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GEOSPATIAL ANALYSIS OF THE IMPACTS OF FLOOD VULNERABILITY ON LAND USE LAND COVER CHANGES IN BAUCHI METROPOLIS

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Abstract

This study investigates the geospatial impacts of flood vulnerability on land use and land cover (LULC) changes within Bauchi Metropolis. Using a combination of satellite imagery, Geographic Information Systems (GIS), and statistical analyses, the research identifies flood-prone areas and their correlation with various land cover types. The study reclassifies LULC into flood vulnerability categories, highlighting areas with very high, high, moderate, low, and none vulnerability levels.Results indicate that 5.87% of the area falls into the very high vulnerability class, predominantly comprising urban and built-up zones. Conversely, 52.11% of the area is moderately vulnerable, representing mixed land uses with moderate flood susceptibility. The analysis further reveals the critical role of farmlands and woodlands in mitigating flood risks. High-risk zones, including Baraya, Gwallagan Mayaki, and Zango, require immediate intervention to prevent severe flood impacts. Moderate and low-risk areas demand proactive urban planning and sustainable land management to prevent escalation in vulnerability.The study employs advanced geospatial techniques to classify flood risks and presents actionable insights for policymakers, urban planners, and disaster management agencies. By identifying flood-prone areas and their specific LULC types, the research provides a foundation for targeted flood mitigation strategies, such as enhanced drainage systems, improved land management practices, and the preservation of natural vegetation. This comprehensive geospatial analysis underscores the necessity of integrating land use planning with flood risk management to enhance the resilience of Bauchi Metropolis to future flooding events.

Keywords: Flood, vulnerability, Geospatial, mapping, geospatial, LULC and GIS

Introduction

Flood is the flowing of excess water onto land that is usually dry (Djmesah, Okine, and Mireku, 2018). Floods can happen during heavy rains, when ocean waves come on shore, when snow melts too fast, or when dams or levees break. Flooding may happen with only a few inches of water, or it may cover a house to the rooftop. It can also occur quickly or over a long period and may last for days, weeks, or longer. Floods are the most common and widespread of all weather-related natural disasters (National Severe Storm Laboratory [NSSL], 2019).

Flooding is the most devastating natural disaster worldwide (Komolafe, Adegboyega and Akinluyi 2015). Flooding is excess water flowing onto land which is usually dry, e.g. when rainfall exceeds the absorption capacity of the soil, which in turn causes significant environmental consequences.

Floods are of several types such as Flash floods, River floods, Inland floods, and Urban floods. Flash floods occur through heavy rainfall or sudden release of water within a short period (Djmesah, 2018)

Floods are natural phenomena, human activities and interventions in to the processes of nature, such as alterations in drainage patterns from urbanisation, agricultural practices and deforestation, have considerably changed the situation at the same time, exposing them to risk and vulnerability to flood in flood-prone zones mostly along riverine areas (Mohammed et al. 2013). Flood risk is defined as the probability of occurrence multiplied by its impact (Osadolor and Henry 2013).

In Bauchi metropolis, almost in every rainy season, floods are experienced, Flash floods due to some natural e.g (heavy rainfall) and other anthropogenic factors for example, Yakubu (2020) found that some of the houses were built without considering building line regulations from the streams, existing hydrological structures were not positioned properly and some needs to be desilted to enable the flow of water.

Problem

Floods happen in varying locations and at varying magnitudes giving them different effects on environment. Flood hazard comprises many aspects which include structural erosion damage, contamination of food and water, disruption of social and economic activity including transport, communication, loss of lives and property (Mohammad I., 2013). Olajuyigbe et al. (2012) discussed how floods disrupt socioeconomic activities in Nigerian cities, particularly Bauchi Metropolis, leading to property destruction, forced migration, and reduced productivity. There is evidence that the problem of flooding in Bauchi metropolis is getting more and more acute due to anthropogenic activities, most people erect their buildings without considering building line regulation from the river banks (Yakubu, 2020).

The Study Area

Bauchi metropolis is located between latitudes 10° 19′ 55′′ N and 10° 20′ 58′′N and longitudes 9° 50′ 50′′E and 9° 51′ 29′′E. Located in the northeastern part of Nigeria.

It is the capital of both Bauchi Local Government Area (LGA) and Bauchi state (Bauchi-Wikipedia February, 2017).

There are two major seasons in Bauchi i.e. rainy and dry seasons. The rainy season months are May to September, while humidity ranges from about 37% to 68%. The onset of the rains has been often in March and they end virtually in October while the dry season starts from November to May (Shuaibu *et al.*, 2015).

