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Influence of Urbanisation on Landforms/Landscape Changes in Benin City, Edo State, Nigeria

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Abstract

The study examined the influence of urbanization on landforms/landscape Changes in Benin City, Edo State, Nigeria. The study made use of Landsat imagery of 1990, 2000, 2010 and 2020 to determine the rate of urbanization and digital elevation model of 2000 and 2020 to discover the geomorphological changes over time in the study area. Descriptive statistics were used for data analysis. Findings reveal that built up area increased from 194.24 km^2 in 1990 to 407.19 km^2 in 2020 of the total study area suggesting 109.62% increase in the spatial extent of the built area, The landforms evolution between 2000 and 2020 in Benin City observed that the valley covered a spatial extent of 487.16 sq km (19.21%), flat surfaces/middle slope covered 703.42 sq km (27.74%), upper slope covered 1016.66 sq km (40.09%) and peak/hill covered 328.49 sq km (12.95%). In the year 2020, the landform evolution revealed valley covering 384.62 sq km (15.10%), flat surfaces/middle slopes covering 1366.9 sq km (53.66%) and peak/hill covered 795.62 sq km (31.24%). The study concluded that the landuse and land cover change over time has affected the evolution of landforms pattern in Benin City; and in most areas, erosion has deeply taken place which has reduced the heights of some parts of the topography. It is recommended that the urban growth or sprawl evidently demonstrated in Benin City should be controlled under the supervision of the Town Planning Offices at the State level and Local Government Areas levels to ensure that the environment is prevented against unwanted environmental hazards.

Keywords: Urbanisation; Landforms; Landuse; Evolution; Elevation; Hazard

1. Introduction

Urbanization is one of the major challenges that the world faces today. At least 0.5% of the terrestrial area is now urbanized (Schneider et al. 2009). In 2015, 54% of the world population was living in urban areas and in some countries this percentage is close to 100%. Humans have been using land and its resources for centuries in a pursuit of their better lives. The way humans have used land and exploited its resources over time is a serious problem (Cieslewicz, 2002; Ochola, 2024) as it has altered land cover and impacted the functioning of the ecosystem. With the advent of agriculture, modern technology, and the rise of capitalist mode of economy, the exploitation of land and its resources has increased dramatically.

More seriously, at least 0.5% of the terrestrial area is now urbanized (Schneider et al. 2009).

In 2015, 54% of the world population was living in urban areas and in some countries this percentage is close to 100%). In several parts of the world annual urbanization rates exceed 5% (e.g. Oman 8.54%; Rwanda 6.43%; Burkina Faso 5.87%; Uganda 5.43%; Burundi 5.66%; Tanzania 5.36%; Niger 5.14%; Data: CIA), which means that urban sprawl is a widespread phenomenon. Urbanization and correlated infrastructure building highly impact and sometimes completely destroy landforms. Human activities have a substantial and cumulative effect on the landscape and its landforms.

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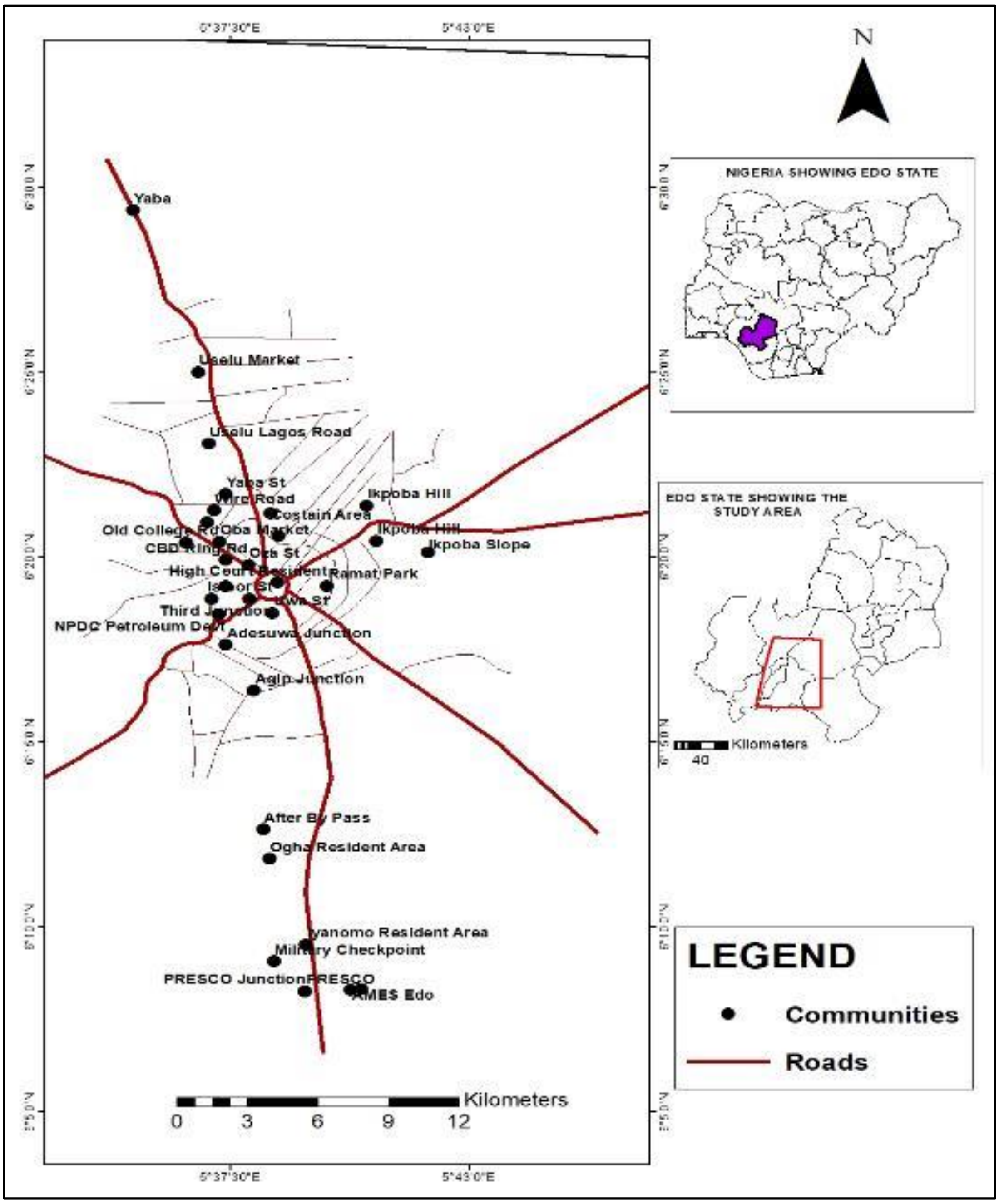
Geomorphologic changes result from a range of anthropogenic activities including forest clearing, agriculture, land draining and filling, mining and quarrying, channelization, irrigation, and construction of dams or other engineering features (Nir, 1983). These activities involve the intentional removal and deposition of material as well as the unintentional effects of hydrological changes and resulting erosion and sedimentation (Hooke, 2000). Anthropogenic landforms are created at a variety of spatial scales. Local scale landforms result from excavation, cutting, and grading to modify slopes and drainage patterns to create level ground for development and transportation infrastructure (Nir, 1983). Broader scale landforms are created by mining and quarrying, as well as subsidence due to water or mineral resource extraction. Depositional landforms, or 'man-made ground' typically entail the use of fill material, as well as waste dumps, and may occur at a range of scales (Douglas et al., 2010). The cumulative geomorphologic effects of anthropogenic activity are most pronounced in areas of dense human occupation (e.g. in urban spaces) and primarily occur in the early-urban to the mid-urban stages of development (Nir, 1983).

