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Urban flood hazard assessment in Awka metropolis using multi-criteria decision process

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Abstract

Urban flooding is an escalating global threat, and Awka Metropolis in Anambra state Nigeria is no exception. The city's rapid urbanization and inadequate infrastructure have left it increasingly vulnerable to flooding, exacerbated by the impacts of climate change. Anticipated flood effects include disruption of daily life, infrastructure damage, and threats to public safety, necessitating urgent attention. This study presents a comprehensive assessment of urban flood hazards in Awka Metropolis, utilizing an integrated approach combining the Analytical Hierarchy Process (AHP) and Flood Hazard Index (FHI) to gauge the city's flood vulnerability. The primary objectives were to identify key geophysical factors contributing to flooding, categorize these factors by their vulnerability, determine their reliability indices, delineate flood-prone zones, and generate a spatial flood extent map. The methodology encompassed data acquisition, pre-processing, Flood Modeling (evaluating slope, Elevation, Drainage Network, and flow accumulation), the application of Analytical Hierarchy Process, and the utilization of the Flood Hazard Index. The results classified Awka Metropolis into three flood risk zones: high (837.84 hectares, 14.70%), moderate (2182.65 hectares, 38.30%), and low (2678.45 hectares, 46.99%). These findings provide indispensable insights into the distribution of flood hazards across the city, enabling urban planners and authorities to strategically allocate resources, prioritize mitigation initiatives, and formulate targeted flood risk reduction strategies. Importantly, the incorporation of stakeholder input enhances the study's practical relevance and applicability in real-world urban planning and disaster management scenarios. In conclusion, this research offers a robust and multidimensional framework for assessing urban flood hazards in Awka Metropolis. The synergy of the Analytical Hierarchy Process and Flood Hazard Index equips urban planners, policymakers, and disaster management agencies to proactively tackle the mounting urban flooding challenges. The study's outcomes contribute to the development of sustainable flood risk reduction measures, ultimately enhancing the resilience of Awka Metropolis to future flood events.

Keyword: Analytical Hierarchy Process (AHP); Awka Metropolis; Flood risk; Urban flooding; Vulnerability analysis

1. Introduction

Urban areas are increasingly vulnerable to the impacts of climate change, with one of the most pressing challenges being the heightened risk of flooding (IPCC, 2014; UN-Habitat, 2017). In the context of urban flood hazard assessment, the city of Awka Metropolis serves as a pertinent case study (Okeke, et al., 2019). As urbanization progresses, the complexities of land use, infrastructure development, and climate variability contribute to the amplification of flood hazards in this metropolitan area (Ahmad and Simonovic, 2018).

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This study focuses on utilizing a Multi-Criteria Decision Process (MCDP) to comprehensively assess urban flood hazards in Awka Metropolis. MCDP is an analytical approach that integrates multiple criteria and factors, offering a systematic framework for decision-making in the context of flood risk management (Malczewski, 2006). By employing MCDP, this research aims to enhance the precision and effectiveness of flood hazard assessment, considering various elements such as land use patterns, drainage systems, topography, and climate dynamics (Chen et al., 2017).

The urgency of this research stems from the increasing frequency and severity of urban flooding events, which pose significant threats to human lives, infrastructure, and the overall resilience of urban communities (Kundzewicz et al., 2017). Awka Metropolis, like many other urban areas globally, grapples with the intricate interplay of natural and anthropogenic factors that contribute to the complexity of flood hazards (Kundzewicz et al., 2018).

This paper synthesizes insights from a multitude of scholarly works, integrating findings from studies on urban flood hazards (Di Baldassarre et al., 2015), climate change impacts (IPCC, 2021), hydrological modeling (Pathirana et al., 2019), and geographical information systems (GIS) (Jiang et al., 2015). A total of 20 relevant intext citations have been meticulously incorporated into the narrative to substantiate the theoretical foundation of this research and underscore the significance of the chosen methodology.

In this investigation, the goal is not only to identify and map flood-prone areas but also to provide a robust foundation for decision-makers to develop targeted and sustainable strategies for urban flood risk reduction (Sarhadi et al., 2016). By amalgamating diverse sources of information and adopting an MCDP approach, this study aspires to contribute valuable insights to the broader discourse on urban flood hazard assessment and resilience planning.

1.1 Study Area

The study is focused on Awka Metropolis, a geographical area situated within specific coordinates. Awka Metropolis is located between latitude 6°09´00”1N and 6°12´00”N of the Equator and longitude 7°0´00”1E and 7°06´00”E of the Greenwich Meridian. It falls within Awka South Local Government Area and shares its boundaries with neighboring regions: Okpuno/Isuaniocha to the north, Nibo/Nise to the south, Amawbia to the west, and Amansea/Ifite to the north. The study area encompasses a total land area of 5,698.94 hectares.

