Expansion of Gombe and Land Use - Land Cover Changes (2000-2020)

Muhammad Sani Abubakar[1] Muhammad Magaji Ibrahim[2*] and Jibril Abubakar Babayo[3]

[1]Yamaltu Deba LGA

[2]Department of Surveying and Geoinformatics, Abubakar Tafawa Balewa University Bauchi, Nigeria.

[3] Zonal Advanced Space Technology Applications Laboratory Kashere, Gombe State.

[*]Correspondence Author: hamzasaji100@yahoo.com

Abstract

Urban sprawl is a result of population growth and human activities such as industrialization and rural-to-urban migration that alter local and regional land use and land cover (LULC) patterns. The purpose of this article is to deduce and forecast the urban sprawl scenario in Gombe metropolis using Landsat satellite data. The collected data was geospatially analyzed to generate landuse and landcover maps, which were then used to forecast future LULC using a CA-Markov model. The results indicate that Gombe metropolis covered 13.812 km^2 in 2000 and expanded rapidly to 44.105 km^2 between 2000 and 2020. Furthermore, the results indicated that the metropolis would continue to sprawl at a rate of 3.48% per year, resulting in 77.623 km^2 of urban land use in 2030. Finally, it is recommended that the government encourage more urban studies that take socioeconomic factors into account in order to ensure proper future planning, growth, and development of the Gombe metropolis.

Keywords: *Urban expansion, Geospatial, planning, extent and classification*

Introduction

Background of the Study

Urban sprawl is a result of population growth, frequent human activity such as industrialization, migration from rural to urban areas, and resettlement, all of which alter local and regional LULC patterns (Ridd & Hipple, 2006; and Bhatta, 2010).

Most urban centers have been impacted by these changes, either directly or indirectly, as a result of a variety of environmental issues (Palmate et al., 2017; Abd-el-Hamid et al., 2020; and Koko et al., 2020). Aging, water bodies, woods, and other vegetated green spaces and barren land loss can exacerbate urban problems such as population density and housing conditions (Yang, 2011).

According to Wakirwa (2015), all cities in Nigeria are experiencing sprawl, and Gombe is no exception, owing to the scale and type of development on some of the city's most agriculturally productive land. The city's built-up area has increased dramatically in recent decades, absorbing previously agricultural land at an alarming rate (Mbaya, 2012). This is a result of unchecked population growth (Alabi, 2009). According to Balzerek (2003), a single urban body formed in the 1990s as a result of the fusion of conventional settlements and peri-urban areas resulted in an urban incursion far beyond the town's original borders. Between 1900 and 1952, the population of Gombe metropolis grew slowly (from 300 to 18,500), but then exploded (from 47,000 to 138,000) between 1964 and 1991. (Balzerek, 2003).

Gombe flourished quickly after becoming the capital of the newly established Gombe state in October 1996. Tiffen (2006) reports that the metropolitan area's population increased from 169,894 in 1996 to 219,946 in 2000 and 312,467 in 2006. As a result of this change in status and population, the urban area evolved into a metropolitan city, devouring and transforming other land uses. To plan land use effectively, one must have a thorough understanding of current LULC and the ability to track the dynamics of urban sprawl caused by changing population demands and natural forces that shape the landscape.

For decades, data from remote sensing satellites (SRS) and geographic information systems (GIS) has been used to detect and identify urban sprawl and other natural resource management issues (Wang and Maduako, 2018). Remote sensing data enables the detection of changes on the earth's surface more rapidly and economically than traditional ground survey methods (Karimi et al., 2018). The data serves as a scientific foundation for land use planning, management, and policy development. Numerous studies have successfully mapped and analysed urban sprawl by utilizing various satellite data sets.

Numerous researchers have examined urbanisation, including Dabara et al. (2012), who examined the dynamics of urbanisation and flood disasters in Gombe, Nigeria. Their findings indicate that rapid population growth has accelerated residential development in Gombe, displacing plant cover and hardening surfaces, limiting rainwater infiltration into the soil and exacerbating flooding.

