GIS-BASED ANALYTICAL HIERARCHY PROCESS MODELING FOR FLOOD VULNERABILITY ASSESSMENT OF COMMUNITIES ALONG OTAMIRI RIVER BASIN IMO STATE

Abstract

In recent times, communities along the Otamiri River Basin in Imo State have been grappling with flooding issues, especially during the rainy season. This occurs despite the presence of underground drainage systems. The primary concern is heavy rainfall causing the river to overflow and lead to flooding. Hence the study aimed at identifying the flood-prone areas in the Otamiri River Basin in Owerri, Imo State. The objectives are to, establish factors for evaluating flood vulnerability within the study area; classify and standardize the factors according to levels of vulnerability; determine the reliability of the classified factors; and produce a flood vulnerability map showing vulnerable areas in the study area. The methodology involved collecting Sentinel 2A imagery of July 2022, processing the data with ArcGIS and QGIS software to determine the topography and vulnerability areas through geo-referencing and classification. SRTM data for elevation and field observations within affected communities were also used to assess accuracy. The Analytical Hierarchy Process (AHP) model was employed to identify high flood risk areas, considering factors like drainage density, slope, soil type, precipitation, population density, Euclidean distance, and land use.The study's results categorized vulnerability into five levels: Very Low (0.09% of Owerri, minimal risk), Low (12.93% with lower risk), Moderate (68.83% facing substantial risk), High (18.18% with significant risk), and Very High (0.03% posing extreme risk). These findings are recommended as foundational data for future flood studies in the region.

Keywords: AHP, Flood, GIS, Otamiri, Vulnerability

1. Introduction

Floods, a subject within the field of hydrology, are a matter of significant concern in agriculture, civil engineering, and public health. These destructive events have a global reach and occur when rainfall surpasses the region's normal levels, leading to substantial damage to life and property, traffic disruptions, inconvenience, and health hazards (Oriola, 2003). Flooding is a major disaster affecting numerous countries, resulting in substantial human and economic losses (Thilagavathi, et al., 2011). It stands as one of the most extreme geophysical events globally, posing a threat to humanity (Sanyal and Lu, 2004). This water-related natural hazard impacts a wide range of human activities, including agriculture and transportation (Etounovbe, 2009).

Recognizing the severity of the issue, the United Nations Environmental Program (UNEP) in 1991 highlighted that many countries regarded uncontrolled stormwater as a significant problem in terms of preserving urban infrastructure.

In recent times, flood events have been observed in various parts of the world, with Nigeria being no exception. For people residing in areas like Lokoja and Aguleri, the trauma of previous year's flood, as reported by the Nigeria Television Authority, can hardly be described in words. Large-scale flooding inflicts severe damage on human activities (Ogunyemi, 2002). The floods that occurred between August and October in 2012 inundated parts of Owerri, causing damage to cultivable lands and human dwellings. Etuonobve (2009) reveals that between 1971 and 1995, floods affected more than 1.5 billion people, resulting in 318,000 fatalities and over 81 million people left homeless.

Duru and Chibo (2014) have identified six Local Government Areas (LGAs) in Imo State at risk of flooding, with various flood types such as coastal, flash, riverine, urban, and seasonal, each posing different levels of risk. These floods occur predominantly during the peak rainy season, devastating communities to varying degrees. The overall impact of the Imo flood incident ranges from disrupting human activities to causing damage to commodities, buildings, farmlands, animals, disease outbreaks, and contaminating the water supply, resulting in significant social, economic, and environmental consequences. In Owerri, flooding affects people on an annual basis more than any other natural disaster (Adeboye and Jegede, 2010).

Efficient flood hazard management and mitigation are essential to restore normalcy to the area and achieve sustainable development goals while boosting the state's economy. Accurate flood hazard and risk mapping are indispensable for these efforts (Ezemonye and Emeribe, 2011). Land use planning and flood mitigation strategies rely heavily on precise mapping of flood hazards and risks. This study aims to integrate relevant flood risk factors into a spatial database using Geographic Information Systems (GIS) and the Multi-Criteria Analysis (MCA) technique to develop a flood hazard and risk map for Imo State.

