

Vulnerability Dynamics and Urban Flood Hazardscape Pattern: A Geospatial Analysis in Gombe City, Nigeria

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ABSTRACT

In many Nigerian states, urban flooding has resulted into the death of numerous people and destruction of properties worth billions of Naira. This study examined the vulnerability dynamics and urban flood hazardscape pattern within Gombe city with a view to providing bases for policy formulation (where necessary), enforcement and decision making on flood risk reduction for enable sustainable urban development. ASTER DEM and Landsat images (2000, 2010 and 2019) was used to generate Digital Terrain Model (DTM) and impervious surface areas. Rainfall data for 2000-2018 was used to examine rainfall trend using regression analysis. The result revealed that flood hazardscape and vulnerability dynamics are largely influenced by physical and social factors. The results for vulnerability dynamics shows that as at 2000, about 1.4km² lies on the relatively low vulnerable area, 4.1km² falls within the moderate, and about 14.6km² falls on critical area. By 2010, only about 1km² lies on the relatively low area, 5.2km² occupied the moderate and about 15km² was found within the critically vulnerable area. In 2019, the vulnerability dynamics depicts that about 33.4km², impervious surface (builtup area) existed, out of which 2.8km² lies on the low vulnerable area, 9.4km² on the moderately vulnerable and 21.2km² in critically vulnerable areas. It is concluded that flood hazardscape and vulnerability dynamics in Gombe city is influenced by both physical and anthropogenic factors. It is recommended that planning departments should put into consideration urban flood hazardscape maps for future development so as to reduce the risk and control future exposure flood impact.

Keywords : Impervious surfaces; Feature extraction; Hazardscape; Urban flood; Vulnerability dynamics

1. Introduction

Floods are a type of natural calamity that cause both property damage and loss of life. They are said to be the most frequent and pervasive disaster in the globe, resulting in fatalities and severe economic and environmental damage (Wang et al., 2011; Mojaddadi et al., 2017). Extreme weather event's frequency and intensity (such as drought and rainfall) that causes floods and landslides, are unavoidable, particularly due to human intervention with the climate system (Hardoy et al., 2013). Between 1995 and 2015, according to estimates from the United Nations (UN), floods affected over 2.3 billion people and claimed 157,000 lives worldwide (Wahistrom et al., 2015). Floods around the world cost the economy close to 386 billion US dollars within the last three decades of the 20th century (Wang et al., 2011).

Studies on flood vulnerability have utilized both physical and socioeconomic indices (Clark et al. 1998). According to Dewan (2013), there are four physical signs that a region is more susceptible to flooding: Elevation (Low-lying lands are riskier and residents' infrastructures exposure to flooding are greater); Distance from channels because susceptibility is increased by closeness to active channels; Given the fact that the potential impact of floods is greater in built-up regions, landuse and or land cover are not a negligible predictor of susceptibility. Lastly, drainage systems: Insufficient canalization is likely to exacerbate vulnerability (Balica et al., 2012). Assessing the spatial flood susceptibility is greatly influenced by the elevation and slope. Flooding is more likely to occur in low-lying plains with gentle slopes than in high-lying places with steep slopes (Huq et al. 2017). A approach to evaluate flood risks was developed by Karmakar et al. (2010) and includes exposure to flood water, vulnerability to floods, and the likelihood that a flood will occur. This study used a conceptual framework of flood vulnerability from the Hazard of place theory of vulnerability by Cutter et al. (2012) to evaluate flood hazardscape, vulnerability, and its dynamics in Gombe city (Figure 1).