Wakirwa (2015) examined urban sprawl in Gombe, Nigeria. Urban sprawl, the report states, increased from 12.78 km^2 in 1999 to 39.50 km^2 in 2014, primarily consuming agricultural lands. As a result, this type of study is necessary to ascertain the rate and pattern of urban sprawl, as well as forecast future urban land use for the purposes of better planning, development, and sustainability.

The purpose of this research is to identify and forecast urban sprawl scenarios in the Gombe metropolis using satellite data and geospatial analysis techniques in order to aid in future planning for sustainable growth and development. The objectives of this study are to classify the extent of urban landuse and other landcover classes in Gombe metropolis for the years 2000, 2010, and 2020; to assess the extent of urban sprawl between the years 2000-2010 and 2010-2020; to ascertain the pattern of urban expansion in the study area; and to forecast the extent of urban areas in the year 2030.

Material and Method

Study Area

Gombe metropolis is located in northeastern Nigeria, between latitudes 10°14' and 10°20'N and longitudes 11°07' and 11°13'E. It is the capital of Gombe state (Figure 1). The metropolis is located in Sudan's savannah and has a subtropical climate with two distinct seasons: the dry season (November–March) and the rainy season (April–October), with an average rainfall of 907mm.

As of the 2006 National Census, Gombe metropolis had a population of 312,467 people. Between 1900 and 1952, Gombe's population increased gradually (from 300 to 18500 people), but then exploded (from

47,000 to 138,000 people) between 1962 and 1990. (Aliyu and Ray, 2014). However, following statehood, the population increased from 169,894 in 1996 to 219,946 in 2000 and 312,467 in the 2006 census. Between 1996 and 2000, the population increased from 169,894 to 219,946. Due to population growth, there was an increase in demand for land, which resulted in development activities such as housing construction.

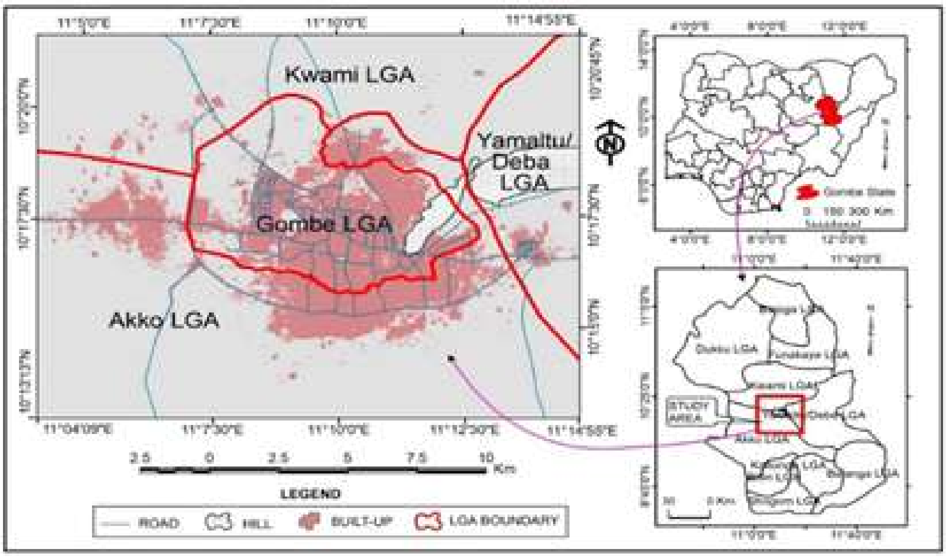

Figure 1. Map of the Study Area

Data Types and Sources

The datasets used in this study are primarily Landsat images acquired at three distinct points in time (Table 1).

Table 1: Data and it Sources

Sensor	Bands	Resolution	Date	Source
Lansat-7 ETM	2, 3, 4	30m	2000	https://glovis.usgs.go
Lansat-7 ETM+	2, 3, 4	30m	2010	https://glovis.usgs.go
Lansat-8 OLI	3, 4, 5	30m	2020	https://glovis.usgs.go

Data Preparation and Preprocessing

Prior to classification, images were preprocessed; three bands were chosen from the ETM, ETM+, and OLI sensor data. The bands were each passed through a red, green, and blue filter before being combined to create three multispectral images using ArcMap 10.7's "Band combination" tool. After combining the images, they were smoothed and sharpened using filtering and stretching to improve visual interpretation and facilitate the delineation of urban areas and other LULC classes.