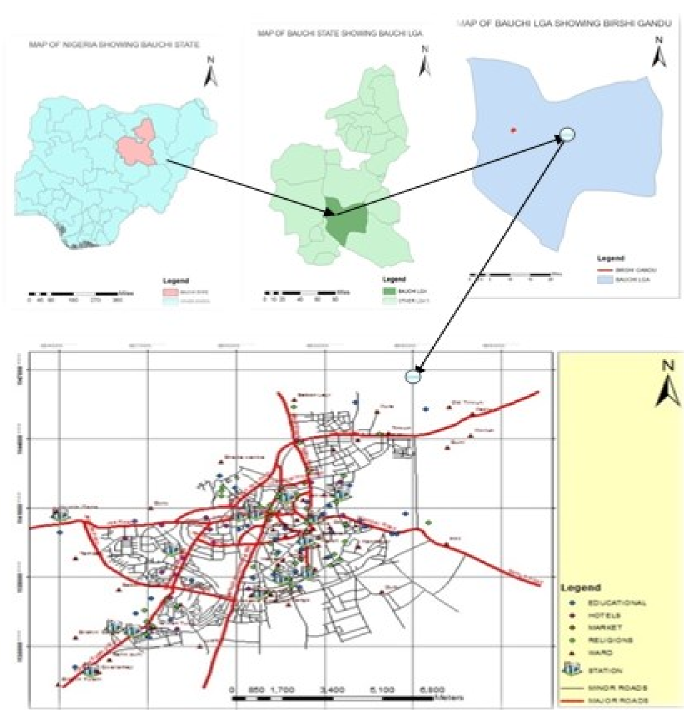

Figure 1: Map of the Study Area

Methodology

Data Acquisation

The research methodology encompasses data acquisition, processing, and management, along with the creation of a flood vulnerability map for the study area using GIS and remote sensing technology. This process involves obtaining satellite imagery of the study area, Shuttle Radar Topography Mission (SRTM) data, and utilizing various associated software and hardware. The satellite imagery and the SRTM data were both sourced from the USGS website.

Data Set

The data used for this research are purely secondary data which include:

Table 1: Data and their Sources

SN	Data type	Scale / Resolution	Date	Source
1	Landst-09	30 m	2024	United States Geological Survey (USGS). Geological Survey USGS
2	Digital Elevation Model (DEM)	30 m	2017	United States Geological Survey (USGS).
3	Precipitation	5 Km	2012 - 2022	Power Data Access Viewer

Device and Software Used

Lenovo ideapad 330 computer was used to have access to specialized software and provision of data procession power**, Microsoft windows accessories** for tabulations and graphical representations were used to present, describe and analyze land use/land cover dynamics and trends of changes that were undertaken during three periods**. ArcGIS version 10.8** was used for mapping, data integration and further analysis of relationships, patterns and trends in a multi-temporal approach.

Flood Vulnerability Mapping

The flood vulnerability map of Bauchi metropolis was generated using Weighted Sum Overlay Analysis in ArcGIS 10.8 by multiplying each contributory criterion with its weight and then combined the results to a single separate flood vulnerability index map. The index map was further reclassified to five classes describing spatial variability of the degree of flood vulnerability in the study area

Flood Vulnerability in Bauchi Metropolis

Olajuyigbe et al. (2012) discussed how floods disrupt socioeconomic activities in Nigerian cities, particularly Bauchi Metropolis, leading to property destruction, forced migration, and reduced productivity.

Land Use Land Cover Classification

To accomplish the primary objective of this research, various image processing techniques were applied, including layer stacking, sub-setting, geometric correction, radiometric correction, spatial enhancement, classification, filtering, and change detection. These processes were conducted to prepare the remote sensing images for analysis. Land use and land cover types affect how water is absorbed or channeled in the landscape. Impervious surfaces such as roads and buildings increase runoff, while vegetation and wetlands can act as natural buffers to flooding. The role of LULC in flood risk has been extensively studied, with **Sivakumar et al. (2017)** demonstrating how land cover change increases flood vulnerability in urban areas.

Image pre-processing

Pre-processing of data is a data mining technique that involves transforming raw data into an understandable format.

Land use land cover mapping

Over the years, researchers have developed various methods for image classification. In this study, several classification techniques were tested to evaluate their effectiveness in classifying land use and land cover. Among these, the maximum likelihood classifier achieved the highest accuracy. Consequently, supervised classification using the maximum likelihood classifier was chosen for its superior performance.

Analysis of the Impact of Flood Vulnerability on LULC maps

The analysis of flood vulnerability on LULC maps provides critical insights into how land use and land cover are affected by flooding and how these changes influence flood susceptibility. By overlaying flood-prone areas with LULC maps, researchers can identify which land cover types, such as built-up areas, farmlands, or forests, are most vulnerable to flooding. This helps assess the extent of damage to infrastructure, agriculture, and natural ecosystems.