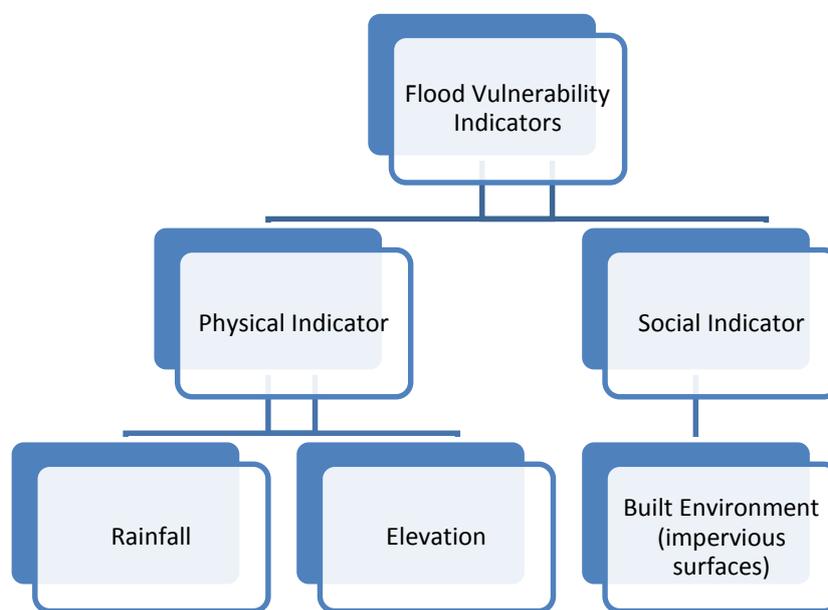


Figure 1. Conceptual framework on flood vulnerability indicators
Source: adapted from Cutter et. al (2012)

The Chambers (1989), Wisner et al. (2004) and other vulnerability models are among those that the Hazard of Place Model of Vulnerability tries to combine. By merging biophysical and social vulnerability theory, Cutter (1996) enables a comprehensive understanding of vulnerability. The biophysical vulnerability theory views vulnerability as an already-existing environmental situation and focuses on the environmental processes that produce dangerous conditions. By evaluating how close people are to the threat, estimates of biophysical vulnerability are primarily determined (Cutter, 1996). According to the social vulnerability theory, a wide range of variables, such as economic conditions, development, social interactions, and political power, as well as indicators such as race, gender, age, and income variables, have an impact on patterns of susceptibility (Wisner et al., 2004). Based on this, this study combined a social factor (built-up or impervious surfaces) with a physical factor (elevation and rainfall) to determine the dynamics of flood hazardscape and susceptibility in Gombe city from 2000 to 2019.

Urbanization's rise in impermeable surfaces, the expansion of informal settlements within low-lying floodplains, improper waste management, lack of adequate and well-connected drainage system,

and inadequate maintenance are only a few human activities that significantly enhance the danger of flooding (Douglars et al. 2008, Agbola et al., 2012, Eguaroje et al. 2015). Because of the location of informal settlements, urban poor in most developing nations who reside in cities are affected by the hazards of climate change resulting in floods (Baker, 2012). Flood as the most common disaster in Africa affects about 500,000 people on average each year in West Africa (Douglas et al 2008). Urbanization-related anthropogenic effect has a significant impact on urban flood risk in African cities. Cities in developing nations are frequently at high risk and vulnerable because of socioeconomic issues and poor physical infrastructure (Henderson, 2004).

Floods have been devastating practically all of Nigeria's states, from riverine regions in the south to northern states, causing infrastructure to collapse, sinking structures in both rural and urban areas, killing people, and compelling many to leave their homes temporarily or permanently (Adedeji et al., 2011). Due to fast population change which creates high demand for land and ensuing urban development processes, particularly the increasing number of settlements on floodplains, Gombe is one of the cities afflicted by urban flooding, making the urban poor vulnerable to flood risk (Daniel et al., 2012). There have been numerous studies on flooding in Nigeria and Gombe city, including those by Dabara et al., (2012); Abashiya et al., (2017); Daffi, 2014; Agbonkhese et al. 2014; Webster et al. 2014; Ejikeme et al. (2015) ; Emmanuel (2016); Chan et al. (2011); Biondi et al. (2013); Eze et al. 2018; Bamidele & Badiora, 2019 and Azua et al. 2019. To influence the creation and implementation of planning and policy aimed at preventing, reducing, and mitigating the risks associated with urban flooding for sustainable urban development, none of these researchers examined the pattern of urban flood hazardscape based on physical factors (location, terrain, and rainfall) and the vulnerability dynamics. Therefore, this study examined the vulnerability dynamics and urban flood hazardscape pattern within Gombe city.

2. Study Area

Gombe city is geographically located within latitude 10° 15' 02" N and 10°20'00" N and longitude 11°05'00"E and 11°15'05"E (Figure 2). The city shares a common border with Kwami from the north, Yamaltu-Deba Local Government Area to the east, and Akko to the south and west. Being the capital of Gombe state, the city has about 52 km² total area of land (Ministry of Lands and Survey Gombe, 2009). Centrifugal expansion, building densification, and changes to the urban design were shown by the geographical and chronological examination of Gombe city's layout. Due to this expansion, the traditional town and 60 peri-urban settlements were combined in 1997 to form one urban area, which grew to a size of 30 km² in 2000 (Balzerek et al., 2003). This growth has caused urban areas to encroach far beyond the designated town boundaries, which was followed by considerable change in land use that increased the impervious surface and decreased the pace at which rainwater infiltrated into the ground. The Gombe urban area has good road access to other regional hubs. The town is home to many residential neighborhoods, including Pantami, GRA, Arawa, State Low Cost, Kumbiya-kumbiya, Madaki, Federal Low Cost, Tudun Wada, Dawaki, Yalanguruza, Bolari, Jekadafari and Shamaki, among others.