Classifying Gombe Metropolis' Urban Landuse and Other Landcover Classifications

This study employs supervised classification to classify satellite images. The use of maximum likelihood classifiers for supervised classification of remotely sensed images from satellites and aircraft is well established (Weng, 2002). In ArcGIS 10.7, 2000, 2010, and 2020 Landsat images were classified by grouping homogeneous cells with similar reflectance values and saving them as "built-up class."

The same procedure was used to select pixels from the remaining LULC classes (bare surface, vegetation, and agriculture). The "signature development" tool was used to create signature statistics from composite bands and selected training sample data. These signature statistics were then saved in a signature file along with sample counts, means, and covariance matrices. Finally, a maximum likelihood classification model was used to generate classified LULC maps of the study area using the composite image of each time period and its associated signature files. The "accuracy assessment" resulted in an acceptable overall Kappa index of agreement between the categorized and reference data.

Assessing the Extent and Pattern of Urban Expansion from 2000 to 2020

The classification result's attributes and statistics were generated and used for cross-year comparisons of post-classification classifications. The degree of urban sprawl from 2000 to 2010 was calculated by subtracting the LULC area of the reference year 2010 from the base year 2000.

The result was then divided by the area of the base year and multiplied by a hundred to obtain the expansion rate, which was then divided by the number of years in the period to obtain the annual rate: ET equals T2 – T1. Where: T_1 = the base year (2000); T_2 = the reference year (2010) and; E_T = the total extent of urban sprawl between 2000 and 2010

.Rate of expansion (R_E) was calculated as: $R_E = (E_T / T_1) * 100$ And yearly urban expansion rate (R_Y) as: $R_Y = R_E / n$. Where 'n' is number of years.

To determine the urban pattern and changing characteristics of the LULC classes, as well as their contribution to the development of built-up areas over the study period, the classified LULC maps were converted to an image raster data format (.img), which enabled overlay analysis in IDRISI 17.0. The Crosstab tool of the Change/Time series analysis tools was used to simultaneously overlay LULC data from 2000, 2010 and 2020. As a result, the changing nature of each pixel associated with urban land use will be revealed.

Prediction of Urban Area Extent in the Years 2030

Urban growth in the Gombe metropolis was predicted using LULC data from the years 2000, 2010, and 2020. Suitability layers for urban sprawl, such as proximity to a road and an urban settlement, slopes, and LULC layers, were used to forecast the future urban growth of Gombe metropolis. Proximity to existing roads was taken into account in the projection for accessibility and ease of transportation; this is because lands adjacent to existing roads grow more rapidly than those further away. Similarly, proximity to urban settlements was incorporated into the model for socioeconomic reasons, as people preferred to associate with their companions to facilitate business transactions and religious obligations. To minimize construction costs and accessibility difficulties, locations with steep slopes were strategically avoided in the prediction of suitable future urban areas.

The most recent LULC map was also used to forecast future urban sprawl. Existing built-up areas serve as a point of reference for sprawling. Due to their inactivity, all bare surfaces were deemed extremely suitable for transformation into urban areas, so there is no objection. Farmland areas are considered moderately suitable, while vegetative areas have been neglected to protect the flora's ecological value. By utilizing overlay analysis, the aforementioned factors were combined into a single future urban sprawl suitability map.

Prior to the simulation, the CA-Markov chain model was validated and found to be projection-capable. The Markovian probability transition matrix was determined using LULC maps from 2000 and 2010. The output was then used to predict the 2020 LULC map using a CA-

Markov model and validated against the 2020 reference LULC. With a Kappa agreement index of 0.98064, the Markov-CA model accurately predicted the LULC in 2020. Finally, we used the LULC data from 2010 and 2020, as well as the suitability transition layers, to model future urban growth for the year 2030 using a CA Markov model and the MOLUSCE tool in the QGIS application.

Results and Discussion

Classified LULC of Gombe Metropolis in 2000, 2010 and 2020

According to the LULC classification (Figure 2), the four major classifications that encompass the Gombe metropolis and environs are built-up areas, farmland, vegetation, and bare surface. In Figure 2, developed areas are depicted in protea pink, farmland is depicted in apple green, vegetation is depicted in leaf green, and barren terrain is depicted in electron gold. Throughout the study period, visual interpretation of the classified images revealed an increase in the built-up class (urban area).