Result and Discussion

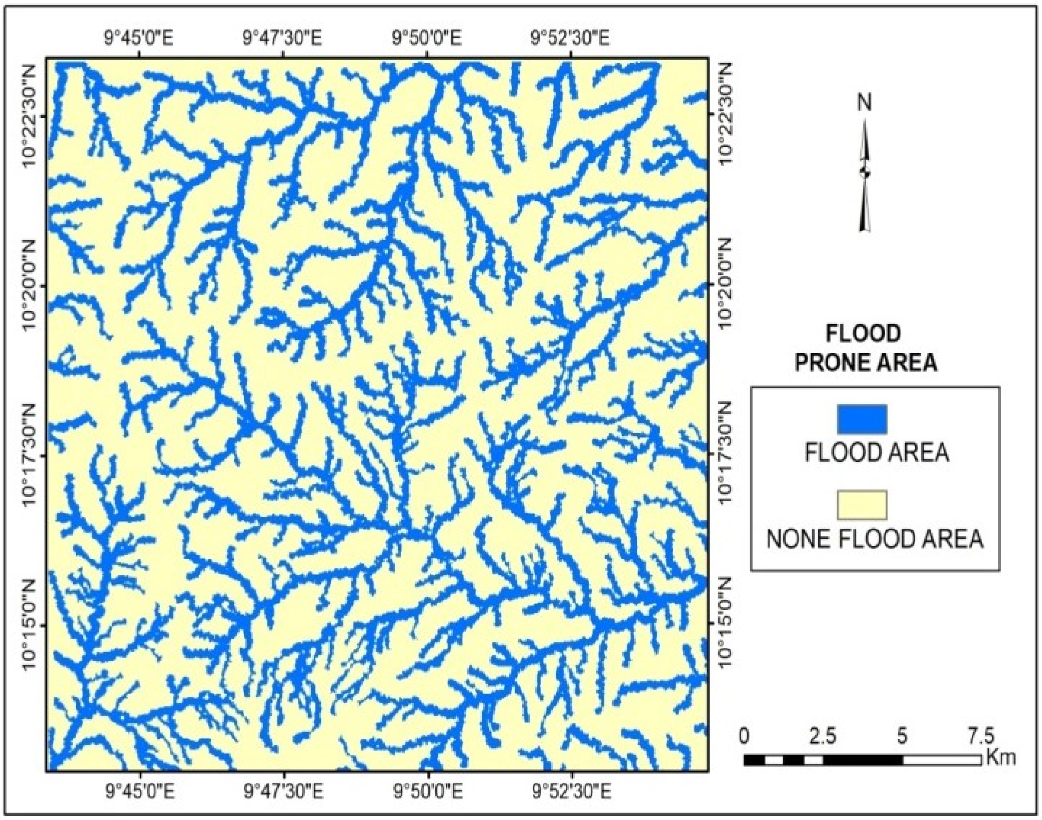

Figure 2: Flood Prone Area Extent

Table 2: Statistics of the Flood Prone Area Extent

CLASS	AREA	%
Flood Prone Area	120.360	120.36
None Flood Prone Area	297.011	297.01
TOTAL	417.371	417.37

Landuse And Landcover

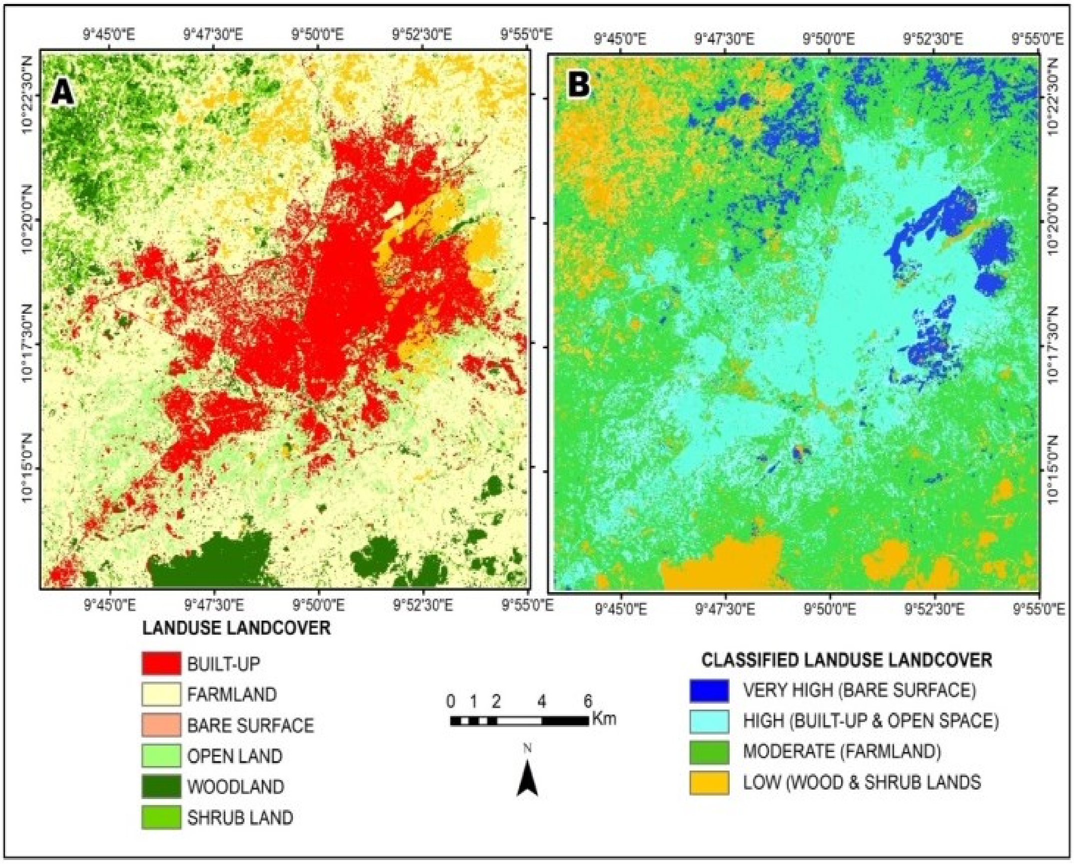

Table 3: Statistics of the Reclassified LUCL to Flood Vulnerability Classes.

Figure 3: Landuse and Landcover (LULC) of Bauchi Metropolis – A: LULC; B: Reclassified LUCL to Flood Vulnerability Classes.

Table 3: Statistics of the Reclassified LUCL to Flood Vulnerability Classes.