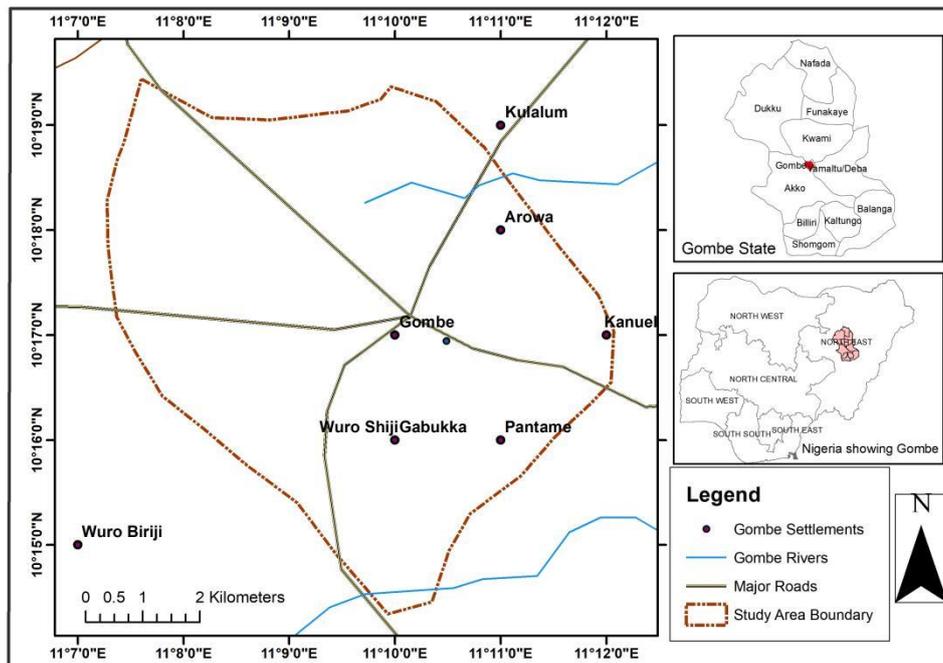


Figure 2. Gombe State and the study area (Gombe City)

The Inter-Tropical Convergence Zone's movement mostly determines the dry and wet seasons of Gombe's climate (ITCZ). It receives 835mm of precipitation on average annually (between May and September), with its peak occurring in August (Amos et al., 2015). The relative humidity follows a similar trend throughout the year, peaking in August at about 94 percent and falling to less than 10 percent during the Harmatan season. The average yearly temperature is roughly 26°C (Balzerek et al., 2003). Flooding is due to a change in the weather (rainfall pattern) (Abashiya et al., 2017).

Sandstones make up most of the bedrock, which is then covered by tertiary and quaternary deposits. The city is situated on a low-lying and undulating terrain that slopes from the Liji hill in the east to the Akko escarpment in the west. The city is continuously expanding into areas with mountainous terrain because of urbanization (with elevation of about 622m). The city was built on a complex geologic relief made up of crystalline bedrock, much of which is supported by sedimentary formation and old crystalline basement complexes. The northern limit of Gombe City is marked by the Kerri-Kerri formation, which forms a plateau. A breached and irregular cliff that rises over 150 meters above the surrounding plain in certain places serves as the southern edge's defining feature. The area is surrounded by terrain that is hilly and with steep sides along the lower portions of the gently undulating slopes (east-facing at 2°–3°). Gombe and Liji hills located within a section of the Benue Trough (Zambuk ridge), are two of the region's most notable landforms. Alluvium deposits make up most soils created in-situ by the bedrock's chemical and physical breakdown. The alluvium covered area rises westward; however, it has been estimated that about 10% of the Gombe Formation is beneath alluvium (Obaje, 1999).

Urban Gombe's population has increased by 6.79 percent from 266,844 in 2006 to the estimated 542,012 in 2019, according to the National Population Census. From 1900 to 1952, Gombe Town's population grew slowly (by 300 to 18,500 people), but from 1964 to 1991, it grew dramatically (by 47,000 to 138,000 people). High demographic pressure on the land because of this population growth led to subsequent development activities like home construction. Indigenous tribes including the Fulani, Tera, Tangale, Bolewa, and other minority tribes live in Gombe. Flooding is a concern in Gombe City, and it is related to urbanization and population growth. Flood disasters will continue to have negative effects on the urban poor as urbanization increases (Alam et al., 2008). Urban flooding has been the

main environmental disaster in terms of ecological risks, leading to the loss of life, property, and homes as well as the eviction of residents in Gombe City.

