Original Research Paper

Evaluating the Impact of Topography on Flooding in Owerri North, Imo State, Nigeria Using GIS and Remote Sensing Techniques

Sylvanus Ibeabuchi Iro

Department of Geography and Environmental Management, Imo State University, Owerri, Nigeria

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Email: sylvanusiro@gmail.com

Abstract: The aim of this study is to analyze the topographical contribution to floods in Owerri, North Imo State, Nigeria. Research was carried out to ascertain whether topographical elements played a role in the flooding in specific areas of Owerri North. As a result, very little research has looked at the effects of topography on flooding. Thus, there is a barrier to the advancement of knowledge regarding topography and flooding. Using remote sensing techniques, the Digital Elevation Model (DEM) is a low-cost data source for the research investigation. The raster's contour, curvature, slope aspect, and ability to flood Owerri North are all modeled using the SRTM data. Floods are mostly caused by the gradient of the slope in reaction to high runoff. The places of floods that are being examined are at the base of slopes that range from 0-20^0 and 21-40^0. The curvature of the slope in the study area indicates that low values of -1 (×106) for plan curvature represent convexity, while high values of 1 (×106) indicate concavity. This study suggests that topographical factors contribute to flooding in several areas of Owerri North, including the Amakohia and Egbu flood zones. As a result, structures should be built alongside contour lines rather than across them and drainage systems should be installed to channel surplus rainwater into adjacent rivers.

Keywords: Topography, Flooding, DEM, GIS and Remote Sensing

Introduction

Global environmental threats are numerous (Iro and Ezedike 2020; Christopherson, 1958). According to Oyegbile (2008), flooding is considered Earth's most destructive natural disaster. It occurs when excess water inundates normally dry land, often when rainfall surpasses the soil's ability to absorb it (Iro, 2020). This seriously affects the environment (Djimesah *et al*., 2018). According to Nwachukwu *et al*. (2018), " the frequency of floods in recent times has been unparalleled, over 800 million people live in flood-prone areas, with 70 million worldwide vulnerable to flooding each year" (Adetunji and Oyeleye, 2013). According to Abolade *et al.* (2013), "During one-in-100-year flood events, approximately 1.47 billion people, representing 19% of the global population, are directly exposed to significant risks"

Flooding in developing nations is driven by a range of factors, including unchecked rapid population growth, insufficient preparedness, lack of political will, excessive rainfall, construction on waterways, rising sea levels, soil moisture conditions, dam operations (particularly along borders), and climate change (MacLeod *et al*., 2021). Flooding can be caused by both human and natural factors (Oyegbile, 2008). According to Hunt (2005), the primary natural cause of climate change-induced flooding is excessive precipitation. However, Tramblay *et al*. (2021) associate the occurrence of floods more with the highest levels of soil moisture than with maximum precipitation.

This essay focuses on the floods in Owerri, North Imo State, Nigeria. Effective flood risk management requires understanding available data and forecasting extreme weather events. However, much work remains to be done. Mashi *et al*. (2019) reviewed Nigeria's emergency management laws and found them lacking in action plan preparation, resource mobilization, risk management strategies, and clear stakeholder responsibilities.

In their study, Odufuwa *et al.* (2012), solely took flood vulnerability and mapping into account. Nkwunonwo (2016) notes Nigeria's barriers to implementing global best practices for mitigation. In 2019, Mashi, Oghenejabor, and Inkani assessed areas vulnerable to flooding disasters and offered solutions to lessen the danger. The strengths and disadvantages of various urban flood models for emerging nations like Nigeria are reviewed by Nkwunonwo *et al*. (2020); and Echendu (2022). West African flood risk management and coastal erosion are reviewed by Alves *et al*. (2020). Echendu's (2022) findings indicate that policymakers are unaware of the link between Nigeria's floods and its food security and Sustainable Development Goals (SDGs). The author provides recommendations for mitigating flooding. Dube *et al*. (2022) utilize the SDG framework and the Sendai Framework for Disaster Risk Reduction 2015-2030 to suggest measures for managing flood risk to human settlements in South Africa.

In this study, we will be examining various methods for flood mapping and modeling that have not been utilized in Nigeria before. We will also be looking at research on flood occurrences in Nigeria from 2011 to 2020 with the goal of highlighting opportunities for managing and reducing the risk of flooding through efficient data modeling and prediction. Our focus is not on conducting statistical analysis. The study will also present data-driven and Bayesian methods as alternatives for flood modeling in Nigeria, emphasizing the importance of better prediction in reducing the effects of floods and managing water resources (Aderogba, 2012). To our knowledge, Nigeria has not made use of these strategies. Furthermore, the subsequent segment will examine the frequency and causes of flooding in Nigeria, along with a collection of statistics on flood frequency. The following sections concern flood mapping and modeling in Nigeria and describe promising approaches used elsewhere that could be exploited in Nigeria. The final sections present discussion and conclusions.

