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Geospatial Application in Urban Flood Risk Analysis in Chanchaga LGA of Niger State, Nigeria

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Abstract

This study represents a significant advancement in the application of Geographic Information Systems (GIS) technology to address urban flood risks, specifically focusing on Chanchaga, Niger State. It highlights GIS as more than just a mapping tool, emphasizing its pivotal role in urban planning and emergency management for informed decision-making. By utilizing various data sources such as DEM, slope, elevation, drainage, and land use land cover data, the study identified and mapped flood-prone areas in Chanchaga. Through the ArcGIS environment and the analytic hierarchy method, a flood risk map was generated, providing insights into the distribution of flood risk within the area. The findings reveal that a considerable portion of the area, approximately 30.59% for very high-risk zones and 41.23% for high-risk zones, is vulnerable to flooding. Additionally, the study notes a significant increase in built-up areas over time, the built up increased from (30.15% in 2003 to 56.08% in 2023), highlighting the importance of proactive flood prediction, early warning systems, and management strategies. The practical application of GIS in mitigating material losses due to floods is underscored, emphasizing its role in implementing sustainable flood management practices. Ultimately, the research underscores GIS as a transformative tool for enhancing urban resilience and combating natural disasters like floods, contributing to the overall efforts in disaster risk reduction and management.

Keywords: Geographic Information Systems, Vulnerable, DEM, Urban flood Risk, Decision-Making, Chanchaga

1. INTRODUCTION

Floods, a natural hydrological phenomenon, result from various factors, such as intense precipitation and landscape characteristics (Sharma*et al.*, 2018). These natural disasters, including floods and droughts, significantly threaten lives and properties. Floods are often linked to extreme climate events (Balch*et al.*, 2020; Towner *et al.*, 2020). Towner *et al.*(2020), identify several factors contribute to their occurrence, including intense short-duration rainfall, topographical features, and human-induced factors such as urbanization and settlement expansion in flood-prone areas (Gigović*et al.*, 2017). Globally, floods are among the most common weather-related hazards, causing property loss, fatalities, and farmland destruction.

Urban flooding studies in the study area remain scarce. The limited number of studies on this topic hinders a comprehensive understanding of the phenomenon, primarily due to the lack of extensive climate event data. Like in many developing countries, detailed records of rainfall and runoff data are seldom available in the study area. Globally, rapid increase in population in major cities has led to urban sprawl at an unprecedented rate which has increased the level of flood vulnerability of cities and urban areas.
The increasing urbanization generally is brought about by many environmental problems, such as the drastic change of land use and development of urban heat island and flood event. This study utilized geospatial application in urban flood risk.
analysis in Chanchaga LGA of Niger state, Nigeria. These were done with the view to determining the effects of changes in land use/cover on flood occurrence in the area. Primary and secondary data were used for the study.

Study Area

Minna is located in Chanchaga which is the capital of Niger State. It is one of the twenty-five local government areas in Niger State, with its headquarters in Minna with a land mass of 1,592 km2 (Dalil *et al.,* 2015).