3. Methods

3.1 Types and Sources of Data

The study's data sources include original sources of qualitative, quantitative, and remotely sensed data. Through interviews, the qualitative data was collected. The remotely sensed data are in the form of satellite images (Landsat images) and digital elevation models, whereas the quantitative data are rainfall data (ASTER DEM). The data's description is shown in Table 1.

Table 1. Characteristics of satellite images and digital elevation model used

Data type	Date	Resolution	Acquisition Source
Landsat (TM) P186/52, P187/52 and P187/53	Dec-2000	30m	USGS Earth Explorer Website
Landsat (TM) P186/52, P187/52 and P187/53	Dec-2010	30m	USGS Earth Explorer Website
Landsat (OLI) P186/52, P187/52 and P187/53	Dec-2019	30m	USGS Earth Explorer Website
Aster DEM	Dec-2019	30m	LP DAAC

Other types of data included rainfall data from NiMet for the years 2000 to 2018, which was utilized to assess the trend in rainfall during the research period. GPS was employed for ground truthing and to capture the coordinates of vulnerable locations discovered through vulnerability analysis. This makes it possible for validation of the identified dynamics.

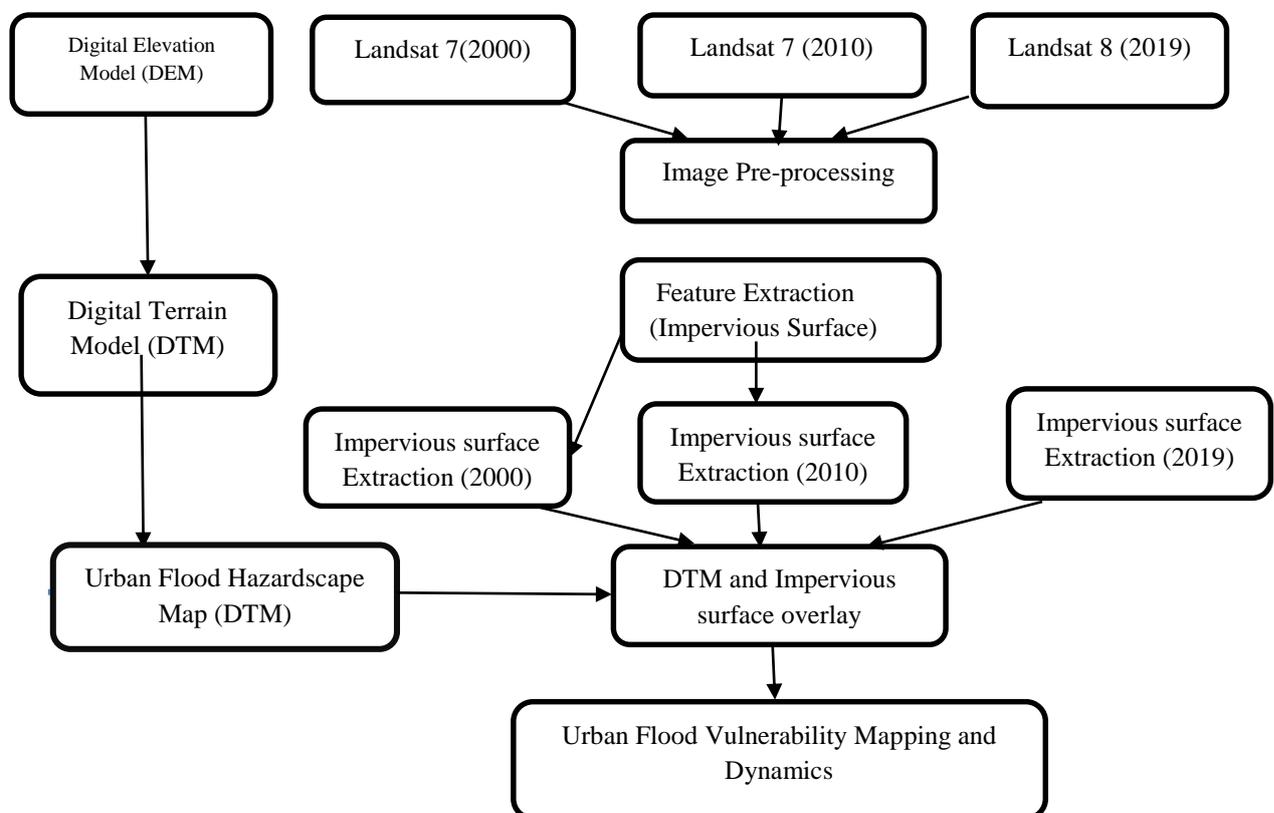


Figure 3. Methodology flow chart

3.2 Data Analysis

Clipping the DEM of Gombe city, from which the DTM was created, is the first step in the data analysis process as outlined in the methodology flowchart (Figure 4). In order to establish the pattern of urban flood threats, the DTM was divided into three elevation zones, referred to as low (360–461), intermediate (461–531), and high (531–622) (based on Natural Breaking). Due to its significance as a physical factor, flood hazardscape pattern was determined based on these elevation zones and divided into three categories (i.e Relatively low hazard, Moderate and Critical). Integrating factors exposed to the dangers, such as built-up areas (impervious surfaces) and the people residing there, is necessary to determine vulnerability and its dynamics. The research area was cut out using the Extraction tool in ArcMap 10.2 after the landsat pictures had first undergone preprocessing (to remove cloud and noise). Using the example-based feature extraction tool in ENVI 5.3 software, impervious surfaces were