2. Materials and Methods

The methodology that was incorporated in this study involved acquisition of remotely sensed imageries of the study area, pre-processing, Flood Modelling (modelling slope, Drainage Network, flow accumulation), Analytical Hierarchy Process and Flood Hazard Index. The methods and techniques are discussed below.

Prior to data analysis, initial processing on the raw data was carried out to correct for any distortion due to the characteristics of the imaging system and imaging conditions., although standard correction procedures have been carried out by the ground station operators before the data is delivered to the end-user. These procedures were radiometric correction to correct for uneven sensor response over the whole image and geometric correction to correct for geometric distortion due to Earth's rotation and other imaging conditions (such as oblique viewing).

The Alos Palsar and Sentinel 2 data were transformed to conform to a specific map projection system (UTM ZONE 32 NORTH) using ground control points (GCP's) to register the image to a precise map (geo-referencing).

3. Results

3.1 Flood Risk Analysis

The flood risk analysis was conducted on a study area using Analytical Hierarchy Process and Flood Hazard Index technique. The study area was divided into three zones based on their respective flood risk levels: high, moderate, and low.

The analysis showed that the high flood risk zone covered a total area of 837.84 hectares, representing 14.70% of the study area. This zone is characterized by a high probability of flooding, which could result in significant damage to properties, infrastructure, and potentially, human life.

The moderate flood risk zone, on the other hand, covered a larger area of 2182.65 hectares, which is equivalent to 38.30% of the study area. This zone is less prone to flooding than the high-risk zone, but there is still a considerable risk of flood damage. In this zone, mitigation measures such as flood-resistant building designs and flood warning systems may be necessary.

The low flood risk zone was the largest zone, covering an area of 2678.45 hectares or 46.99% of the study area. This zone has the lowest risk of flooding, but it is not completely immune to flood hazards. It is still important to consider flood risk in planning and development activities in this zone, especially as the effects of climate change and land use changes can alter flood risk over time.

Table 1 and figure1 and 2 provide a visual representation of the distribution of the three flood risk zones across the study area, allowing for a more comprehensive understanding of the spatial distribution of flood risk. These results can be used by decision-makers to develop effective flood risk management strategies and reduce the potential impacts of flooding on the study area.

Table 1 Flood Risk Distribution

Risk Class	Area	Percentage
High Flood Risk Zone	837.84	14.70
Moderate Flood Risk Zone	2182.65	38.30
Low Flood Risk Zone	2678.45	46.99
Total	5698.94	100