FLOOD VULNERABILITY	AREA Km²	%
Very High	24.542	5.87
High	117.47	28.09
Moderate	217.88	52.11
Low	58.244	13.93
TOTAL	418.14	100.00

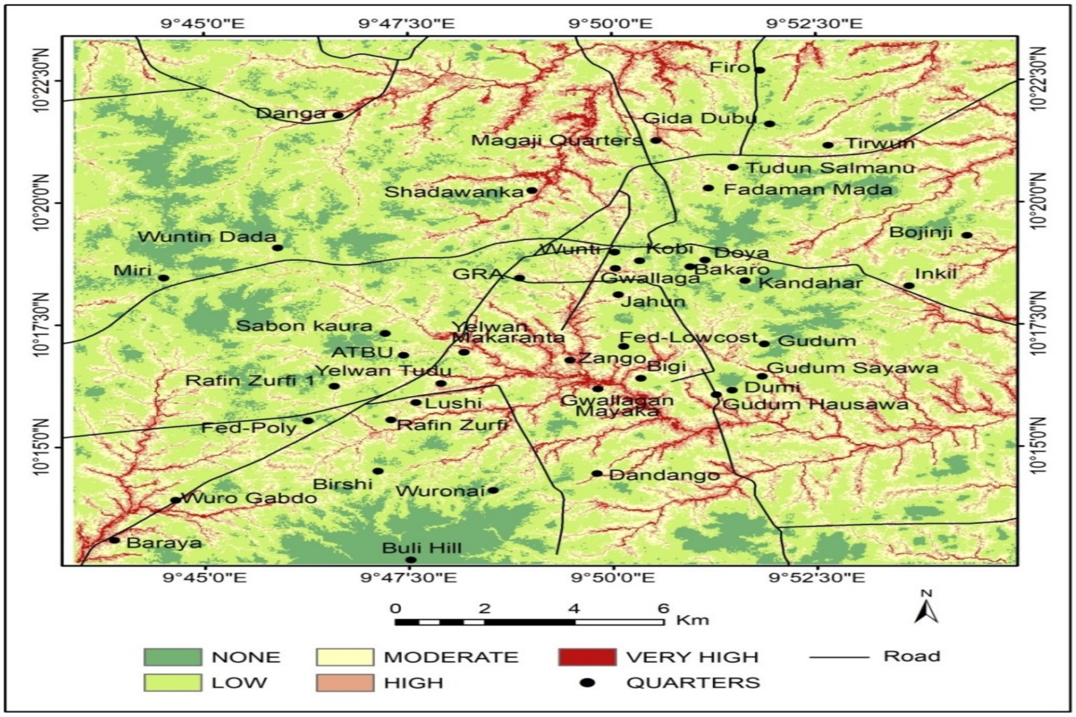

Figure 4: Flood Vulnerability Map Around Bauchi Metrpolis

Risk Vulnerability Analysis Using Landuse Landcover Maps

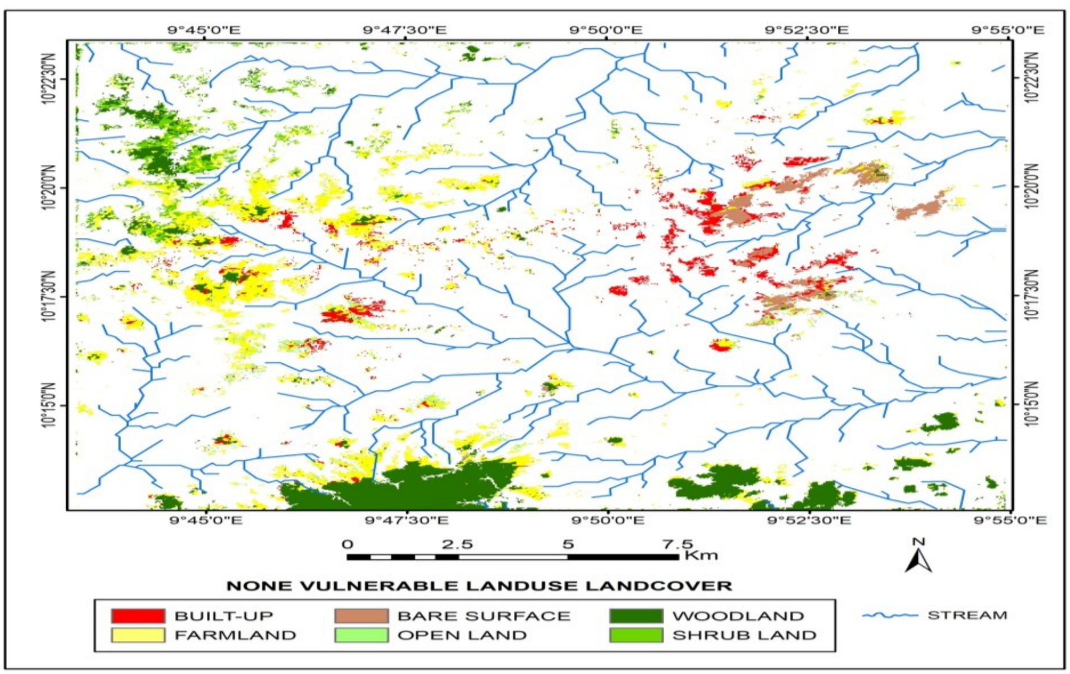

Figure 5: Spatial Distribution of None Vulnerable Landuse Landcover

Table 4: Statistics of the None Vulnerable Landuse Landcover

LULC CLASS	AREA Km^2	%
Built-up area	5.739	11.54
Farmland	18.029	36.25
Bare surface	3.486	7.01
Grass/Open space	1.659	3.33
Woodland	16.683	33.54
Shrub land	4.145	8.33
TOTAL	49.741	100.00