retrieved from all pictures taken at decadal intervals between 2000 and 2019 at each location. This was based on the spectral signature of the impervious surfaces and the textural features of the surfaces. To get intersections of impervious surfaces with the indicated hazard zones at different elevation levels, the classified digital terrain model and the extracted impervious surface data were combined, and the Raster Calculator tool (Arcmap 10.2) was used to run several queries. This made it possible to identify sensitive regions and how they changed over time because of urban growth. The area of the extracted impervious surfaces from the three time periods at different vulnerability levels was calculated using a zonal statistics program. To study the trend in rainfall pattern and the relationship with the dynamics of urban flood susceptibility, the rainfall data for Gombe city from 2000 to 2018 were studied using linear regression. Results were presented in tabular form, graphs, and maps to present the analysis' findings.

4. Results and Discussion

4.1 Urban Flood Hazardscape Based on Physical Factors (Elevation and Rainfall)

As rainfall receiving amounts are nearly consistent throughout the study area, it was discovered that the terrain's characteristics and elevation have a significant impact on the flood hazardscape. Figure 4 shows the pattern of urban flood dangers, which were classified into three zones: comparatively low, moderate, and critical.

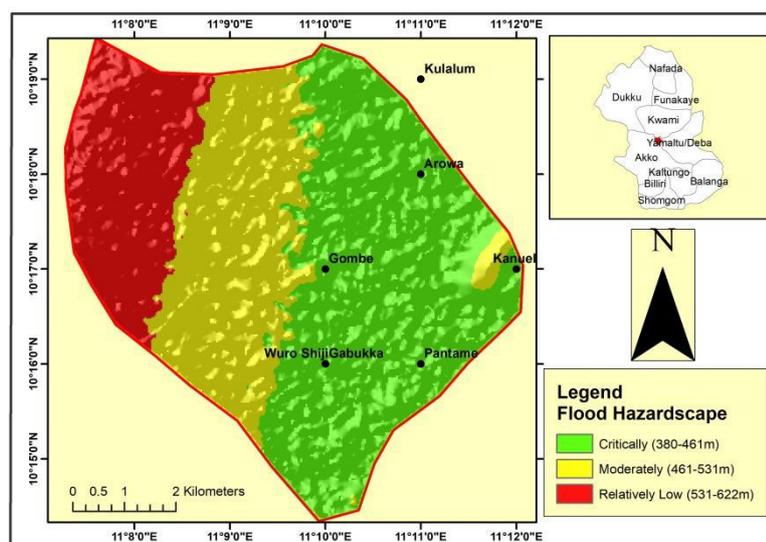


Figure 4. Flood hazardscape map

This, therefore, signifies that flood hazardscape pattern in Gombe city is largely influenced by elevation which defines the terrain into flood hazard zones (Table 2).

Table 2. Flood hazardscape zones

Elevation	Hazardscape Zone
380-461m	Critical Hazardscape Area
461-531m	Moderate Hazardscape Area
531-622m	Low Hazardscape Area

Arowa, Pantame, and Wuro Shijji Gabukka's environs were discovered to be particularly exposed to flooding, because they are in regions with very low elevation (ranging from about 380-461m above sea level). On the other hand, locations inside the extremely high elevation of roughly 531-622m between latitude 10⁰16'03" N and longitude 11⁰07'6" E and 11⁰08'6" E are nearly exempt from flooding (Low vulnerability).