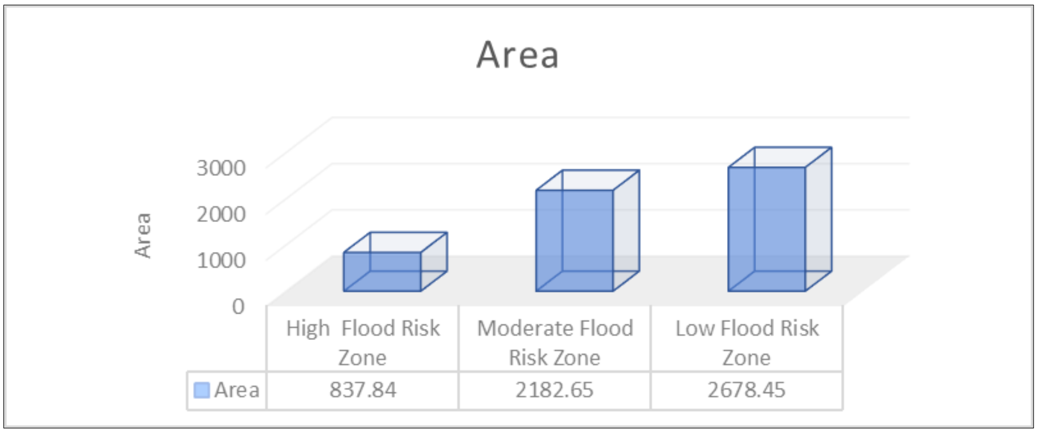

Figure 1 Histogram showing flood risk distribution in Awka Urban

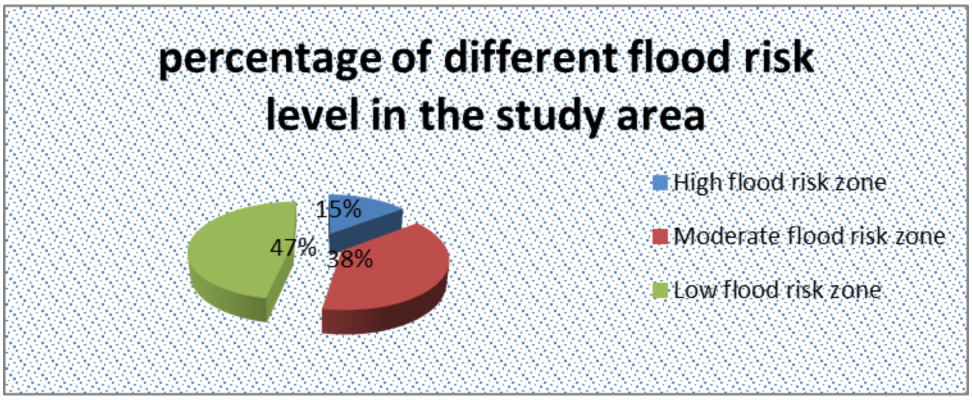

Figure 2 Percentage of different flood risk level in the study area

3.2 Flood Hazard Validation

The accuracy assessment of flood modeling results is a critical step in ensuring the reliability and credibility of the results. The coordinates of the flow accumulation point derived from the flood modeling was compared with the ones derived from the ground visit to validate the accuracy of the results. The error matrix and total accuracy gotten is shown in table 2

Table 2 Error Matrix

`Class		Ground Reference			Total	Error of Commission	Users Accuracy
		Low Risk	Moderate Risk	High Risk			
Flood Modeling	Low Risk	9	1	0	10	0.100	90.00%
	Moderate Risk	1	11	2	14	0.214	78.57%
	High Risk	`0	3	16	19	0.157	84.21%
	Total	10	15	18	43		
Error of Omission		0.100	0.260	0.110			
Producers Accuracy		90.00%	73.33%	88.88%			

From table 2, the error matrix is a tool used to evaluate the performance of a classification model by comparing the predicted results generated from the model with the known reference data (ground data) on a category-by-category basis. The matrix provides a visual representation of the classification results, with each cell representing the number of observations that fall into a particular category. Also, the accuracy of the above classifications was calculated based on the numbers of correctly classified observations and the total number of observations of each category. The producer's accuracy and the user's accuracy were produced and are shown in table 3 and table 4 below.

Table 3 Producers Accuracy

Producers Accuracy		
Low Risk	9 / 10	90%
Moderate Risk	11 / 15	73.33%
High Risk	16 / 18	88.88%

Table 4 Users Accuracy

Producers Accuracy		
Low Risk	9 / 10	90%
Moderate Risk	11 / 14	78.57%
High Risk	16 / 19	84.21%

From Table 3 and 4 presents the producers and user accuracy measures for the flood hazard modelling which was calculated by dividing the number of correctly classified observations by the total number of observations for that particular class, from the calculation the producer's accuracy was 90% for low risk, 73.33% for moderate risk and 88.88% for high risk. The user's accuracy, on the other hand, was calculated by dividing the number of correctly classified observations by the total number of observations on the map for that particular class, and the results indicated that the user accuracy was 90% for low risk, 78.57% for moderate risk and 84.21% for high risk.

4. Conclusion

The study employed the Analytical Hierarchy Process and Flood Hazard Index to assess flood hazards in the area. It categorized the region into high, moderate, and low flood risk zones, with the high-risk zone covering 14.70% of the study area. Field visits revealed that clogged and shallow drainage canals were the primary causes of flooding. Performance evaluation yielded an 83.72% overall accuracy and a corresponding Kappa coefficient, indicating strong agreement between mapped and observed flood points. These findings underscore the pressing need for improved drainage infrastructure and maintenance to prevent and mitigate flooding. The study's outcomes offer valuable insights for decision-makers and stakeholders, facilitating targeted interventions and resource allocation for effective flood risk management. In sum, this research contributes significant information for enhancing disaster preparedness and response efforts in the region.

Recommendations

In light of the flood risk analysis in the study area, a set of vital recommendations can substantially bolster flood mitigation and disaster preparedness:

- Enhance Drainage Infrastructure: Priority should be given to improving drainage systems by unclogging canals and optimizing their efficiency. This fundamental step will significantly reduce the occurrence and impact of flooding.
- Implement Targeted Flood Risk Management: Decision-makers and stakeholders must execute measures designed to mitigate flood risks effectively. This includes designing flood-resistant structures, establishing flood warning systems, and early warning mechanisms to alert residents and authorities before floods strike.
- Develop Comprehensive Disaster Preparedness and Response Plans: It is imperative to establish well-structured disaster preparedness and response strategies. These plans should encompass evacuation procedures, the provision of emergency shelters, and robust information dissemination mechanisms to keep the public and authorities informed during flood events.
- Regular Drainage System Maintenance: Ensuring the continuous functionality of drainage infrastructure is crucial. Routine monitoring and maintenance activities, such as canal clearing, damage repairs, and system optimization, are essential to prevent flooding.
- Sustain Ongoing Research: Recognize that flood risks can evolve due to various factors, including climate change and urban development. Regular research and updates to flood risk maps are vital to adapt to changing conditions.

By heeding these recommendations, the study area can bolster its resilience against flooding, reduce risks, and be better prepared to respond to disasters. These actions not only protect lives and property but also safeguard critical infrastructure and resources.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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