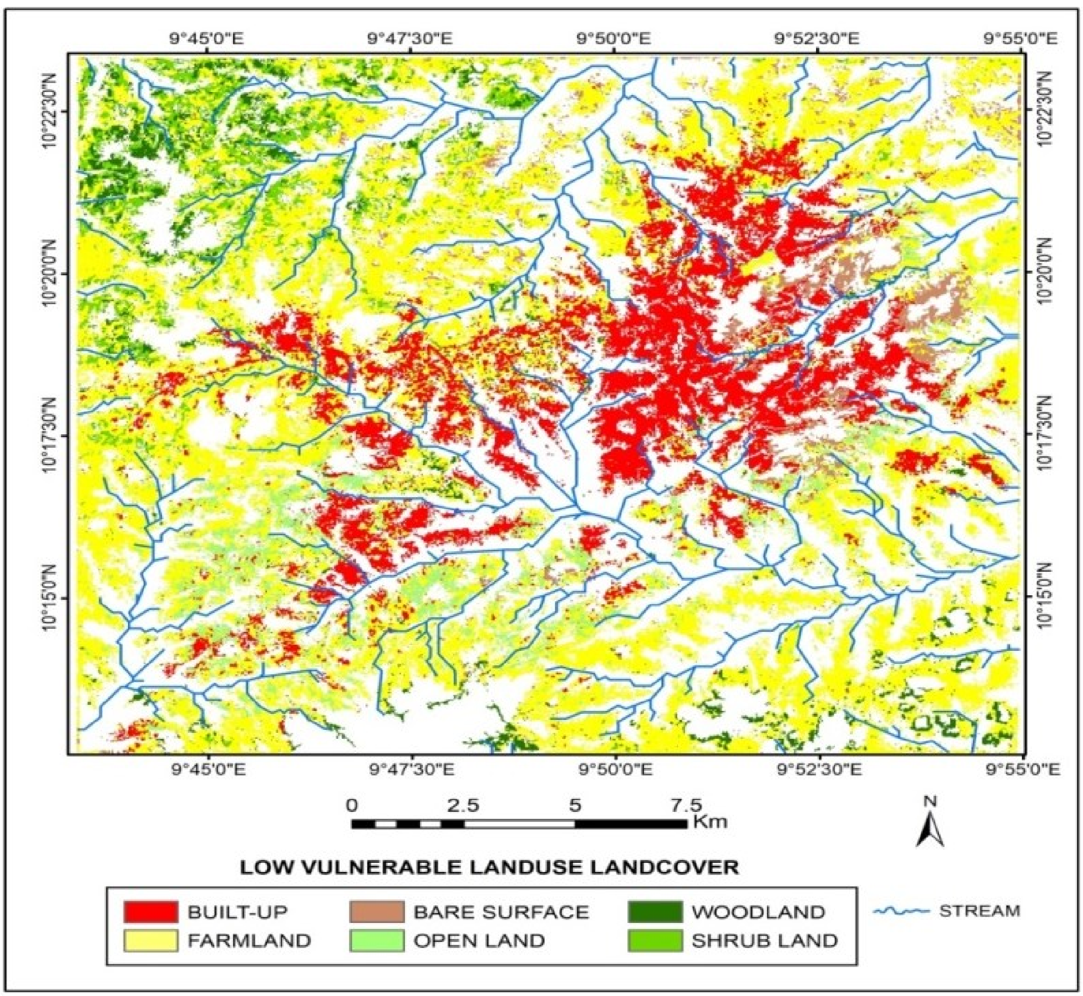

Figure 6: Spatial Distribution of Low Vulnerable Landuse Landcove

Table 5: Statistics of the Low Vulnerable Landuse Landcover

LULC CLASS	AREA Km^2	%
Built-up area	46.579	22.02
Farmland	115.196	54.47
Bare surface	7.994	3.78
Grass/Open space	16.011	7.57
Woodland	10.963	5.18
Shrub land	14.759	6.98
TOTAL	211.501	100.00