Statement of the Research Problem

This study investigates the topographical factors contributing to flooding in Owerri North, with a focus on the natural environmental components that exacerbate flood risk. Building on existing research that has predominantly emphasized anthropogenic influences, this inquiry highlights the crucial role of terrain characteristics, such as slope morphology, contour patterns, and flood-prone areas, in shaping flood vulnerability. Despite governmental efforts to mitigate flooding, the persistence of flood events underscores the need for a more nuanced understanding of the interplay between urban development and natural environmental factors. By conducting a comprehensive topographical analysis of Owerri North, this research aims to inform evidence-based land use planning and flood risk management strategies that accommodate the natural hydrological processes and mitigate the impacts of flooding in the study area.

Aim and Objectives of the Study

The aim of the article's research is to create an affordable GIS and remote sensing method for analyzing the topographical impact on flooding in Owerri North.

The specific goals of this study are to:

1. One of the main objectives of the study is to generate Digital Elevation Models (DEMs) to assess the impact of topography in the study area.
2. To investigate the effects of slope, slope type, aspect, and stream order on Owerri Urban floods, ascertain the flood dimensions of the selected flood locations.
3. Determining flood-prone and flood-prone regions in the research area and recommending them to town planners and environmental agencies for effective town planning

The rationale of the Study

Despite numerous studies on the human impact, the damage caused by flooding in Owerri North has yet to be fully quantified. To address this issue, a method that utilizes modern GIS and remote sensing technologies for topographical analysis is needed. The study suggests using affordable, medium-resolution remote sensing data to reach this objective. By comprehending the factors and trends behind major floods in the region, proactive steps can be implemented to minimize the requirement for expensive interventions. The impacts of flooding are extensive and encompass loss of life and property, damage to infrastructure, spread of disease, and loss of agricultural land. Without accurate mapping and resolution, the problem of flooding in the area will persist.

Materials and Methods

Study Area

One of the three local governments of Imo State, Nigeria's capital city of Owerri Urban Fig. (1), is Owerri North. The region was once home to the Igbo people but in the late 19^{th} century, the British colonized it. During the colonial era, Owerri saw substantial development as administrative and educational institutions were established. Following independence, Owerri grew even more and in 1976 it was designated as the capital of Imo State. Since then, the city has developed into a thriving center for government, business, and culture (Ogbonna *et al*., 2015). Owerri North has experienced significant infrastructure and economic growth, establishing itself as a major metropolitan hub in Imo State, southeast Nigeria (Fig. 2). The city embodies a blend of traditional Igbo heritage and modern influences, making it a unique and dynamic part of Nigeria's history (Iro, 2020).

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Landscape of Owerri North Owerri

Nigeria's Imo State capital, Owerri, features a diverse terrain that includes suburban and urban areas. The city's skyline is characterized by modern structures, administrative buildings, schools, and shopping malls. Owerri North has experienced urbanization and development, with the city's infrastructure, including highways and bridges, connecting its various areas (Wizor and Week, 2014). In Imo State, there are extensive open spaces, parks, and residential neighborhoods surrounding the metropolitan centers. The area also features markets, cultural hubs, and places of worship, reflecting the diverse and vibrant population. The terrain of Imo State is diverse, including plains, hills, and rivers, which greatly impact agriculture, land use, and settlement patterns. Hills and rivers contribute to the overall richness of the environment, while plains are suitable for agricultural and urban development.

Owerri North serves as a regional administrative and economic hub, thanks to its relatively flat topography. It's important to note that, like any city, Owerri's landscape evolves over time due to infrastructure development, construction projects, and urban planning.