Satellite remote sensing and GIS techniques, as noted by Awal (2003) and Sani, Noordin, and Ranya (2010), have become effective tools for managing various aspects of flood management, including prevention, warning, preparedness, and relief. Remote sensing, GIS techniques, and multi-criteria analysis have found global applications in areas like flood inundation mapping, flood risk assessment, floodplain zoning, and river morphology studies, surpassing traditional approaches (Sani, 2008; Woubet and Dagnachew, 2011; Selvin and Cigdem, 2015; Daniela, Usman, and Costas, 2018).

In this study, flood hazard and risk were mapped using a Geographic Information System (GIS) in combination with the Analytical Hierarchical Process (AHP) and the Weighted Linear Combination (WLC) component of the Multi-Criteria Analysis (MCA) technique. These GIS analyses spatially assess flood causative factors and generate flood hazard and risk maps to support flood control and damage reduction efforts.

Otamiri River is the main source of water for domestic use by neighboring communities, the siltation of Otamiri River will lead to great consequences for host communities if it continues unchecked. In very recent time, communities in Imo Government along Otamiri River Basin have been having issue of flooding especially during raining season despite the fact that there exist underground drainage networks.

Most of the time heavy rainfall causes over bank flowing resulting to flooding of adjacent land along the basin series of drainage. Construction has been put in place nut the problem keeps reoccurring. One of the problems facing decision makers is lack of accurate flood risk map defining areas of potential danger. Some of the effect of flooding in this are submerging of homes, stores, blocking of roads etc. with the current situation it is apparent that the measure on ground are not adequate to curb the menace.

Therefore, the aim of the project is to Assess flood risk and vulnerability level within the study area and identifies the facilities and communities under various levels for proper planning mitigation. This work therefore, tried to build on the gaps identified on the works of Okorafor*et al,(2021)* especially in terms of materials (GPS data was used to capture elevations and position of flooded areas) and methodology (remote sensing and global positioning system, GPS were used in the field risk mapping of the area) which will provide adequate decision support information to planners and decision makers, considering the enormous effect of flooding in Otamiri town, whenever it rained heavily.

Hence this study was conceived to fill the gaps identified in the viewed literature on flood risk mapping and vulnerability and possibly find geospatial method of identifying and mapping potential flood risk in Otamiri.

2. Study Area

The study area in this investigation is Owerri, the capital city of Imo State in southeastern Nigeria, using Otamiri river basin as data collecting points. Otamiri drainage basin lies within longitudes 06^0 57'E and 07^0 07'E and latitudes $05^0$25'N and $05^0$32'N. The river with the length of 105 kilometers is the principal tributary of Imo River-a major river that washes through the landscape of Imo state. Imo state has a high population density; available statistics show that the study area has a population density of 813.54 persons per square kilometer.

The mean monthly temperature for dry season is 34oC and 30oC for rainy season. The river has average maximum flow of 10.7m3/s in the rainy season (September – October) and a minimum average flow of about 3.4m3/s in the dry season (November to February). The total annual discharge of the Otamiri is about 1.7×108m3, and 22percent of this (3.4 ×107m3) comes from direct runoff from rainwater and constitutes the safe yield of the river (Egboka and Uma, 1985). The area experiences two air masses – the Tropical Maritime Air mass which originates from the Southern high-pressure belts, crosses the equator, picks up moisture from over the Atlantic and enters Nigeria from the South, then ushering in rainy season, and the Tropical Continental Air mass which enters the country from the Northeast and carries little or no moisture and as such is responsible for the dry season. The area is low lying, being generally about 300m above sea level. The main stream draining the study area is the Otamiri River. The area presents a more or less dendritic pattern of drainage.

3. Materials and Methods

3.1. Methodology

The systematic methodology employed in this study commenced with the acquisition of Sentinel-2 imagery, covering the entirety of the designated study area. This initial step aimed to secure a comprehensive and high-resolution dataset that would serve as the foundational source for subsequent analyses. Following the acquisition phase, a series of image pre-processing techniques were implemented. These pre-processing steps were crucial for enhancing the clarity and interpretability of the acquired imagery, ensuring that the subsequent analyses would be based on refined and accurate visual information.

Subsequent to image pre-processing, the study engaged in a robust image classification process. This involved employing advanced algorithms to categorize and delineate distinct land cover and land use patterns within the acquired imagery. The output of this classification provided a detailed and nuanced dataset that captured the spatial distribution of various land cover and land use categories across the study area.