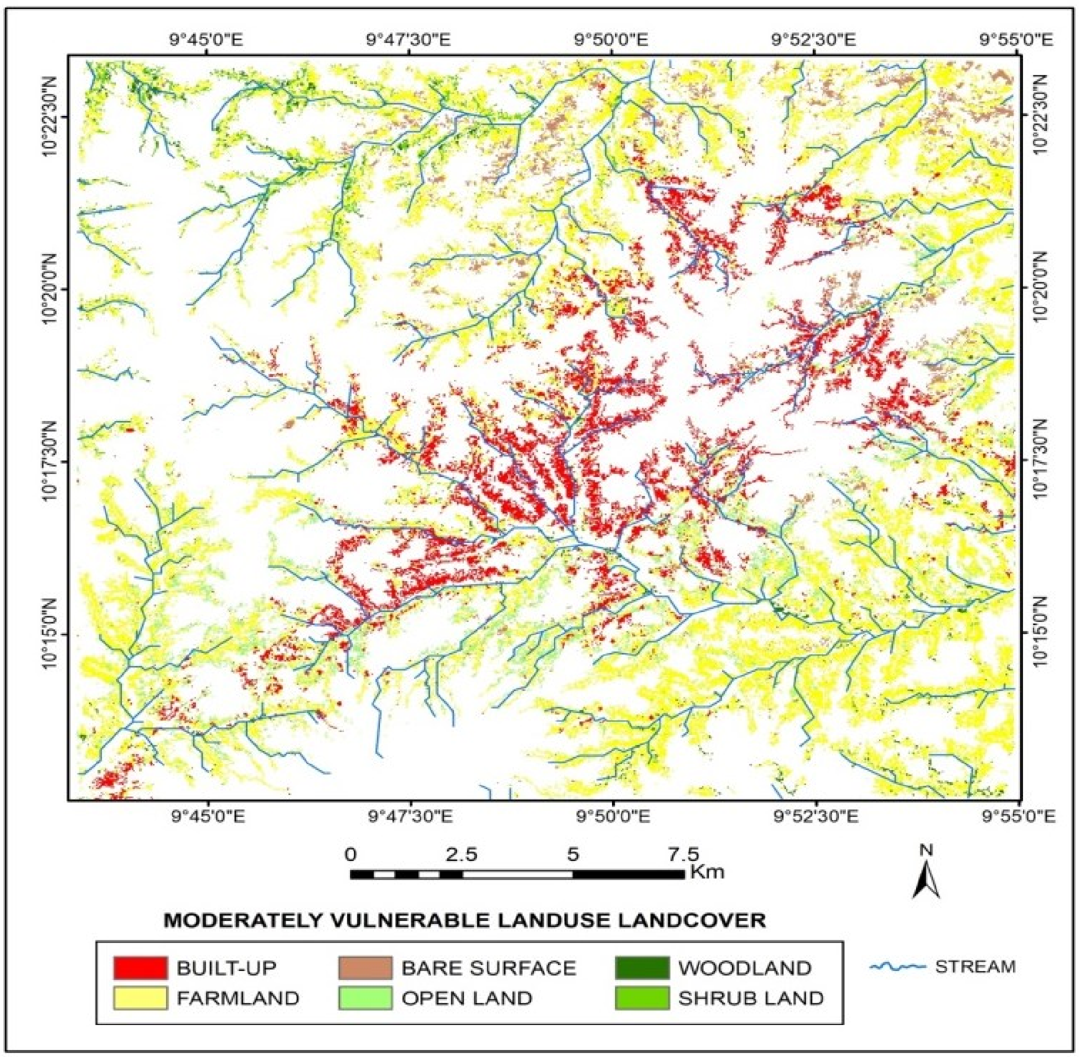

Figure 7: Spatial Distribution of Moderate Vulnerable Landuse Landcover

Table 6: Statistics of the Moderate Vulnerable Landuse Landcover

LULC CLASS	AREA Km^2	%
Built-up area	21.370	20.57
Farmland	60.408	58.16
Bare surface	5.936	5.71
Grass/Open space	10.046	9.67
Woodland	2.194	2.11
Shrub land	3.914	3.77
TOTAL	103.867	100.00