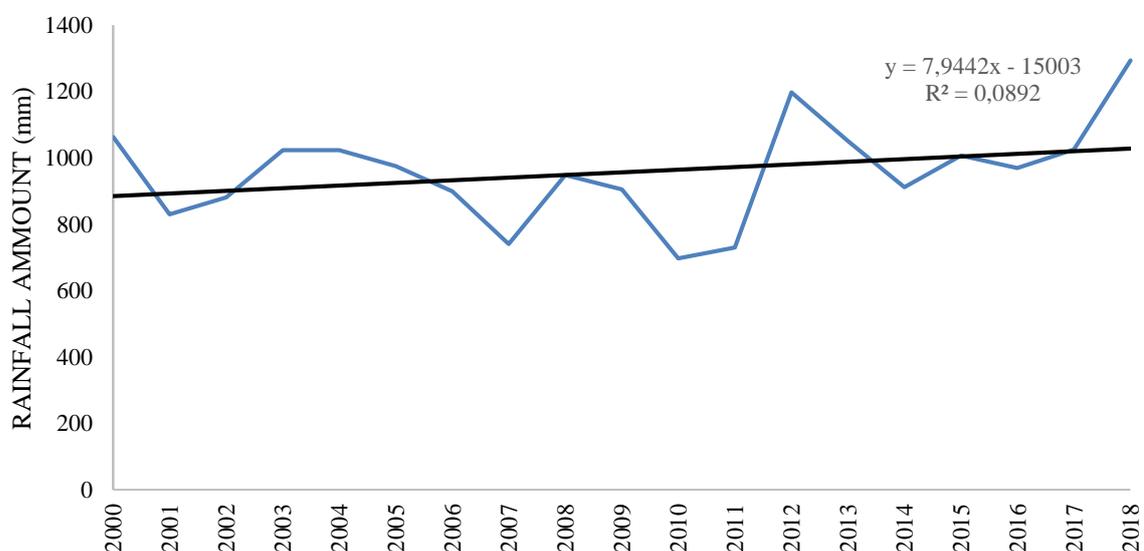


Figure 5. Annual Total Rainfall Trend in Gombe City (2000-2018)

Regarding the distribution of rainfall and how it affects flooding, Figure 5 illustrates a trend line that depicts variations in the rainfall pattern, particularly over the past ten years. A positive trend line showing an increase in rainfall reception in Gombe city is shown by the trend analysis. The increasing rainfall trend in Gombe is consistent with studies by Abaje et al. (2014) and Abashiya et al. (2017). These researches confirmed that Gombe is seeing an increase in rainfall, which also contributes to the occurrence of floods.

Regression analysis depicted rainfall trend/pattern the area, which is shown in Table 3. For the 19-year study period, the P-value derived from the rainfall slope is 0.2143; the value is greater than 0.05 and indicates that there is no statistically significant link between rainfall over time. Only 8.9% of the rainfall values match the regression analysis, according to the R² statistic (coefficient of determination), which is 0.08915. Given that rainfall intensity is one of the primary causes of urban floods in Gombe city, a rise in rainfall inevitably has an impact on the vulnerability of built-up areas to flooding.

Table 3. Summary of linear regression analysis showing rainfall trend in gombe (2000-2018)

Variable	Regression Equation	P-Value	Significance	R ²
Gombe	Y=7.9442x-15003	0.214344409	No	0.089152663

4.2 Impervious Surfaces (social factor) and Urban Flood Vulnerability Dynamics

According to the analysis of impervious surface and flood vulnerability dynamics, there were approximately 20.1 km² of impervious surfaces in the study area as of 2000, of which 1.4 km² fell within a relatively low hazard area, 4.1 km² fell within a moderate hazard area, and approximately 14.6 km² fell within a critically flood hazard area (Table 4). This relates to the vulnerability levels because the degree of vulnerability of built-up regions is determined by how exposed they are to different flood danger landscapes. In other words, this means that the vulnerability patterns represent the built-up places that are most often located in severely sensitive environments.