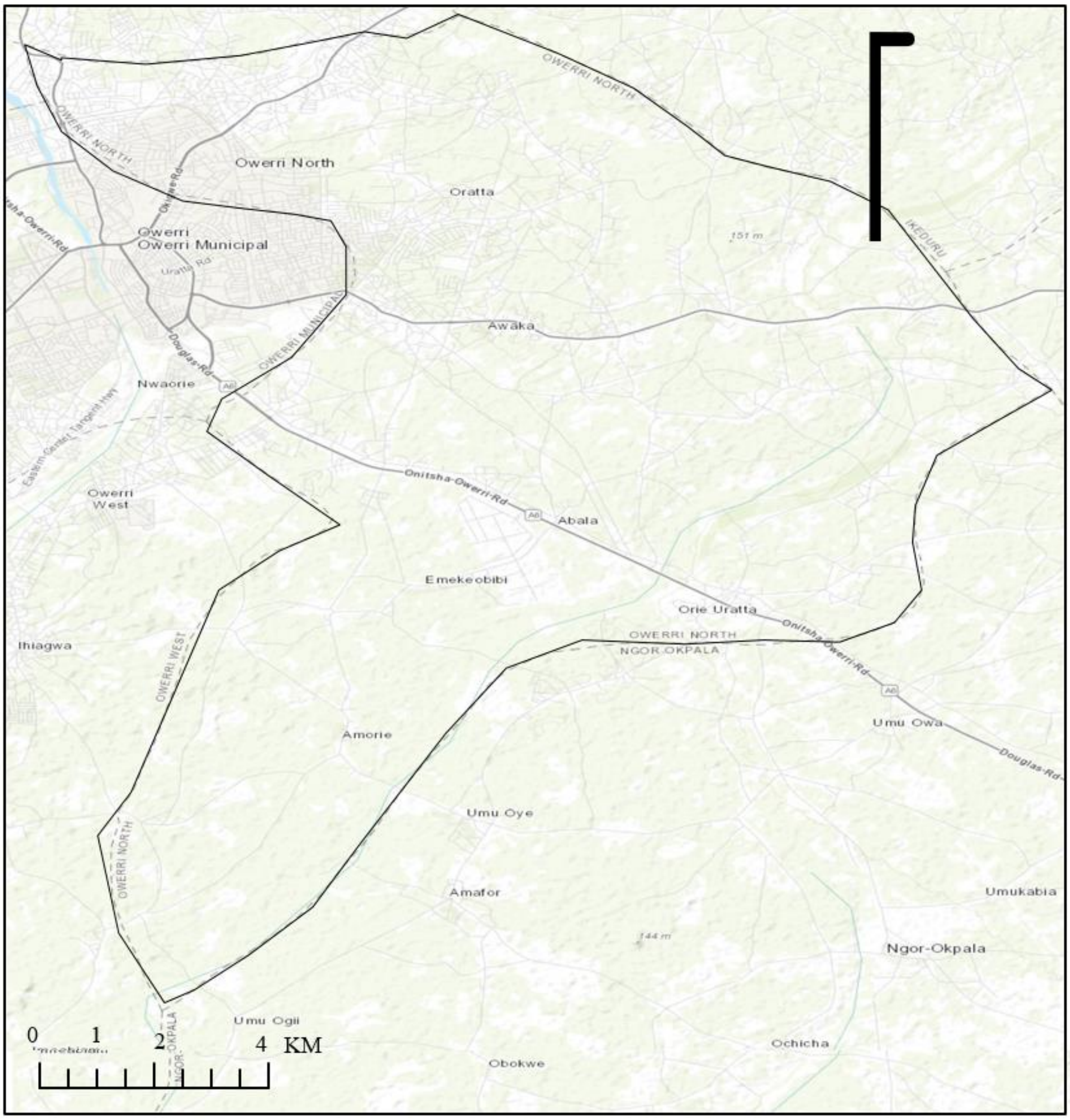

Fig. 1: Map of Owerri North Imo state

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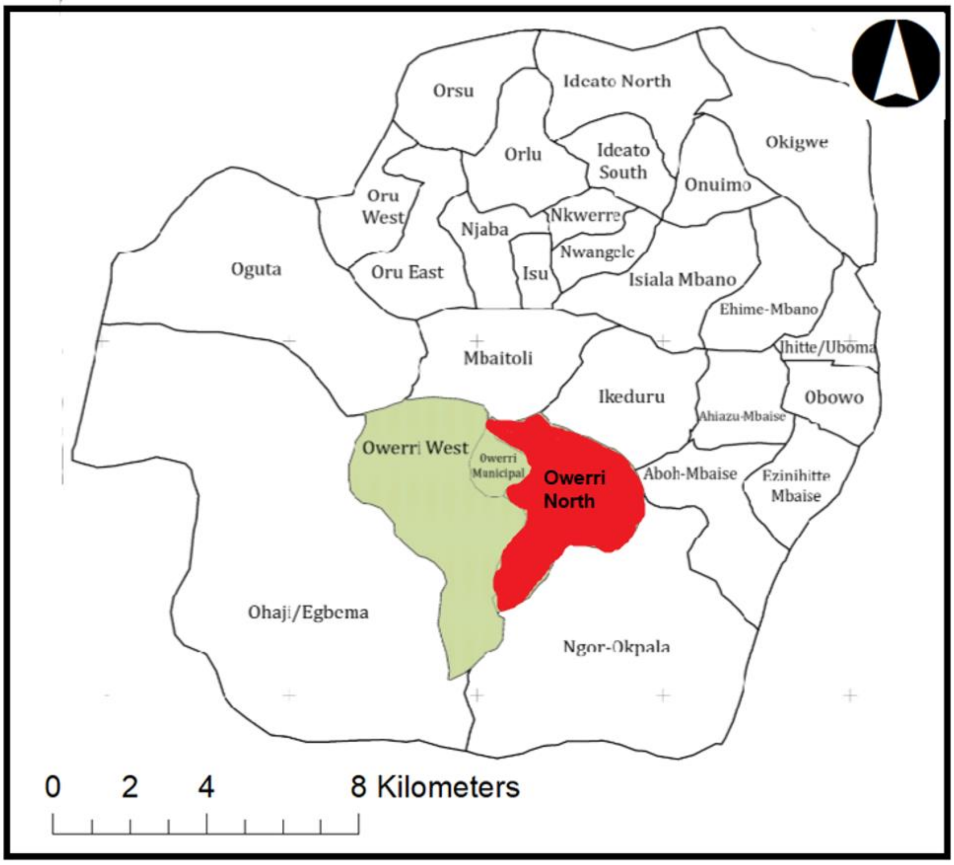

Fig. 2: Owerri North highlighted within Imo State. Study area outlined for context

Data Acquisition and Sources

As previously said, the purpose of this study was to use satellite remote sensing to examine and evaluate the function of the physical environment as a precipitating factor for floods and flood inundation in Owerri Urban.