Additionally, it depicted farmland as the dominant landuse, which is primarily found outside of the built environment and throughout the research area. Additionally, it demonstrates that vegetation cover exists in the study area's southern and eastern regions.

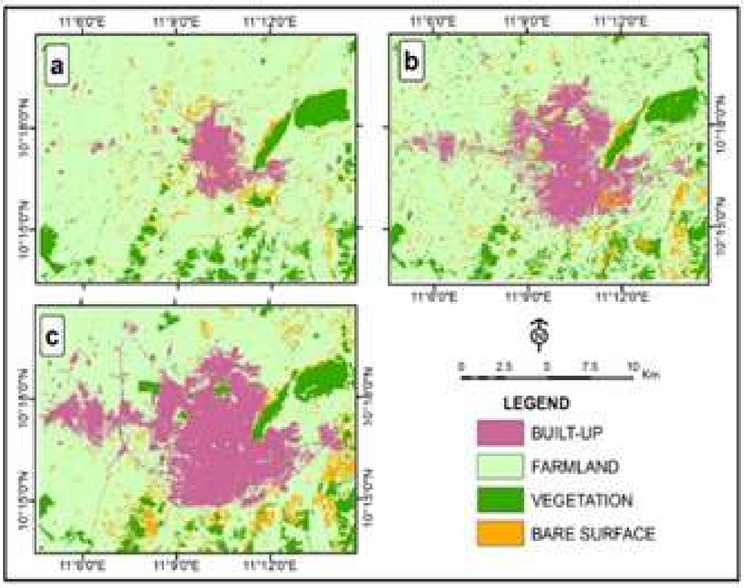

Figure 2: Spatial Extent of LULC Classes: (a) Year 2000, (b) 2010 and (c) 2020.

Table 2: Statistics of LULC Classes in 2000, 2010 and 2020.

LULC Class/year	2000		2010		2020	
	Area (Km²)	%	Area Km²	%	Area (Km²)	%
Built-up	13.812	5.63	35.065	14.29	57.917	23.61
Bare Surface	12.403	5.06	14.252	5.81	15.627	6.37
Farmland	193.362	78.82	171.641	69.97	150.600	61.39
Vegetation	25.741	10.49	24.360	9.93	21.174	8.63
Total	**245.318**	**100.00**	**245.318**	**100.00**	**245.318**	**100.00**

Table 2 demonstrates that farmland has the greatest area covered throughout the study period, despite the fact that it is decreasing; its dominance demonstrates that farming is a common activity for residents of Gombe metropolis. Farmland initially covered a maximum of 193.362 km^2, or 78.82 % of the total area studied (245.318 km^2). By 2010, it had decreased to 171.641 Km^2 (69.97%) and finally to 150.50 Km^2 (61.39%). This is because of population growth, which increased demand for residential land.

Additionally, the table indicates that vegetation cover is decreasing. Vegetation covered 25.741 km^2 in 2000, 24.36 km^2 in 2010, and 21.174 km^2 in 2020, accounting for 10.49, 9.93, and 8.63% of the total study area, respectively. In contrast to farmland and vegetation landcover, Table 2 indicates that built-up area increased over the study period. The built-up area in the beginning (2000) was 13.812 kilometers square, or 5.63 % of the total study area (245.318 kilometers square). Built-up landcover increased by 14.29% and 23.61% between 2010 and 2020, respectively.

The increase in built-up areas occurred to accommodate the metropolis's burgeoning population growth. The bare surface is the least covered land, occupying only 12.403km^2 or 5.06% of the total area under consideration in 2000. Then it increases slightly to 14.252 km (2.81%) before gradually increasing to 15.627 km (2.37%).

Extent of Urban Expansion between the Period of 2000, 2010 and 2020

The changes in various landuse and landcover classes from 2000 to 2010 and 2010 to 2020 are depicted in Table 3. Significant landuse and landcover changes occurred in Gombe metropolis and its environs over the 20-year study period. As a result, it is critical to evaluate the nature of changes in each landuse and landcover class.