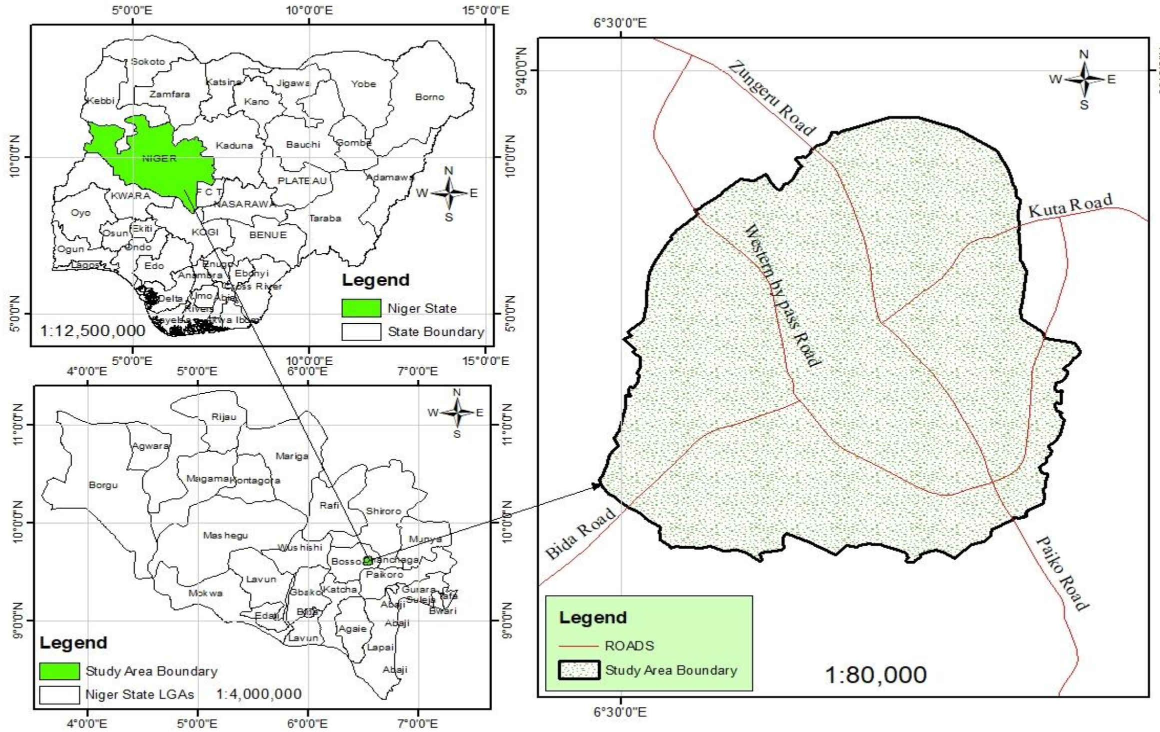


Figure 1: Map of the Study Area
Source: Department of Geography, FUT, Minna.

The study area is located between Longitude 9o 38”0 North and Latitude 6o 25”0 East (Figure 1). It covers a total area of about 297.5 km2 and has a population of about 147,359 as at 2006 census. Minna is a commercial urban area or more of a central place in Minna. The study area has two distinct seasons the dry and wet season. Precipitation per year varies between 1000- 1400 mm on the average. The duration of rainy season ranges from 150 to 210 days or more from the north to the south. Mean maximum temperature remains high throughout the year, hovering about 37 oC and 20^{o} C respectively (Adeoye *et al*., 2018). However, the lowest minimum temperature occurs usually between December and January when most parts of the state come under the influence of the tropical continental air mass which blows from the north (Dalil et al., 2015).This study is aimed at analysis of impacts of urbanization on land use and land cover dynamics on flood occurrence in Chanchaga local government area, Niger state, Nigeria through a geospatial approach so as to achieve these specific objectives:

i. Analyze the trend and rate of LULC changes between 2003 and 2023.
ii. Produce flood risk map

3. MATERIALS AND METHODS

The primary data used for the study is fieldwork and includes Photographs from the field GPS for picking geographic coordinates. The secondary data were sourced from the earth explore website. The Geo-referencing properties of 2003, 2013and 2023 made up of universal Transverse Mercator (UTM) projection, and datum WGS 84, zone 32, IDRISI Terrset was used for the development of land use and land cover maps for the study areas. ArcGIS 10.3 was used in developing, displaying and processing of the location maps.