The methodology based on the Digital Elevation Model (DEM) is recommended for analyzing the physical effects of floods in Owerri Urban and is crucial for the significance of this study. The research methodologies mentioned offer a cost-effective approach to flood investigation by helping determine the causes. Remote sensing data is considered a reliable and accessible technology for the study region, with a reasonable price and high utility. The Shuttle Radar Topography Mission's instant accessibility and extensive coverage make it superior to other remote sensing methods.

Shuttle Radar Topography Mission (SRTM) DEM

The White House announced on September 23, 2014, that the highest-resolution topographic data created by NASA's Shuttle Radar Topography Mission (SRTM) in 2000 would be made publicly available by 2015. Following this announcement at the UN Heads of State Climate Summit in New York, an accelerated schedule was implemented, leading to the publication of all SRTM data worldwide. The publicly available SRTM topographic data with 90 m pixels and lower resolution has been widely available since 2003 and has become the industry standard for many applications. The recently updated data provides detailed information about the world's landforms, originally estimated by SRTM Figure, with a pixel spacing of 30 m (National Aeronautics and Space Administration, 2014). The Digital Elevation Model at a 30-meter resolution has been particularly beneficial for mapping Africa's topography since its publication. It has been used for terrain analysis and calculations in various studies such as soil/gully erosion, hydrology, flooding, geographical mapping, and changes (Dalil *et al*., 2015; Ikusemoran *et al*., 2014). Ever since the introduction of this 30 m resolution, there have been fewer artifacts. There has been an improvement in horizontal and vertical precision and the values for the water bodies are more accurate (Mispan *et al*., 2015). According to recent research by Yue *et al*. (2015), the SRTM dataset can represent the ground more accurately than the Aster version 2 elevation model in hilly and rugged terrain.

Materials and Methods

This study utilizes remote sensing methodology to process satellite data. The process includes analyzing Digital Elevation Models (DEMs) of the study area, studying Landsat imagery, and correlating coordinate points from the field with satellite images.

SRTM (DEM) for Topographical Analysis of the Study Area

SRTM (USGS DEM) image was utilized to obtain the topography's structure and contribution to flooding in the research area. This study utilized the recently released 30×30 m SRTM data for the research area, which was obtained from the Shuttle Radar Topography Mission Dataset (Iro, 2020). The dataset was selected to provide a current topographical view of the research area to aid in both qualitative and quantitative topographic analysis. The DEM was downloaded and then limited to the area of interest as shown in Fig. (3). The low elevation is 45 m and the high elevation is 144 m. The elevation data from the study area includes hill shade, slope gradient, slope aspect, and area contour. Topography is a crucial factor influencing flooding (Iro and Acholonu, 2020). Geographic Information Systems (GIS) frequently use Digital Elevation Models (DEMs) to depict topography and to extract topographical and hydrological features for a variety of purposes, such as studying floods and their effects (Iro 2020). Studies use a Digital Elevation Model (DEM) to analyze the topographical features of a research area, as topography plays a crucial role in flood modeling (Iro, 2021).

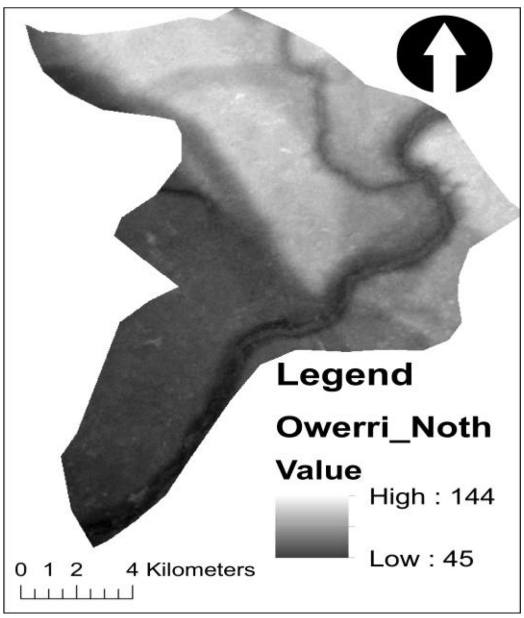

Fig. 3: An SRTM DEM image of the study area, cropped to the area of interest (USGS 2023)

The phase of the hydrologic cycle closely related to runoff is surface runoff. It is influenced by the landscape's topography and must be thoroughly analyzed throughout its full range. Digital Elevation Models (DEMs) are used to achieve this (Oliveira, 2013). The studies created using a DEM allow for a flat geometric projection of the model. They include greyscale images, shaded images, themed images, profile studies, and the production of derivative maps for analysis. This includes steepness and exposure maps, drainage maps, contour maps, slope maps, and aspect maps, all of which were created from the Owerri North DEM.