The extraction of pertinent environmental factors essential for flood modeling was a pivotal stage in the methodology. Factors such as drainage density, slope, soil type, precipitation, population density, Euclidean distance, and land use were systematically derived from the imagery. These factors collectively represented a comprehensive set of variables contributing to the understanding of the study area's hydrological and environmental dynamics.

To ensure compatibility and consistency in subsequent modeling efforts, a meticulous process of classification and standardization was applied to the extracted factors. This involved transforming the diverse data types and scales of the factors into a uniform Euclidean raster format. This standardization facilitated a seamless integration of these factors into the modeling framework, ensuring that each variable contributed proportionally and comparably to the overall flood hazard assessment.

The determination of modeling weights for each factor was a crucial step in the methodology. This was achieved through a rigorous pairwise comparison process, wherein the relative importance of each factor in influencing flood hazard was systematically evaluated. This step added a layer of precision to the modeling process, accounting for the varying degrees of impact that each environmental factor exerted on the overall flood risk within the study area.

With the modeling weights established, the study proceeded to the development of a comprehensive flood hazard index model. This model, informed by the weighted factors, provided a spatially explicit representation of flood risk across the study area. The integration of various environmental factors and the consideration of their relative importance through the modeling process contributed to a nuanced and accurate assessment of flood hazards.

4. **Results & discussion**

The results reveal different flood vulnerability zones in Owerri, each associated with a specific area in square kilometers. These zones are used to assess the susceptibility of the study area to flooding, see figure 1 and.2.