Table 1: characteristics of Landsat images used for the study

Date of Acquisition	Sensor	Path	Row	Multispectral Band	Thermal Band	Spectral Range (micrometers)	Spatial Resolution (pixel spacing)	Source
2003	TM	189	53	1to5 and 7	6	10.45-12.45	30	glovis.usgs.gov
2013	ETM+	189	53	1to5 and 7	6	10.45-12.45	30	glovis.usgs.gov
2023	OLI and TIRS	189	54	1to7 and 9	10 and 11	10.60-12.51	30	glovis.usgs.gov

3.1 DATA COLLECTION

3.1.1 Spatial Data Collection and Source

In order to determine the effects of LULC changes on flood occurrence on the study area, spatial data-sets were obtained from Landsat7 and Landsat 8 archives from U.S Geological Survey (USGS), 30m DEM and ground observations obtained from Google Earth. The three data sets used for the study; its source of acquisition is shown in table 1 below. The Landsat data were obtained from the USGS and Earth Observation database. These imageries were selected based on date of acquisition and itsavailability. To prevent bias in the data, the images were of the same season free from cloud cover and have the same identifiable features. This gives uniform radiometric and spectral characteristic which helped reduce or prevent seasonal variation in the spectral reflectance of the land cover data-sets (Nzunda, 2013). Also, the data were georeferenced to the coordinate system of the study area i.e. WGS84 projection; UTM zone 32N.

Table 3.2: Software Components of the Research

S/N	Software	Purpose
1	Idrisi & ArcGIS 10.3	GIS analysis & classification of the Landsat images
2	Microsoft Excel	Statistical analysis for the calculation of percentage
3	Global Positioning System	For picking geographic co-ordinates

3.2 DATA ANALYSIS

The acquired Landsat imagery was analyzed using ArcGIS 10.8, Idrisi Terrset, Google earth and MS Excel. The methods used in processing the imagery for this study was image extraction of study area of interest (AOI), image restoration/ pre-processing, image enhancement and image classification. Image Pre-processing for mapping or analyzing the change in the land cover, Geometric restoration gives the accurate orientation of the satellite images, thus geo-referencing of the imagery. The imageries acquired were already geo-referenced from the World Geodetic System (WGS84); they were re-projected to the coordinate system of the study area, i.e. Universal Transverse Mercator (UTM) zone 32 North for Nigeria using ArcGIS version 10.8.

Image Enhancement: This technique deals with modification or improving the quality of the imagery, making it more suitable as perceived by humans. In order to improve the visibility of the imagery, a colour composite for the imageries were established using Landsat TM bands 4, 3 and 2 (i.e. Near infrared, Red and Green) and this gave a false colour composite.

Image Classification: The imageries were classified using supervised classification method prior to the knowledge of the study area available at hand. Anderson *et al.* (1987) level one classification method was used. This method involves extracting land cover information from the imagery and it is mostly referred to as clustering. The main objective for classification was to produce a land cover classes that resemble the actual land cover types ofthe earth surface (Sunday*et al.*, 2020).

4 RESULTS AND DISCUSSION

4.1 Analysis of the various Land use/Land cover (2003, 2013 and 2023)

The classification results for the LULC changes of the study area (Chanchaga) were presented using charts and figures for illustration and interpretation of all land use/land cover classes of the study area.

4.1.1 Analysis of 2003 land use/land cover classification for the Study Area

Studies on land use change and urban expansion have become critical for environmental monitoring and changes over time and space for better decision making by policy makers. The land use/ land cover map reveals the spatial distribution of the various categories of land use/land cover over the study area. Figure 2, shows the classified land use/land cover map of the study area for the year 2003. The map reveals five (5) categories of land use/land covers; built-ups, cultivated land, grassland, bare surface and water bodies. The areal extent of these classes reveals that the dominant class grassland areas with 28.17km^2 (40.68%). This is seen scattered mostly at the north western, western and south western section of the map as well as the south west, cultivated land area covers 13.34km^2 (19.27%) while built up areas on the other hand, occupies an area of 20.88km^2 (30.15%), and the water body covering 0.28km^2 (0.41%). Bare surface occupies an area of 6.58 km^2 (9.50%), The total land area is 69.25km^2.