Results

This section will present the results of the data analysis. The landscape's topography significantly influences the runoff of an area (Poesen *et al*., 2003; Boardman and Poesen, 2007; Bochet, 2004; Igbokwe *et al.*, 2008). According to Iro (2021), the topography of Owerri Urban, Imo State, Nigeria, is the main cause of flooding in the area. Specifically, Iro (2020) identified the topography of Owerri North, Imo State, Nigeria, as the primary factor contributing to flooding in the region. Additionally, Iro and Pat-Mbano (2022) found a positive correlation between topography and runoff in Owerri, indicating more severe flood inundation in flat regions than in valley lands.

Regional Topographical Analysis

The topography of the land has been found to have a significant impact on runoff and flooding processes (Iro and Ezedike, 2020). This study examines the natural factors contributing to flood development in the study area, which is known to be influenced by both topographic and human disturbances (Nkeki *et al*. 2013; Igbokwe *et al.*, 2008). This chapter presents an analysis of elevation, slope, slope aspect, contour generation, and hillshade, with subsections discussing the influence of each variable.

Elevation

Generating Digital Elevation Models (DEM) to analyze the topographical impact on flooding in Owerri North, considering aspect, hills-hade, slope, and slope type as shown in Fig. (4), is one method for accomplishing the objectives. This study aims to examine how topographic characteristics influence flooding and flood inundation in the study area, with a specific focus on elevation.

Slope

The gradient of the slope is one of the key factors causing floods and this section addresses goal 1. By demonstrating that the flood spots that are being examined are at the base of slopes that range from $0\text{-}20^0$ and $21\text{-}40^0$. The significance of the slope is further emphasized in Fig. (5) (Iro, 2021). According to Iro (2020), most flood-inundated areas are on level ground, although land on steep inclines is more vulnerable to water runoff.

The gradient of the slope is a key factor contributing to floods and this section addresses the first goal mentioned. It demonstrates that the flood-prone areas being studied are located at the base of slopes ranging from $0\text{-}20^0$ and $21\text{-}40^0$. The significance of the slope is further highlighted in Fig. (5). According to Iro (2020), while the majority of flood-affected areas are on level ground, land on steep inclines is more susceptible to water runoff.

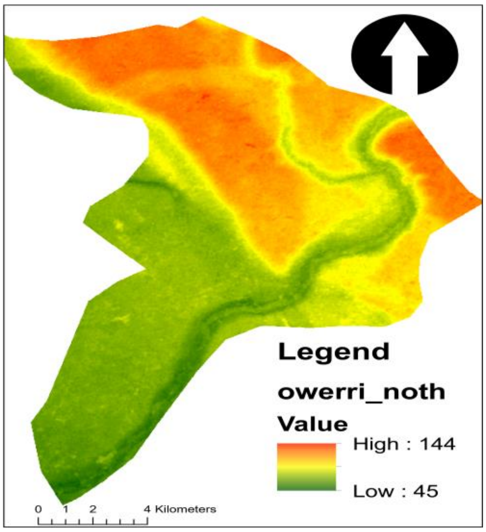

Fig. 4: An SRTM Elevation image of the study area, cropped to the area of interest (USGS 2023)

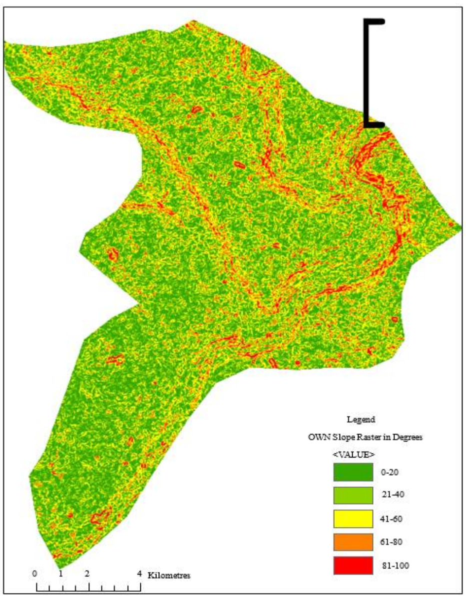

Fig. 5: Maximum slope map of the study area shown as a degree gradient (flat areas have 0-40, $41\text{-}60^0$ gentle slope and 61^0 and greater or higher)

Slope Aspect

Additional topographic investigation was carried out by examining the slope aspect. Ten classes were identified from the study area's aspect map (Fig. 6): Flat, N, NE, E, SE, S, SW, W, and NW. Based on this, Owerri North's aspect classes show a rather uniform distribution. When compared to the south, southeast, and southwest, slopes facing north to north-west somewhat prevail; Flat areas, such as flood plains, fluvial terraces, river courses, and hill plains, are assigned a value of 1. This value indicates the location of flood plains.