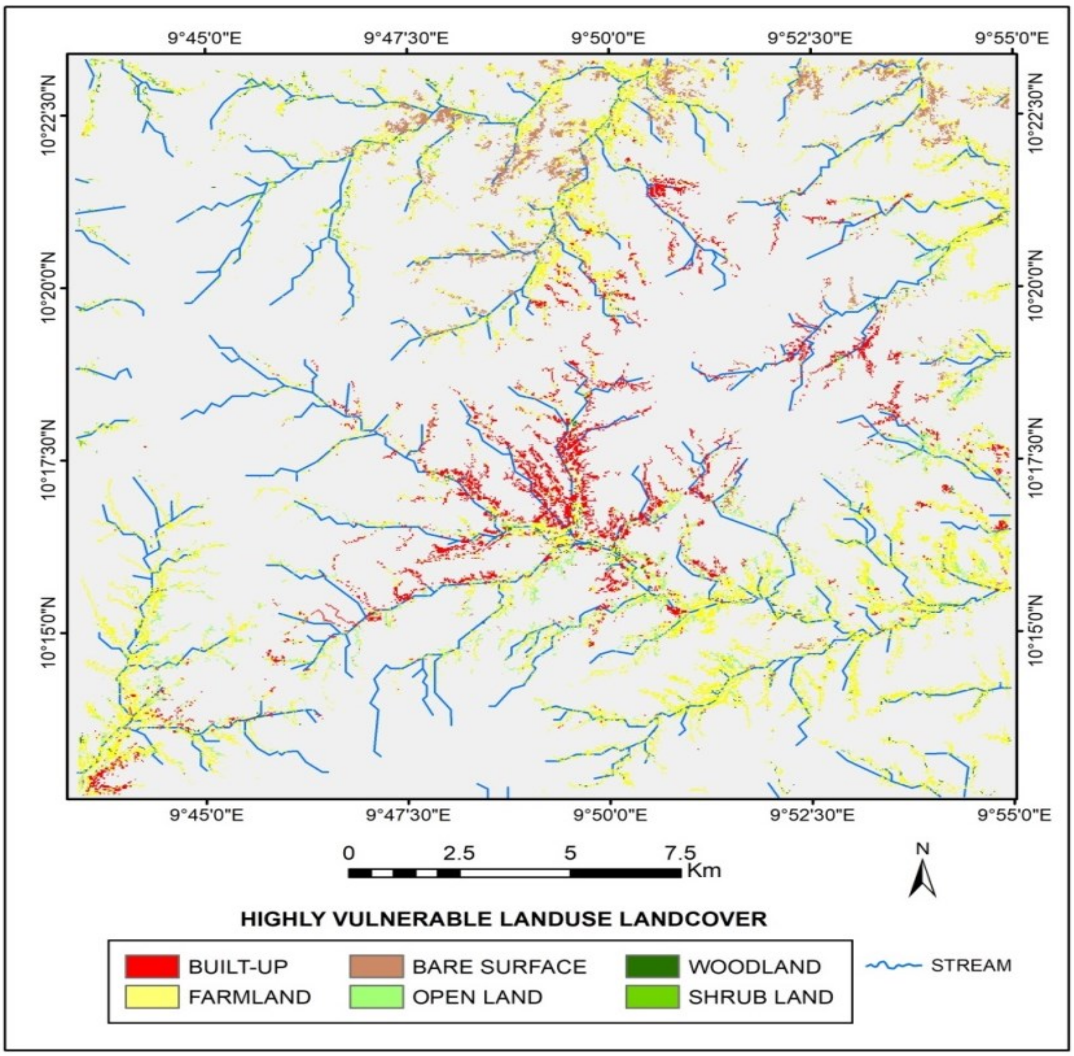

Figure 8: Spatial Distribution of High Vulnerable Landuse Landcover

Table 7: Statistics of the High Vulnerable Landuse Landcover

LULC CLASS	AREA Km^2	%
Built-up area	7.536	19.52
Farmland	21.028	54.47
Bare surface	4.450	11.53
Grass/Open space	4.205	10.89
Woodland	0.570	1.48
Shrub land	0.814	2.11
TOTAL	38.601	100.00

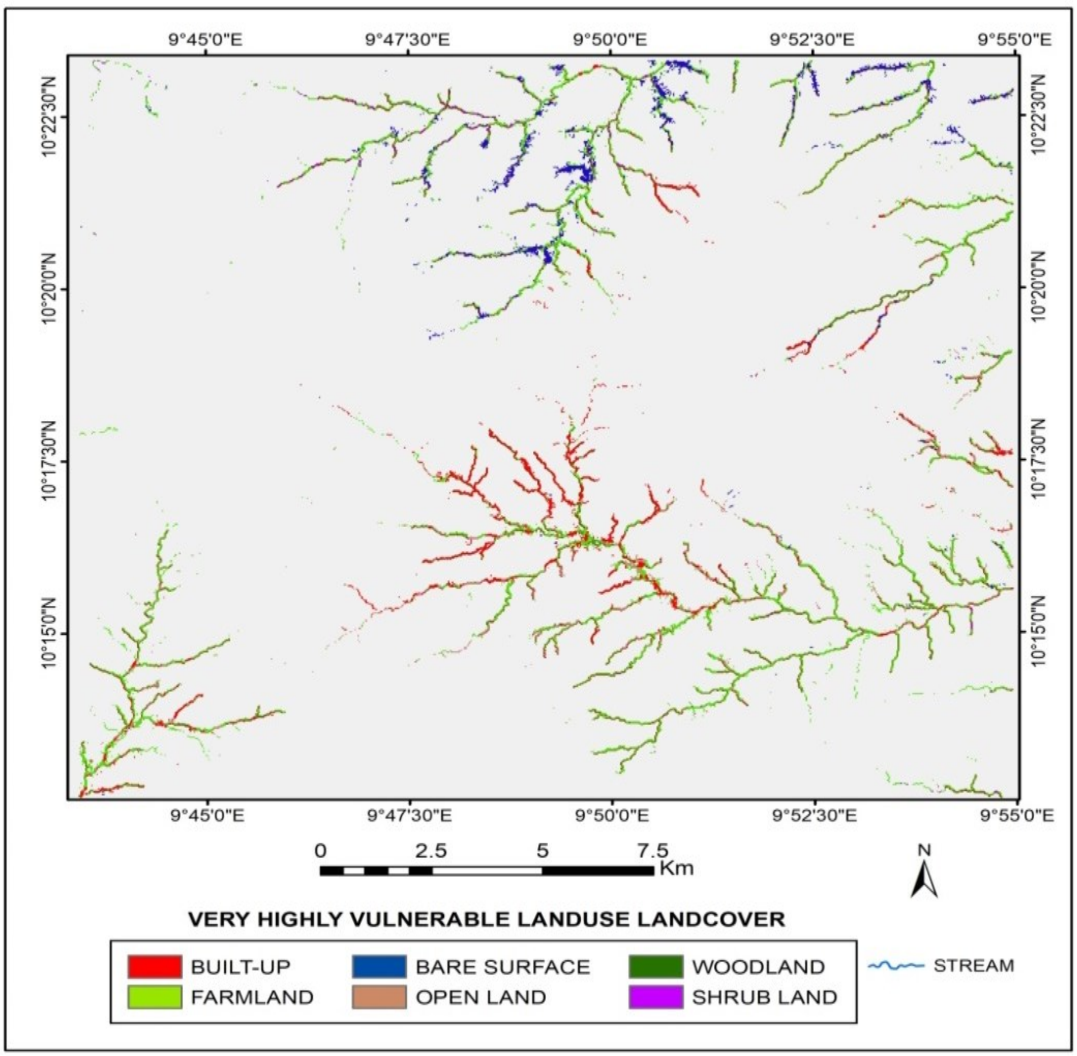

Figure 9: Spatial Distribution of Very High Vulnerable Landuse Landcover

Table 8: Statistics of the Very High Vulnerable Landuse Landcover

LULC CLASS	AREA Km²	%
Built-up area	2.201	15.47
Farmland	7.719	54.26
Bare surface	1.987	13.97
Grass/Open space	1.372	9.64
Woodland	0.395	2.78
Shrub land	0.551	3.87
TOTAL	14.225	100.00