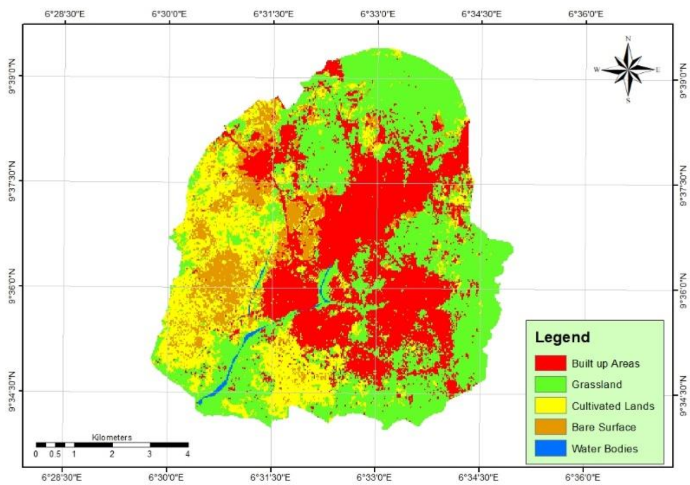


Figure 2: Classified 2003 LULC Distribution map Generated from Landsat 5

4.1.2 Analysis of 2013 land use/land cover classification for the Study Area

Figure 3, indicates the classified land use/land cover map of the study area for the year 2013. The map reveals five (5) categories of land use/land covers; built-ups, forest cover, cultivated land, grassland and water bodies. There were drastic changes in the various land use and land cover classes as some increase and other decreases.The areal extent of these classes reveal that the dominant class is built up areas which covers an area of 29.83km^2 (43.07%) in 2013, witnessing an increase of (12.92%). This increase in built up area can be attributed to high rate of population growth as well as the presence of higher institution in the area.

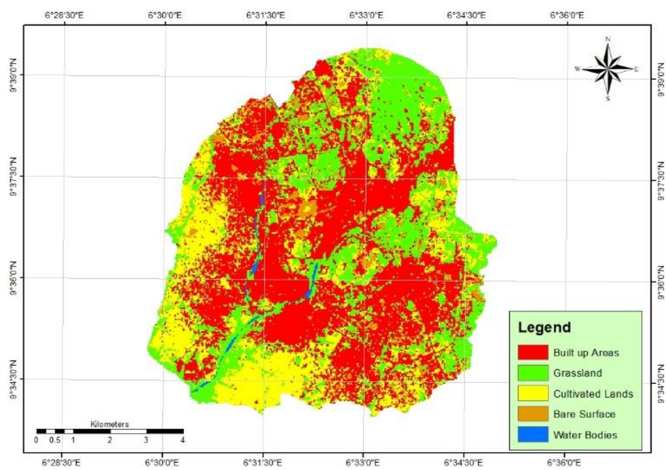


Figure 3: Classified 2013 LULC Distribution map Generated from Landsat 8 (OLI)

Cultivated lands area covers 13.34 km2 (19.27%) in 2003 but increased to 15.84km2 (22.87%) in 2013 while bare surface on the other hand, occupies an area of 6.58 km^2 (9.50%), in 2003 but decreased to 4.07km^2 (5.88%) in 2013, and the water body covering 0.29 km^2 (0.02%) in 2003, however increased to 3.82km^2 (0.23%). Furthermore, there was a drastic change in grassland. The grassland decreased from 28.17 km2 (40.68%) in 2003 to 19.21km^2 (27.74%) in 2013. These changes can be attributed to increase population influx into the study area. Water bodies also witness a slight increase to 0.31 km^2 (0.45%).

4.1.3 Analysis of 2023 land use/land cover classification for the Study Area

The areal extent of the various LULC categories reveal that the dominant class for the year 2023 was still built-up areas which covers an area of 38.84km^2 (56.08%) in 2023, witnessing an increase of (13.01%). This increase in built up area can be attributed to high rate of population growth as well as the presence of higher institution in the area. This is also because of the relatively peaceful nature of the study and been the state capital.