Contour Map

Gradient indicates the rate of elevation change over distance. A contour map is created using the DEM data of the study area. Observing the contour map Fig. (7) will show how the areas around the flood-inundated points are higher ground above 61 m than the areas where the flood-inundated areas are located that are below 61 m. The contour map reveals that areas, where the contours are higher (61-100 m), are areas where the highest runoff is generated to form a flood at the flat area (0-60 m).

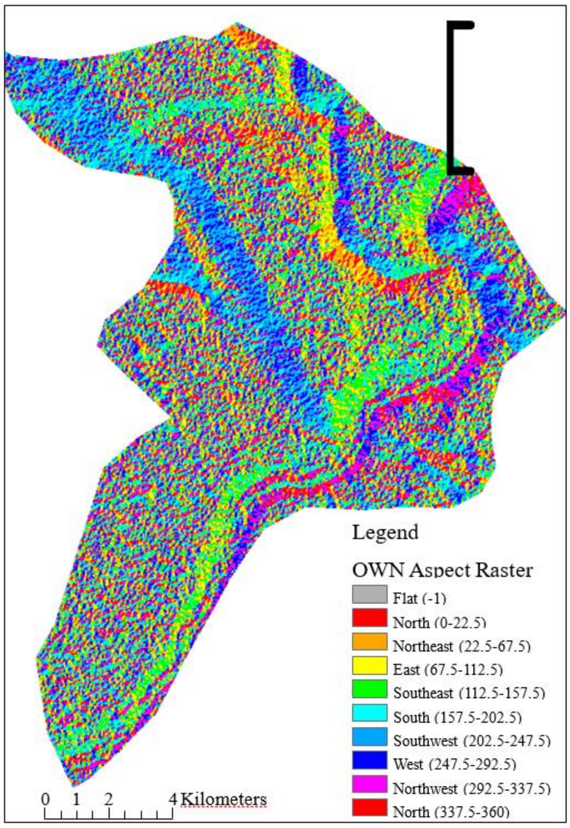

Fig. 6: Slope Aspect map: Flat (-1), N (0-22.5), NE (22.5-67.5), E (67.5-112.5), SE (112.5-157.5), S (157.5-202.5), SW (202.5-247.5), W (247.5-292.5), NW (292.5-337.5 and N (337.5-360)

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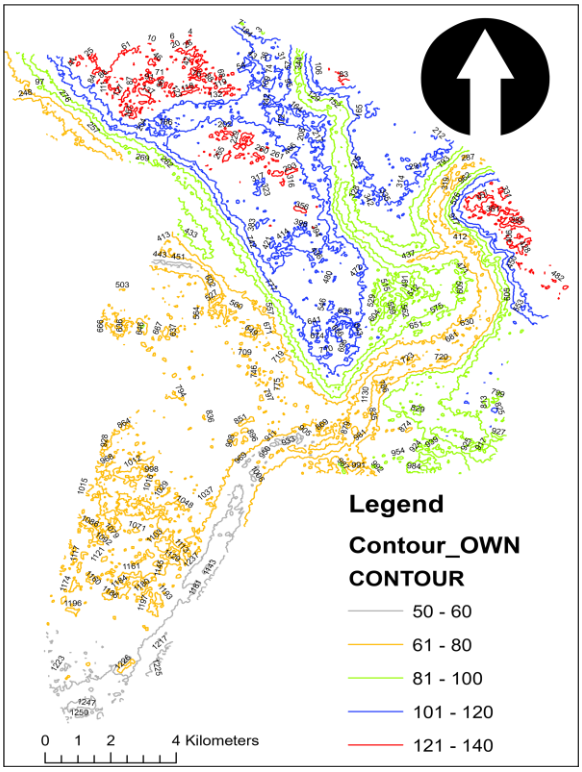