Table 3: LULC Change Statistics of Gombe Metropolis from 2000 to 2020

LULC Class	2000	2010	2020	Change from 2000-2020		Change from 2010-2020	
	Area (Km²)	Area (Km²)	Area (Km²)	Area (Km²)	Annual Rate %	Area (Km²)	Annual Rate %
Built-up	13.812	35.065	57.917	21.253	15.39	22.851	6.52
Bare	12.403	14.252	15.627	1.849	1.49	1.375	0.97
Farm Land	193.362	171.641	150.6	21-.72	-1.12	-21.041	-1.23
Vegetation	25.741	24.36	21.174	1.-381	-0.54	-3.186	-1.31
Total	245.318	245.318	245.318				

As shown in Table 3, the built-up (urban) class grew significantly during the study period, as shown in Figure 3. In 2000, the built-up area accounted for only 13.812 km^2 (5.63%) of the total area under investigation. It had increased to 35.065 Km^2 after a decade (i.e., in 2010), representing a growth of 21.253 Km^2, or a 15.39 % annual growth rate.

The built-up area had increased by more than 150.39 % in 2010, implying that the urban area had more than doubled in size since 2000.This development is attributed to rapid population growth, which increased from 219,946 in 2000 to 312,467 in the 2006 census and 420,498 in 2010.

During this period, a transition to democratic governance occurred, accompanied by a slew of socioeconomic policies, including an increase in worker salaries, which increased money circulation and sparked the construction of houses to address ever-increasing housing crises. Additionally, Table 3 indicates that the second part of the study (2010–2020) observed rapid urban growth, with the built-up area increasing by 22.851 km^2 from 35.065 km^2 in 2010 to 57.917 km^2, implying an annual growth rate of 6.52 %.

The primary factor influencing this development is Gombe's relatively peaceful nature in Nigeria's North East region, which is frequently afflicted by civil unrest, most notably the Boko Haram crises in Borno, Yobe, and Adamawa states, as well as cattle rustling and banditry.

Due to its proximity and the hospitable nature of its residents, this resulted in the metropolis serving as a safe landing place for displaced people. The cumulative growth of 44.105 km^2 over the study period (2000–2020) indicates that the built-up area is rapidly expanding in size, with a growth rate of 319.31 %. This means that the built-up area has increased by more than threefold. On the other hand, farmland is rapidly shrinking in size, by a total of 42.762 km^2.

Similarly, vegetation cover shows a gradual decline in area, with a narrowing in the early decades and a widening in the last decade (from 1.381 to 3.186 Km^2), resulting in a combined decline in vegetation areas of 4.567 Km^2. The bare surface shows a slight increase in area, totaling 3.307 km^2. Growth has, however, slowed significantly in the last decade (2010–2020), from 1.949 to 1.375 Km^2, or 1.49 to 0.96 %. The profit and loss outline pattern for all LULC classes is depicted in the figure. Over the research period (2000 to 2020), the built-up (urban area) area increased by 44.105 km^2.

Urban Growth Pattern of Gombe Metropolis

Figure 3 depicts the spatial distribution of the Gombe metropolis's temporal urban growth pattern as generated by the simultaneous overlaying of LULC images from 2000, 2010, and 2020. The pattern of successive metropolis expansion depicted in the figure has a centrifugal inclination, with the visible urban covers forming a nearly circular shape and advancing in all directions.

The yellow colour in Figure 3 denotes those urban areas that have remained constant over the research period; this portion of the metropolis covers 13.366 km^2 and accounts for 23.078 % of the total urban area in 2020. (Table 4). The red colour represents farmland in 2000, which transitions to built-up status in 2010 and continues to be a built-up class in 2020. This category encompasses 18.221 kilometers square, or 31.461 % of all recent urban land.