Cultivated lands area covers 15.84km2 (22.87%) in 2013 but reduced to 8.26km^2 (11.93%) in 2023. This is attributed to the quest for development in the study area. Bare surface on the other hand, occupies an area of 4.71km^2 (6.81%) in 2023 indicating a slight increase of (0.93%) in 2023, water body covering 0.16km^2 (0.23%) in 2023, Furthermore, grassland decreased from 19.21km^2 (27.74%) in 2013 to 17.28km^2 (24.95%) in 2023. These changes are attributed to increase population influx as well as other developmental activities in the study area. This is in line with the work of (Sunday et al., 2020).Furthermore, figure 4.5 reveals the fluctuating trend across the various land use and land cover categories, findings show that built up areas continues to witness increasing trend while other shows decreasing trend, an indication increased urbanization.

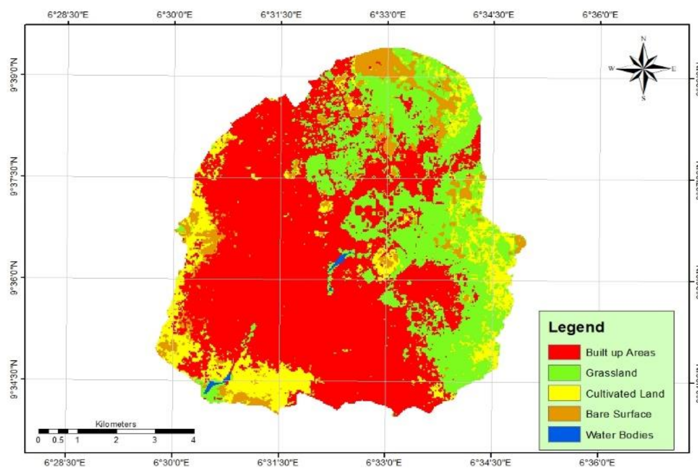
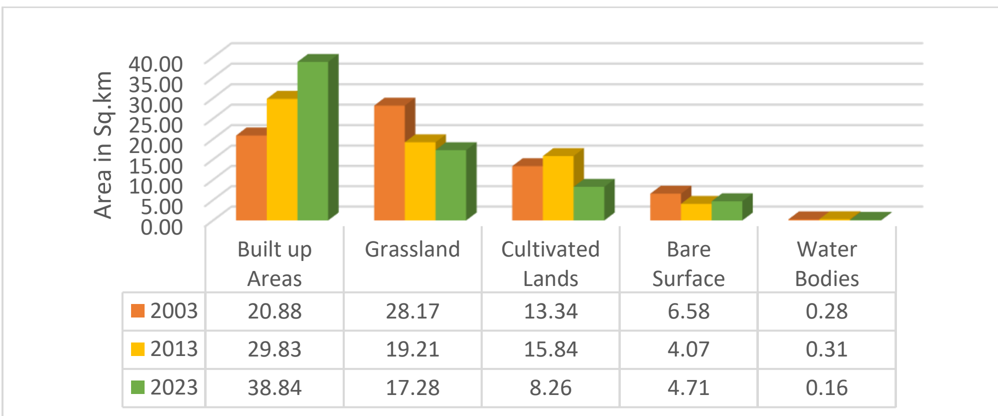


Figure 4: Classified 2023 LULC Distribution map Generated from Landsat 8 (OLI)



	Built up Areas	Grassland	Cultivated Lands	Bare Surface	Water Bodies
2003	20.88	28.17	13.34	6.58	0.28
2013	29.83	19.21	15.84	4.07	0.31
2023	38.84	17.28	8.26	4.71	0.16