Fig. 7: Contour map of the study area showing the contour lines

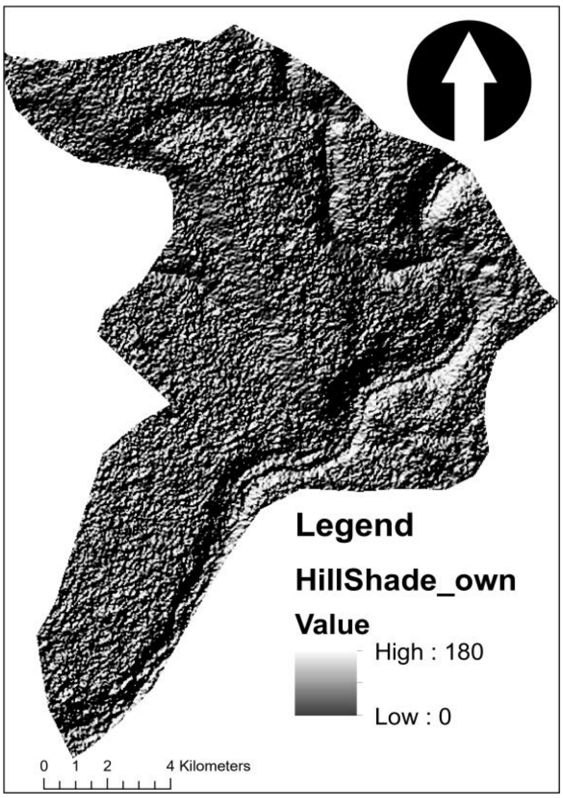

Fig. 8: Hillshade map showing Sunken areas as rivers and water bodies

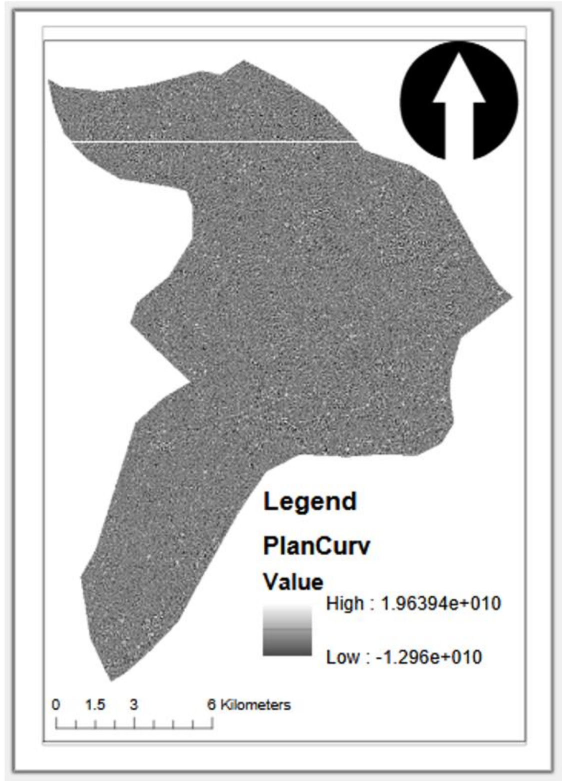

Fig. 9: Curvature of the slope of the study area. The low values of -1 ($\times10^6$) of plan curvatures define convexity; while high values of 1 ($\times10^6$) plan curvatures characterize concavity of slope curvature.

Hill Shade

The hill shade of the study area was created from the Digital Elevation Model (DEM), producing a shaded representation of the terrain by accounting for the angle of the light source and shadows. This visualizes the topography of the study area (Fig. 8). The Slope tool is commonly applied to elevation data sets.

Slope Plan Curvature

The curvature is crucial in understanding how run-off flows in the study area, which can affect flooding. Low values of -1 (×106) for plan curvatures indicate convexity, while high values of 1 (×106) for plan curvatures indicate concavity of slope curvature. Plan curvature values around zero suggest that the surface is flat. The curvature data from across the study region is depicted in Fig. (9).

Discussion

In this section, the results will be discussed in relation to the aims and objectives, with reference to theories and expectations derived from the literature. The discussion will begin by analyzing the physical activities and topographical influences that affect flood development, based on the analyses undertaken. Following this, the main results will be explored in greater detail. When necessary, the discussion will refer back to the results section and the literature review.

Nature of Flood Development on Slope

The study aims to Create Digital Elevation Models (DEM) to evaluate the impact of topography in the study area, representing one of the specific goals. Determine the flood dimensions of targeted flood sites to examine how Owerri Urban flooding is influenced by slope, slope type, aspect, and stream order. Determining flood-prone and flood-prone regions in the research area and recommending them to town planners and environmental agencies for effective town planning. The South East Nigeria study area exhibits a varied topography, featuring gentle to steep slopes, with extreme inclines reaching up to 400% in certain areas (Fig. 4). Conversely, areas with slopes less than 200% are characterized by gentle slopes and flat terrain, including river courses, floodplains, and hilltops. According to Igbokwe *et al*. (2008), areas with slopes greater than 100% are prone to high runoff, as the kinetic energy increases with higher slope angles, supporting the theoretical notion that steeper slopes facilitate greater runoff. The findings of this study indicate that most floodplains are located at the base of flat land slopes. For instance, areas like Dick Tiger, Egbu, and Amakohia experience flood inundation at slopes with areas of 20^0 and below while the upper part of the slope ahead of them has areas ranging from 21^0 and above at a 30 m resolution. As the streams converge from lower to higher stream orders at the slope base, there is an increase in energy-carrying eroded materials from deep incisions made at those points. The slope influences runoff and drainage, significantly impacting the soil's moisture regime. Previous studies by Poesen *et al*. (2003); Teme (2001); and Bennard (2012) have noted that slope generates runoff, leading to flooding and flood inundation. The studies highlighted that valley topography plays a significant role in flood generation. They suggested that steeper and longer slopes lead to higher runoffs. However, they also emphasized the importance of other factors for such runoffs to occur, with the loss of vegetation being identified as a key driver. In Owerri North, Iro (2020); and Oyegbile (2008) all concurred that most flooding in the area can be attributed to the natural slope of the topography, with inclinations of greater than 20 degrees contributing to high runoff and eventual flooding in the study area. In Owerri North, 95% of the flood sites investigated in this study are found in the lower areas of high slopes. This was determined through field visits and by overlaying flood points on slope maps (Fig. 5). The analysis of the slope at flood sites such as Afor Egbu, Amakohia, and Umuoba indicates that these areas have developed on slopes greater than 200 at 30 m resolution. The analysis has revealed that flooding in the study area, along with other contributing factors, is influenced by the nature of the slope. It has been observed that when other factors such as vegetation loss, gully stream order, and unconsolidated soil are in place, the slope provides the ideal conditions to trigger flood development. Without this characteristic, it is unlikely for the level of flooding required to form flood sites to occur.