Table 4. Impervious surface and vulnerability dynamics

Impervious surface Dynamics	Area (km ²)	Level and Extent of vulnerability (km ²)		
		Critically	Moderately	Relatively low
Impervious (2000)	20.1	14.6	4.1	1.4
Impervious (2010)	21.2	15	5.2	1
Impervious (2019)	33.4	21.2	9.4	2.8

When compared to the change in the distribution and area of impervious surfaces across the three danger zones by 2010, which encompassed a total of 21.2km², it was discovered that the dynamics of the vulnerability to floods were more vivid. In this instance, the comparatively low hazard area is only around 1 km², the moderate hazard area is about 5.2 km², and the critical hazard area is about 15 km². According to the vulnerability dynamics, there were approximately 33.4 km² of impervious surface (built-up area) by 2019. Of that, 2.8 km² are in low vulnerability areas, 9.4 km² are in moderate vulnerability areas, and 21.2 km² are in critically susceptible areas (Table 4). Figures 6 and 7 show the impervious surface dynamics from 2000 to 2010 and 2019 respectively.

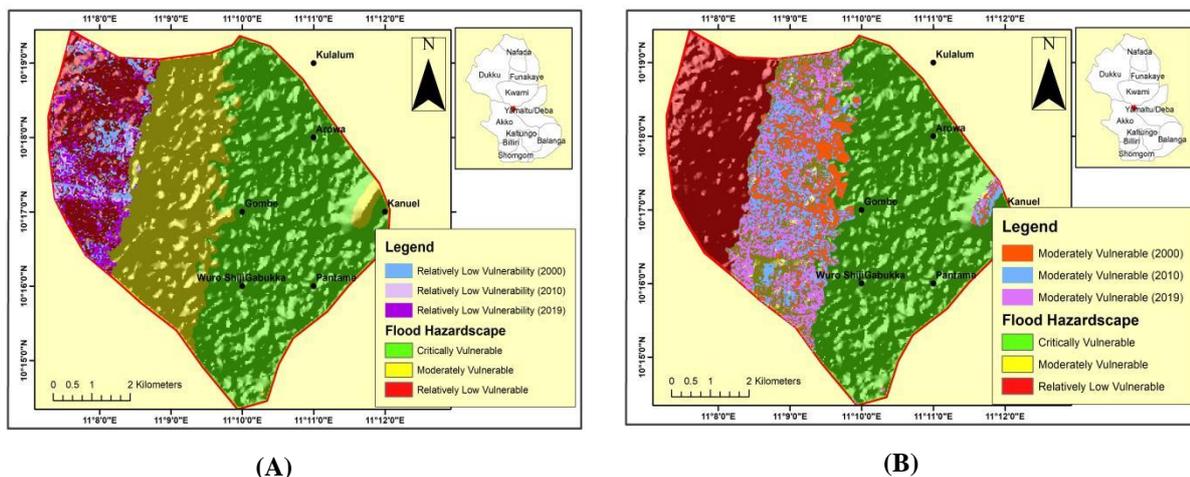


Figure 6. Relatively low (A) and moderate flood vulnerability (B) dynamics for the years 2000, 2010 and 2019 against flood hazardscape map

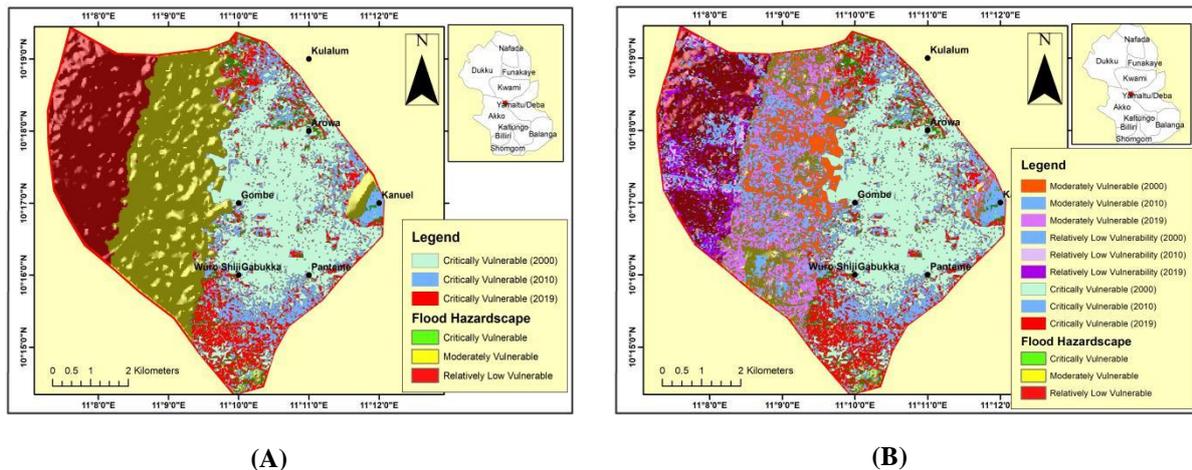


Figure 7. Critical flood vulnerability dynamics (A) and composite map of vulnerability distribution (B) across the study period against Flood Hazardscape Map