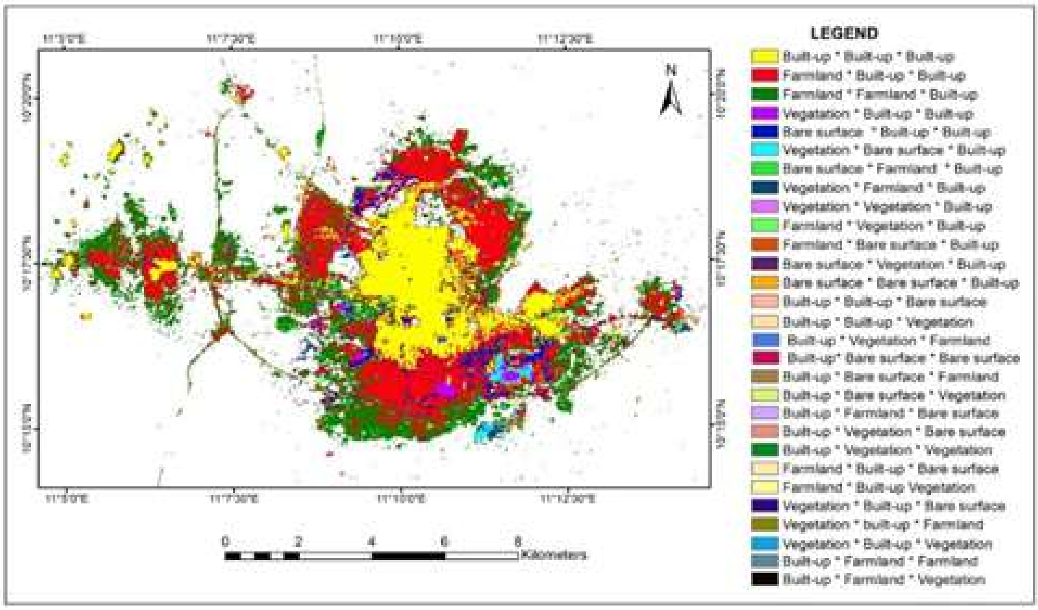

Figure 3: Urban area in 2000, 2010 and 2020.

Areas that were classified as farmlands between 2000 and 2010 but were converted to built-up land use by 2020 were shaded dark green; this class encompasses 17.841 km^2, or 30.805 % of the total recent urban area. Similarly, the protea pink colour represents those areas that were covered in vegetation in 2000 but were converted to built-up landuse in 2010 and remain as built-up landuse in 2020, totaling 0.645 Km^2 (1.114 %). Additionally, urban development from the bare surface in 2000 to built-up areas in 2010 and 2020 is depicted in dark blue on a 2.725 km^2 scale (4.705 %). Additionally, the overlay analysis results (Figure 3 and Table 4) indicate that the cyan colour represents the conversion of vegetation in 2000 to bare surface in 2010 and to built-up area in 2020; a total area of 1.453 Km^2 (2.509 %). In the years 2000, 2010, and 2020, the green colour denotes lands that transition from bare surface to farmland and then to built-up areas, and it covers an area of 1.031 Km^2, or 1.781 % (Table 4) of the total urban area. In 2000, 2010, and 2020, a light green area equal to 0.794 Km^2 (1.371 %) represents the transition of landcover from farmland to vegetation and then to built-up area. There are additional conversions, primarily from built-up to other LULC classes, that are not large enough spatially to be seen in Figure 3. However, Table 4 indicates that their cumulative value is 3.176 % of the year 2020's total urban area.