Influence of Aspect (Slope Direction) on Flooding

Please take note of the following text.

The aspect map for Owerri North is mainly characterized by slopes facing N (337.5-360) to NW (292.5-337.5) (Fig. 6 and histogram). Despite this dominance, the floods do not consistently follow this pattern. The southern slopes intermittently experience both dry and wet conditions due to greater sun exposure and higher rainfall from the Tropical Maritime Air mass moving up from the southern part of Nigeria (Oladipupo 2003). The southern-facing slopes in the study area are subject to both extremes, as the northern slopes are exposed. Areas with aspect map values around -1 represent flat surfaces (Fig. 6), which are prone to flooding and are often locations of rivers. The slopes undergo rapid geomorphic changes due to the high rainfall from the Tropical Maritime Air Mass (as reported in Igwe, 2020). Pulice *et al*. (2009) note that the slope's aspect indirectly influences flooding processes by affecting exposure to various climate conditions such as sunlight duration, precipitation intensity, and moisture retention. Although flooding occurs in various aspect locations in the study area, it is predominantly concentrated on the south-facing slopes, where climatic extremes are more severe.

Curvature as an Aspect of Slope in Flood Development

Slope curvatures were determined in conjunction with slope magnitudes. The curvatures of the study area ranged from -1 plan, defining convexity; to high values of 1 plan characterizing concavity Fig. (9). The relationship between gullies and plan curvatures in Owerri North Nigeria shows that runoff processes commonly occur on concave slopes. Studies by Gobin revealed that 60% of the gullies in southeast Nigeria occur on concave slopes (Gobin *et al*., 1998). In terrain analysis, hills, and moderate relief can produce curvatures that range from -0.5 to 0.5. For mountains, and steep, rugged terrain, the values can vary between -4 and 4 (Environmental Systems Research Institute, 2011). The landscape's nature can be partially determined by analyzing these curvatures; negative values typically represent gullies and river courses, while positive values are more indicative of uneroded landscapes. This analysis demonstrates that the topography partly contributes to flooding in the study area. In this study area, the values range between -5 and 6, signifying a gentle slope relief (Fig. 9). Accordingly, the area receiving high runoff from hilly areas could be the cause of flooding in flat areas. A high value of 6 indicates that the surface is upwardly concave at more cells, contributing to accelerated flow and potentially influencing runoff development. This helps to explain the development of flooding in the area in combination with other identified factors. The finding is supported by Beshah (2003); Bewke (2003); Igwe (2020), observing that concave hillsides' slope geometry can significantly contribute to runoff and flood development in level areas. Most of the flooding sites surveyed in the study area are located on convex slopes, demonstrating a high proportion.

Influence of Contour of Owerri North in Flooding

Observing the contour map Fig. (7) will show how the areas around the flood-inundated areas are higher ground above 50 m than the areas where the flood-inundated areas are located that are below 50 m. The contour map reveals that areas where the contours are higher are areas where the highest runoff is generated to form a flood in the flat area.

Conclusion

Although flooding is a yearly issue in Nigeria, the negative effects can be lessened with wise management. Therefore, research that can help control the hazards connected with flooding more effectively is quite valuable. Comprehending the data at hand and forecasting extreme occurrences are necessary for this. Flood risk management should be concentrated in Owerri North, as this area is the most affected by flooding.

Different methods, such as GIS and Remote Sensing, have been used to model flooding in Nigeria. However, these approaches have been found to have limitations. Therefore, it is important to consider alternative methods that have proven effective in other countries. For example, data-driven and Bayesian methods used in simulating extreme precipitation, water-level discharge, or river flow gauge data in countries like Australia, China, Vietnam, and the United Kingdom could be valuable in comprehending, forecasting, and reducing flood hazards in the Owerri North region as part of a comprehensive flood management approach. Although not yet applied in Nigeria, these methods could offer important resources for managing floods.

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Ethics

The research is conducted in a responsible, transparent, and accountable manner.

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