The overall finding indicates that impervious surfaces have increased from 20.1 km² in 2000 to 21.2 km² in 2010 and 33.4 km² in 2019, which has led to vulnerability dynamics as built-up areas have increased in all danger zones. Due to the area's elevation, there has been a 100 percent change in the extent of impervious surfaces inside the relatively low risk zones between 2000 and 2019. Similarly, there has been a 129.3 percent change in impervious surfaces covering moderately sensitive areas from 2000 to 2019. The terrain's potential for both residential and commercial use meant that the rate of change was rapid in this area. Finally, the critically susceptible area's percentage is 45.20 percent (i.e. from 14.6.1km² to 21.2.4km²). Despite the fact that people live mostly in places that are extremely susceptible, they nevertheless regard these areas to be more suited because there is no height and a steep slope. Some portions of the wards of Nasarawo, Bolari East, Dawaki, Herwagana, Ajiya, and some portions of Tudun Wada Shamaki were identified on the 2000 urban flood vulnerability map as being among the most vulnerable. Jeka da Fari and Federal Lowcost are considered to be slightly vulnerable, whereas the high stream sections of GRA are considered to be less vulnerable. In 2010, Shongo Estate is in the low vulnerable area, whereas parts of Madaki are very vulnerable. The same zones are shown on the 2019 map of urban flood vulnerability with increased impervious areas, which has increased urban flood sensitive areas.

Most of the the city's areas are susceptible to urban flooding, however between 2000 and 2018, there was a significant urban expansion and rise in impervious surfaces from 19 km² to 25 km². The moderate and critical zones contain most of the increases. The main causes of flood recurrence are an increase in impervious surfaces and altered rainfall patterns. The changes are significant because more places are becoming vulnerable to flooding because of the construction of additional buildings in the most densely populated, most vulnerable locations, which lack proper drainage infrastructure and amenities. The dynamics of flooding vulnerability are directly correlated with the amount of built-up area (impervious surfaces) within the hazard zones. The results of Zhang et al. (2018), who discovered a significantly positive link between the dynamics of impervious surfaces and urban waterlogging risk areas in Guangzhou, South China, are similar to those of this study. Therefore, in order to direct urbanization toward the low sensitive areas, as also discovered by Sohn et al. (2020), planners and policy makers must take into account impervious surfaces of various types in relation to the hydraulic system under specified rainfall depths.

4.3 Factors Influencing the Vulnerability Dynamics

The elements impacting the flood vulnerability dynamics were determined using the findings from the analysis of flood hazardscape and vulnerability dynamics. Another element impacting the dynamics of vulnerability is the increase in rainfall amount brought on by a shift or variability in the pattern of precipitation. This agrees with research such as [Abashiya et al \(2017\)](#) who also found that rainfall in Gombe metropolitan area increased from 2000 to 2014, which may have contributed to the floods of August 20, 2004, July 12, and September 5, 2014. The nature of urban expansion, which shows an increase in impervious surfaces from 2000 to 2019 is mostly in peri-urban settlements like Arawa, Burundi, Bye Pass, Bogo, Tumfure, Kagarawal, and Shongo Idrisa despite its lying on floodable areas, is another factor that influenced the vulnerability dynamics. This increase in impervious surfaces can be attributed to land value. This supports the findings of [Acheampong & Anokye \(2013\)](#), who found that affordable housing costs and cheap land prices are two factors that affect where people choose to build their homes in metropolitan areas. Despite the locations' vulnerability to flooding, individuals nonetheless choose to live there.

5. Conclusion

The study concluded that physical and social elements, particularly elevation, rainfall, and the distribution of impervious surfaces (built-up area) within Gombe city, had a significant impact on the urban flood hazardscape pattern and susceptibility dynamics. Increased rainfall combined with an uneven growth in impervious surfaces and their distribution across all hazard zones continue to affect the dynamics of flood susceptibility. The study suggests that when planning for future development, the planning authorities should take urban flood hazardscape maps into account. To remove the increasing surface runoff brought on by the rise in impermeable surfaces, the city should have effective and efficient drainage systems. Additionally, city growth should be managed and directed toward the less vulnerable areas, namely the western side of the city. To make land inexpensive and accessible to urban poor and avoid constructing on flood-prone locations, the State Government should reform the Land Use Act. Finally, it's important to enforce building codes, especially in flood-prone areas.

Conflicts of Interest

The authors declare no conflict of interest.

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