Table 4: Statistics of the urban transition pattern from 2000 to 2010 to 2020

YEAR 2000	YEAR 2010	YEAR 2020	AREA (Km²)	%
Bare surface	Built-up	Built-up	2.725	4.705
Bare surface	Farmland	Built-up	1.031	1.781
Bare surface	Vegetation	Built-up	0.041	0.070
Bare surface	Bare surface	Built-up	0.395	0.683
Built-up	Built-up	Built-up	13.366	23.078
Built-up	Built-up	Vegetation	0.007	0.012
Built-up	Built-up	Bare surface	0.002	0.003
Built-up	Farmland	Farmland	0.005	0.009
Built-up	Farmland	Vegetation	0.009	0.016
Built-up	Farmland	Bare surface	0.002	0.003
Built-up	Vegetation	Farmland	0.009	0.016
Built-up	Vegetation	Vegetation	0.006	0.011
Built-up	Vegetation	Bare surface	0.002	0.003
Built-up	Bare surface	Farmland	0.004	0.006
Built-up	Bare surface	Vegetation	0.005	0.009
Built-up	Bare surface	Bare surface	0.003	0.005
Farmland	Built-up	Built-up	18.221	31.461
Farmland	Built-up	Vegetation	0.002	0.003
Farmland	Built-up	Bare surface	0.009	0.016
Farmland	Farmland	Built-up	17.841	30.805
Farmland	Vegetation	Built-up	0.794	1.371
Farmland	Bare surface	Built-up	1.453	2.509
Vegetation	Built-up	Built-up	0.645	1.114
Vegetation	built-up	Farmland	0.002	0.003
Vegetation	Built-up	Vegetation	0.004	0.006
Vegetation	Built-up	Bare surface	0.004	0.006
Vegetation	Farmland	Built-up	0.540	0.932
Vegetation	Vegetation	Built-up	0.220	0.379
Vegetation	Bare surface	Built-up	0.571	0.986
Total			57.917	100.00

Gombe Urban Growth Prediction

Figure 4 shows the spatial distribution of the classified integrated urban transition suitability map for Gombe metropolis expansion, and Table 5 reveals the extent of each class, defining the grades of where to expect to see built-up areas in the next ten years. Table 5 reveals that about 43%, corresponding to 107.145 Km2 of the study area, is highly suitable for transition urban (built-up) areas in the year 2030. The moderately suitable class encompasses 48.945 Km^2, or 19.95% of the total.65.201 km^2 is classified as not suitable to become urban land use. While 24.028 Km^2 (9.79%) is termed as very suitable to be converted to urban landuse in the year 2030.

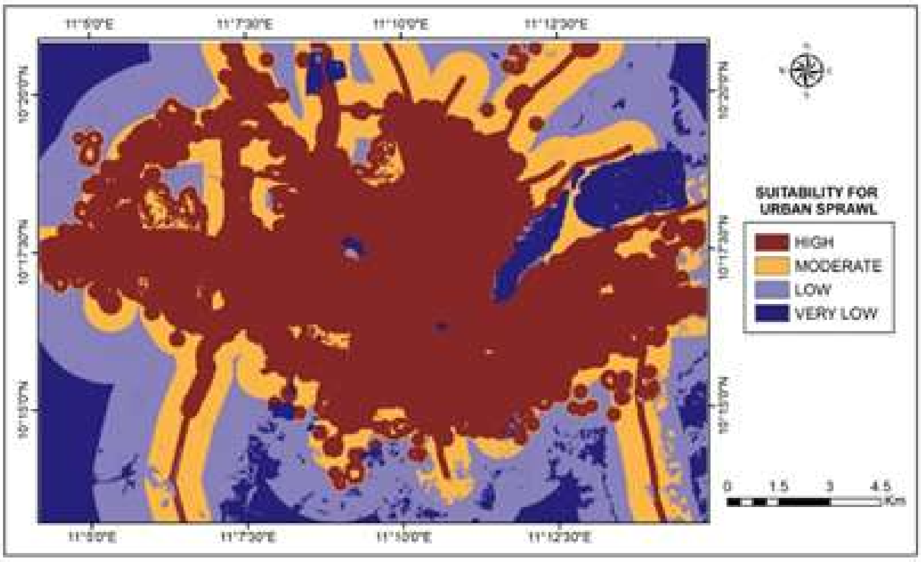

Figure 4: Future Urban expansion Suitability Map

Table 5: Statistics of the classified suitability to urban expansion

SUIT CLASS	High	Moderate	Low	Very Low	**TOTAL**
AREA (Km²)	107.145	48.945	65.201	24.028	245.319
%	43.68	19.95	26.58	9.79	100.00

The results of the CA-Markov model simulation of the predicted LULC types for the Gombe metropolis in 2030 are shown in Figure 5. The model forecasts future land use in the area based on the assumption that change rates remain constant. To maintain Gombe metropolis's centrifugal expansion pattern from the preceding epochs (2000-2010 and 2010-2020), new urban development will be concentrated around existing urban land use (Figures 5).