Figure 4.5: Comparative trend Chart

Flood risk vulnerability map of the Area

The classified DEM reveals areas of high and low elevation and level of flood risk, based on height, figure 6.Further classification of the DEM into risk levels figure 6, shows the classified DEM based on risk levels. The areas marked as very high-risk areas are mostly the areas closet to the rivers. Flooding is experienced yearly in most communities that falls under this classification. The areas are characterized by low relief and water-logged soils. The result from the classified DEM shows that about 21.19square kilometer (30.59%) of the area is on lower elevation which is evidence of recurrent flooding in the study area indicating high-risk areas. 28.55square kilometer (41.23%) are on moderate risk areas and 14.10square kilometer (20.36%) are low risk areas while 2.24square kilometer (3.24%) is on high elevation, indicating no risk areas. It can therefore be concluded that substantial part of the study area is on a flood plain area.

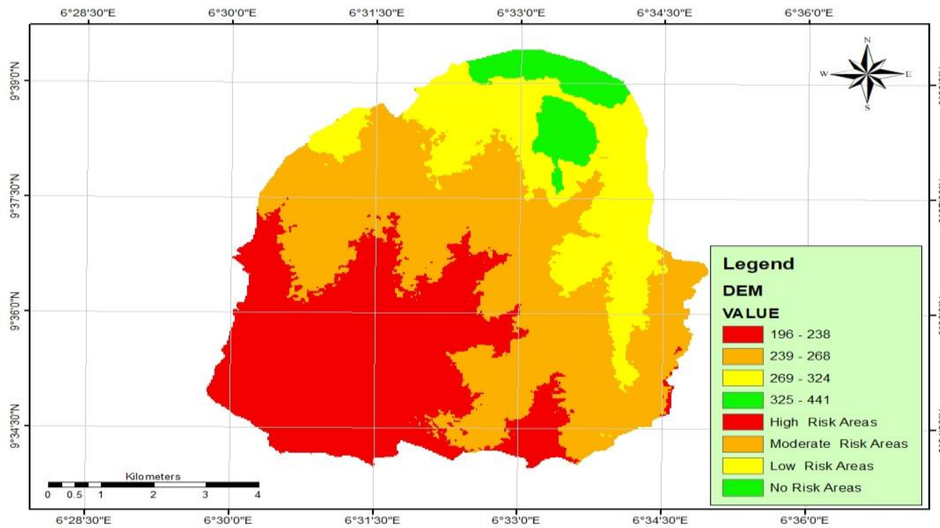


Figure 6: Flood Risk Map of the Study Area

Conclusion

The use of remotely sensed data and GIS techniques for flood analysis of study area in order to assess the flood disaster vulnerability has been demonstrated in this paper. In summary, the judicious application of Geographic Information Systems (GIS) in managing flood risks, particularly in high-vulnerability areas like the study area. GIS's unparalleled capacity to integrate and analyze diverse data sets, transforming them into practical, actionable insights, is crucial for safeguarding infrastructure and communities against flood risks. However, the essence of an effective flood management strategy goes beyond just technological implementations. It calls for a holistic approach that melds the precision of technology with the richness of community engagement, the foresight of dynamic modeling, and the synergy of interdisciplinary collaboration. Expanding on this, the role of GIS must be viewed as part of a larger tapestry of flood management efforts. It should be integrated with community-led initiatives, where local insights and experiences play a key role in shaping risk assessment and response strategies. This community-centric approach ensures that the solutions are not only scientifically sound but also culturally and socially relevant.

Recommendations

- **i.** With the rapid influx of people from surrounding LGAS and States and high rate of building construction, there is every need to make sure that these developments should adhere to master plan.
- **ii.** Automated mapping and analysis of the terrain of the State so as to generate data bank and a kind of master plan for flood disaster monitoring and management in the areaas well asgeneration of a comprehensive data and periodical reviews of all the communities that are vulnerable to flood in the state for quick decision making especially during flood disaster .

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