Moderate vulnerability (Table 6) covers 103.867 km², with **farmland** again dominating at 58.16%. **Built-up areas** constitute 20.57%, indicating that urban areas in this category are more exposed to flood risks compared to none and low-vulnerability zones. **Grass/open space** also increases to 10.046 km² (9.67%), suggesting that such areas, despite their potential to absorb water, may be inadequately managed to resist moderate flooding. The decline of **woodland** to 2.11% and **shrub land** to 3.77% underscores their diminishing protective roles as vulnerability increases, potentially due to deforestation or land use changes.

The Land Use and Land Cover (LULC) analysis, as presented in *Figure 3* and summarized in *Table 3*, illustrates the spatial distribution of flood vulnerability based on land use characteristics within Bauchi Metropolis. The LULC map (Figure A) provides an overview of the land cover types, while the reclassified LULC map (Figure B) categorizes the area into flood vulnerability classes. The "Very High" vulnerability category, covering 24.542 km² (5.87%), corresponds primarily to areas with impervious surfaces or low infiltration rates, such as urban and built-up zones. The "High" vulnerability class, at 117.47 km² (28.09%), includes agricultural and semi-urban areas. The "Moderate" category, which constitutes the majority of the study area (217.88 km² or 52.11%), represents zones with mixed land uses that moderately influence flood risk. Lastly, the "Low" vulnerability class covers 58.244 km² (13.93%), typically corresponding to vegetated or undeveloped regions with higher infiltration capacity. This analysis highlights the critical role of land use and land cover in determining flood vulnerability, emphasizing the need for sustainable urban planning and land management to reduce flood risks in highly vulnerable areas.

Table 4 indicates that **none vulnerable land use** covers a total area of 49.741 km², with the majority being **farmland** (36.25%) and **woodland** (33.54%). These two categories collectively account for nearly 70% of the total none vulnerable area. Smaller proportions are attributed to **built-up areas** (11.54%), **bare surfaces** (7.01%), and **grass/open space** (3.33%). The negligible vulnerability in these areas suggests either natural resilience, such as good drainage or low susceptibility to waterlogging, or effective land use practices. This finding highlights the importance of preserving woodlands and farmlands as natural buffers against flooding.

The area of **low vulnerable land cover** is significantly larger, spanning 211.501 km². Similar to the none vulnerable category, **farmland** dominates this group, comprising 54.47% of the total area, followed by **built-up areas** at 22.02%. Notably, the presence of 10.963 km² (5.18%) of **woodland** and 14.759 km² (6.98%) of **shrub land** demonstrates their continued role in flood risk reduction at this vulnerability level. The data suggests that low-vulnerable areas may benefit from enhanced flood management strategies to prevent future risks as urbanization or agricultural expansion occurs.

High vulnerability land use spans 38.601 km², with farmland maintaining its dominance at 54.47% (Table 7). However, the proportion of **built-up areas** rises to 19.52%, reflecting increased exposure of urban infrastructure to high flood risk. Interestingly, the share of **bare surfaces** increases significantly to 11.53%, which suggests that areas with little to no vegetation are especially prone to flooding due to reduced water absorption. **Grass/open space** makes up 10.89%, further emphasizing that these areas, if left unmanaged, can transition to higher-risk categories. **Woodland** and **shrub land** remain marginal, accounting for 1.48% and 2.11%, respectively, signaling their near-complete degradation in highly vulnerable zones.

The most vulnerable category, with a total area of 14.225 km² (Table 20), shows a clear trend of farmland dominance at 54.26%, followed by **built-up areas** at 15.47%. The high proportion of farmland in this category may indicate poor flood management practices, such as lack of drainage infrastructure, soil degradation, or improper agricultural techniques. **Bare surfaces** account for 13.97%, highlighting the role of soil exposure in exacerbating flood risk. While **grass/open space** constitutes 9.64%, its presence diminishes compared to earlier categories, reflecting its susceptibility to degradation in very high-risk zones. The minimal representation of **woodland** (2.78%) and **shrub land** (3.87%) underscores their near-total loss in these areas, further aggravating flood vulnerability.

Conclusion

The findings emphasize the significant influence of LULC on flood vulnerability, highlighting the need for targeted actions in high-risk zones to mitigate potential damage and safeguard communities. Immediate interventions, such as improved drainage systems and strengthened flood defenses, are essential in these areas. Meanwhile, low and non-vulnerable zones should adopt sustainable land management practices, including preserving natural vegetation and promoting environmentally friendly urban planning, to maintain their resilience and prevent future risks. This study reinforces the importance of integrating LULC planning with flood risk management to enhance overall regional sustainability and disaster preparedness.

Recommendations

- Implement advanced flood drainage systems in high-risk zones.
- Promote reforestation to enhance natural flood barriers.
- Develop land-use policies focusing on sustainable urban planning.

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