Table 6 summarizes urban expansion statistics and forecasts future LULC change dynamics. According to the table, the built-up area will be 77.623 km^2, or 31.64 % of the total study area, in 2030. Between 2020 and 2030, the Gombe metropolitan area will grow by 19.706 km^2 (34.0%) per year at a rate of 3.40 %. This remarkable increase in urban areas is consistent with the findings of Wakirwa (2015) and Gadiga and Galtima (2017).

The study area's bare surface area is 17.643 km^2, or 7.19 % of the total study area. This equates to a 16.7% change in area (3.531 km^2) and a 1.67 % annual decrease rate. At a 0.74 % annual rate, farmland will shrink to 139.427 km^2, or 56.84 % of the study area, a loss of 11.173 km^2, or 7.4 % of its previous size. The amount of vegetation will decrease by 5.002 km^2 (32%), to 10.625 km^2, or 4.33 % of total land area.

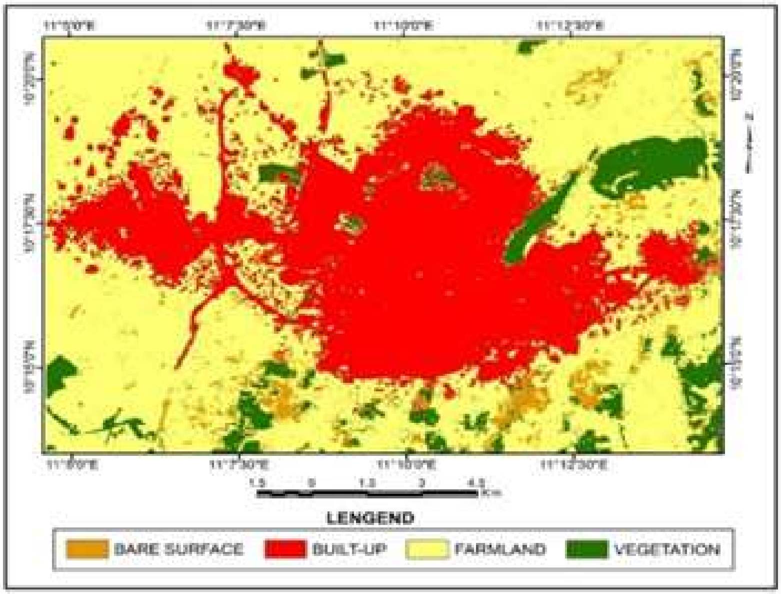

Figure 5: Gombe Metropolis 2030 LULC Map

Table 6: Projected Urban LULC Statistics and Change Dynamics

LULC Classes	2020 Area (Km²)	2030 Area (Km²)	Prediction from 2020-2030 Area (Km²)	Annual Rate
Built-up Area	57.917	77.623	19.706	3.40
Bare Surface	21.174	17.643	-3.531	-1.67
Farm Land	150.600	139.427	-11.173	-0.74
Vegetation	15.627	10.625	-5.002	-3.20
Total	245.318	245.318		

Conclusion and Recommendations

According to the research, the metropolis had grown rapidly in the four years since it became the capital of Gombe State (2000). Between 2000 and 2020, urban built-up areas and bare land increased steadily, while agriculture and vegetation declined significantly. Additionally, it was discovered that the LULC change projection from 2020 to 2030 predicts an annual rate of growth in built-up areas of 3.48 %. Conversely, the amount of bare surface, agricultural land, and vegetation will decrease by 1.67, 0.74, and 3.20 %, respectively, each year. This study established the value of combining GIS and RS approaches in order to create accurate LULC maps and change statistics for urban sprawl in Gombe metropolis. Additionally, it illustrates how the MOLUSCE tool, which incorporates a CA-Markov model, was used to forecast future spatiotemporal LULC patterns and extents. The information gathered indicates that urban expansion will continue within the research area, implying that the ever-increasing demand for residential land will persist.

Similarly, as vegetation cover declines, the urban climatic conditions will deteriorate, resulting in the emergence of more urban hot spots. As a result, the information provided is critical for making urban planning decisions and tracking growth to ensure environmental sustainability.

As a result of the research findings, it is recommended that all stakeholders in the state's urban land use management strictly adhere to urban land use legislation. The government should encourage additional urban studies that take socioeconomic factors into account in order to improve urban management and sustainability.

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