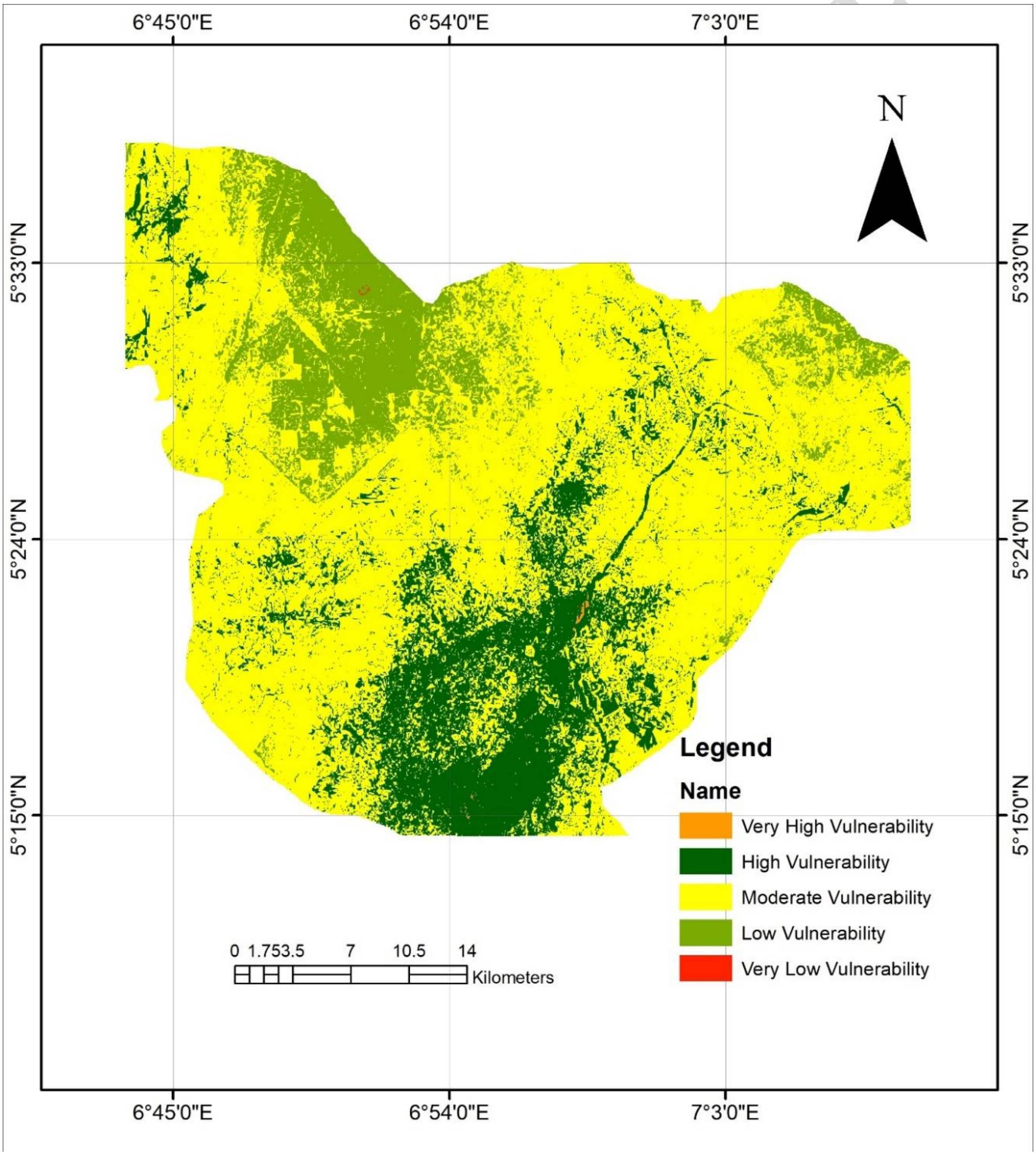

Figure 1: Flood Vulnerability Map

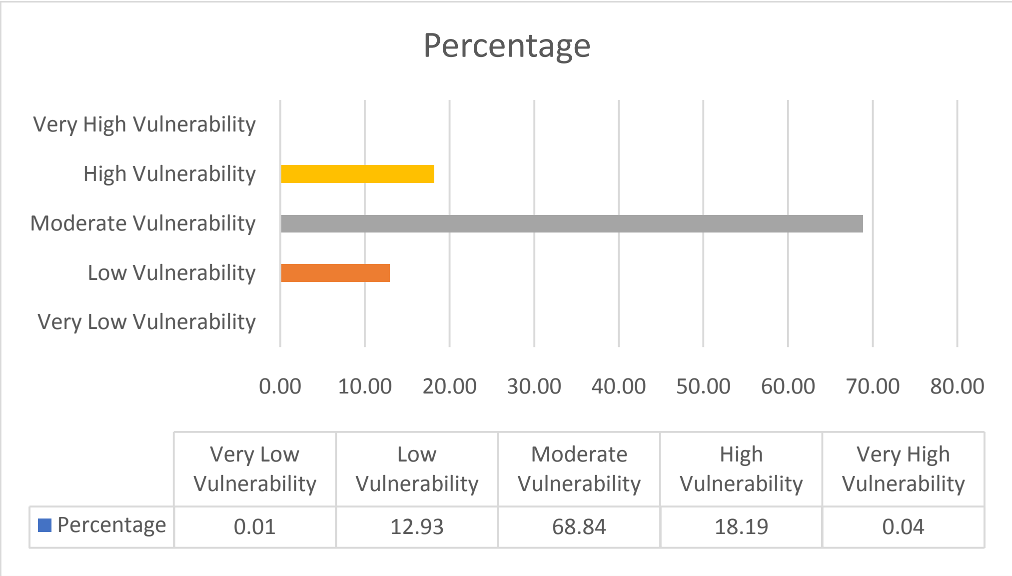

Figure 2: Flood Vulnerability Zones within the Study Area

Referring to Figure 1 and .2, the vulnerability levels in Owerri can be segmented into five distinct categories, each with varying implications for flood risk and development:

Very Low Vulnerability: This zone, covering a mere 0.090 km², accounts for just 0.09% of the total area. It signifies that this area is at the lowest risk of flooding in Owerri. Consequently, it is a relatively safe region for diverse development and infrastructure projects. Residents and authorities can approach this zone with greater confidence, experiencing fewer concerns regarding flood-related issues.

Low Vulnerability: Spanning 166.013 km², which corresponds to 12.93% of Owerri's total area, the low vulnerability zone is significantly larger. It indicates a lower risk of flooding compared to other parts of the city. This implies that urban development and infrastructure projects can proceed with a reasonable degree of confidence within this zone. However, it's essential to exercise caution and preparedness measures, given that no area is entirely immune to the threat of flooding.

