossRef]
19. Musa, S.D.; Shabu, T. Using geographic information system to evaluate land use and land cover affected by flooding in Adamawa State, Nigeria. *Jamba J. Disaster Risk Stud.* **2019**, *11*, a494. [CrossRef]
20. Su, S.; Yan, L.; Xie, H.; Chen, C.; Zhang, X.; Gao, L.; Zhang, R. Multi-Level Hazard Detection Using a UAV-Mounted Multi-Sensor for Levee Inspection. *Drones* **2024**, *8*, 90. [CrossRef]
21. Safabakhshpachehkenari, M.; Tonooka, H. Modeling Land Use Transformations and Flood Hazard on Ibaraki's Coastal in 2030: A Scenario-Based Approach Amid Population Fluctuations. *Remote Sens.* **2024**, *16*, 898. [CrossRef]
22. Singh, S.; Singh, S.K.; Prajapat, D.K.; Pandey, V.; Kanga, S.; Kumar, P.; Meraj, G. Assessing the Impact of the 2004 Indian Ocean Tsunami on South Andaman's Coastal Shoreline: A Geospatial Analysis of Erosion and Accretion Patterns. *J. Mar. Sci. Eng.* **2023**, *11*, 1134. [CrossRef]
23. United Nations Development Programme. Nigeria Flood Impact, Recovery and Mitigation Assessment Report 2022–2023. Available online: https://www.undp.org/nigeria/publications/nigeria-flood-impact-recovery-and-mitigation-assessment-report-2022-2023 (accessed on 10 March 2024).
24. Bashir, O.O.; Oludare, H.A.; Johnson, O.O.; Aloysius, B. Floods of Fury in Nigerian Cities. *J. Sustain. Dev.* **2012**, *5*, 69–79. [CrossRef]
25. Manfré, L.A.; Hirata, E.; Silva, J.B.; Shinohara, E.J.; Giannotti, M.A.; Larocca, A.P.C.; Quintanilha, J.A. An Analysis of Geospatial Technologies for Risk and Natural Disaster Management. *ISPRS Int. J. Geo-Inf.* **2012**, *1*, 166–185. [CrossRef]
26. Kemper, G. Geoinformation for Disaster and Risk Management Examples and Best Practices. 2010. Available online: www.fig.net/jbgis (accessed on 14 March 2024).
27. Goal 13: Climate Action—The Global Goals. Available online: https://www.globalgoals.org/goals/13-climate-action/ (accessed on 12 March 2024).
28. Vitale, C. Understanding the shift toward a risk-based approach in flood risk management, a comparative case study of three Italian rivers. *Environ. Sci. Policy* **2023**, *146*, 13–23. [CrossRef]
29. Kuhlicke, C.; Seebauer, S.; Hudson, P.; Begg, C.; Bubeck, P.; Dittmer, C.; Grothmann, T.; Heidenreich, A.; Kreibich, H.; Lorenz, D.F.; et al. The behavioral turn in flood risk management, its assumptions and potential implications. *Wiley Interdiscip. Rev. Water* **2020**, *7*, e1418. [CrossRef]
30. (PDF) Flood Menace in Nigeria: Impacts, Remedial and Management Strategies. Available online: https://www.researchgate.net/publication/312458086_Flood_menace_in_Nigeria_impacts_remedial_and_management_strategies (accessed on 12 March 2024).
31. Chand, K.; Jamwal, A.K.; Meraj, G.; Thakur, T.; Farooq, M.; Kumar, P.; Singh, S.K.; Kanga, S.; Debnath, J. Integrating geoenvironmental and socioenvironmental analyses for flood vulnerability assessment in the Kullu Valley, Himachal Pradesh, India. *Int. J. Disaster Risk Reduct.* **2024**, *108*, 104494. [CrossRef]
32. Yang, C. Application and Assessment of GIS Technology in Flash Flood Risk Management. *Sustain. Environ.* **2024**, *9*, p26. [CrossRef]
33. A Novel Methodology for Enhancing Flood Risk Communication: The Nines of Safety | Request PDF. Available online: https://www.researchgate.net/publication/377377696_A_Novel_Methodology_for_Enhancing_Flood_Risk_Communication_The_Nines_of_Safety (accessed on 12 March 2024).

34. Debnath, J.; Sahariah, D.; Mazumdar, M.; Lahon, D.; Meraj, G.; Hashimoto, S.; Kumar, P.; Singh, S.K.; Kanga, S.; Chand, K.; et al. Evaluating flood susceptibility in the brahmaputra river basin: An insight into Asia's Eastern Himalayan floodplains using machine learning and multi-criteria decision-making. *Earth Syst. Environ.* 2023. [CrossRef]
35. Dolgorsuren, S.E.; Ishgaldan, B.; Myagmartseren, P.; Kumar, P.; Meraj, G.; Singh, S.K.; Kanga, S.; Almazroui, M. Hydrological Responses to Climate Change and Land-Use Dynamics in Central Asia's Semi-arid Regions: An SWAT Model Analysis of the Tuul River Basin. *Earth Syst. Environ.* **2024**. [CrossRef]