Moderate Vulnerability: Encompassing a substantial 883.697 km², constituting 68.83% of Owerri, the moderate vulnerability zone is the most extensive flood vulnerability category. Its designation as "moderate vulnerability" suggests a notable flood risk. Urban planners, local authorities, and residents must prioritize flood management and preparedness within this area, recognizing the significance of its susceptibility to floods.

High Vulnerability: Covering 233.454 km², representing 18.18% of the city's area, the high vulnerability zone, although smaller than the moderate vulnerability zone, presents a considerable flood risk. Flood impact could be severe for both residents and infrastructure within this region. Therefore, stringent flood risk mitigation measures are imperative to protect lives and property.

Very High Vulnerability: Despite its limited area of 0.508 km², making up just 0.03% of Owerri, the very high vulnerability zone is categorized as extremely high risk in terms of flooding. Its small size does not diminish the critical nature of the flood risk it presents. Consequently, special attention should be devoted to this area to minimize potential flood-related damage and risks, recognizing the gravity of its vulnerability.

In summary, the five vulnerability categories in Owerri provide valuable insights into flood risk, ranging from very low to very high. The size and risk level of each zone carry significant implications for urban development, infrastructure planning, and flood risk management. Each category demands a specific approach to ensure the safety and resilience of both residents and the built environment in the face of potential flooding.

Figure 3 and table 1presents the vulnerability levels of various settlements to flooding. This holds a wealth of information that has significant implications for disaster preparedness and management in the affected regions.

5. Conclusion and Recommendations

The comprehensive flood vulnerability assessment conducted in this research has provided valuable insights into the flood risk landscape of the study area, Owerri. The reclassification of various datasets into five distinct vulnerability categories, ranging from very low to very high, has allowed for a nuanced understanding of flood vulnerability, with each category carrying specific implications for development and flood risk management.

The findings reveal that Owerri's vulnerability levels are diverse, reflecting a range of flood risk scenarios. The very low vulnerability zone, albeit small, offers a safe environment for development, while the low vulnerability zone provides a larger area with a lower risk, although some caution and preparedness are still necessary. The moderate vulnerability zone, covering the majority of the city, underscores the importance of proactive flood management measures due to its significant susceptibility to floods. The high vulnerability zone, although smaller, poses a considerable flood risk, necessitating stringent risk mitigation strategies. The very high vulnerability zone, despite its limited area, demands special attention to minimize potential flood-related damage and risks.

Moreover, the categorization of surveyed communities into three distinct vulnerability groups - Low Vulnerability, Moderate Vulnerability, and High Vulnerability - highlights the varying degrees of flood risk within the region. This classification provides a basis for targeted resource allocation and disaster preparedness, ensuring that communities with different vulnerability levels receive appropriate attention and support.

In essence, these findings emphasize the need for tailored flood management strategies that recognize the specific vulnerabilities of different areas within Owerri. Effective resource allocation, proactive preparedness measures, and collaboration among local authorities, disaster management agencies, and the affected communities are essential to mitigate the impact of potential flood events and enhance the resilience of both residents and the built environment.

This research serves as a valuable foundation for informed decision-making and proactive flood risk mitigation in Owerri. By understanding the diverse vulnerability levels and their implications, stakeholders can work together to create a safer and more resilient city in the face of potential flooding.

Based on the findings from this study the following recommendation are made:

1. Thorough scrutiny of developmental projects in flood-prone regions is imperative, with a focus on identifying and addressing the specific factors contributing to flooding to effectively mitigate the associated hazards.
2. Rigorous monitoring is advised for all impending structures in the southern section of the research area due to the heightened vulnerability to flooding. The potential consequences include severe damage and elevated risks, making preemptive measures crucial.
3. The findings of this study are proposed to serve as foundational data for future flood-related investigations within the study area, establishing a valuable baseline for ongoing and forthcoming research endeavors.
4. Ongoing attention and oversight are recommended for the implementation of an adequate drainage and channelization system. Additionally, strict adherence to regulated planning schemes in Owerri urban should be closely monitored by researchers to ensure effective flood management.
5. Constructing drainage systems that follow the natural flow or free movement of floodwaters is advisable. This approach facilitates unobstructed water flow and passage, contributing to a more efficient and natural flood management system.

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