Anthropogenic activities result in processes that considerably change the landscape (Machar, 2012) and even surpass the activeness of natural exogenic processes (Hooke & Martín-Duque 2012; Nir & Man 1985). These activities often have great importance from the economic point of view (quarrying, mining fossil fuels, urban development, adjusting landscape for agriculture, construction of large dams which provide water reserves for industries and cities etc.), but from the conservation point of view, they lead to degradation of the landscape (Goudie 2006) and protected areas (Oprsal et al., 2018). In some cases the landscape is completely remodeled and there is no evidence of past landforms (Szabó et al., 2010; Kilianova, et al., 2017). An anthropogenic landform is created by human activity, particularly by construction, excavation, hydrological interference and farming (Kilianova et al, 2017). Anthropogenic landforms can be classified by the character of their impact: direct or indirect (Li et al., 2017), and respectively intentional or unintentional (primary anthropogenic landforms and secondary anthropogenic landforms). A few of the previous studies reported the impact of urbanization on landform changes over time and as a result the present study is focusing at examining the influence of urbanisation on landforms/landscape changes in Benin City, Edo State, Nigeria.

2. Materials and Methods

The study was carried out in Benin City, Edo State, Nigeria (Figure 1). Benin is the state capital of Edo State; it is located in the Southern part of Nigeria. Situated approximately 40 kilometers North of the Benin Rivers and 320 Kilometers by road east of lagos. Benin City is one of the oldest cities in Nigeria. The population of Benin at as 2006 is 1,147,188 and a land mass of 56,807 hectares (NPC 2006). The metropolis of the city cuts across four local government areas, Egor, Oredo, Ovia North-East and Ikpoba-Okha. The city has remained a major commercial has linking the western, eastern, northern, and southern part of Nigeria. Agricultural production is a major occupation of the people. The city lies within the tropical rainforest belt of Nigeria and it is a home to several forest production including timber, oil notion and rubber. The people of Benin City are known as Edo or Bini. They have one of the richest dress cultures on the African continent and are known for their beads, body marks, bangles, anklets and raffia work. Benin City is a home of Nigeria's institutions of higher learning. These educational institutions, industrial activities coupled with socio-economic encourage the movement of population growth.

The sources of data for this study were both primary and secondary data sources. The primary data included the recording of the coordinates of some of the landmarks that can guide in the classification of the landuse/land cover and other geomorphic features present in each of the study locations. This was achieved by using the global positioning system (GPS). The secondary data included multi-temporal landsat satellite datasets of 1990, 2000, 2010 and 2020. The 1990 landsat imagery was obtained from Landsat 4 or 5 Thematic Mapper (TM), while that of 2000 and 2010 were obtained from Landsat 7 Enhanced Thematic Mapper-plus and 2020 was Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS). All these imageries have 30 m resolution using nonlinear classification and artificial visual interpretation methods. The Digital Elevation Map of Shuttle Radar Topographic Mission (STRM) of 1 Arc-Second Global resolution from the website of Earth Resources Observation and Science (EROS) Center. This was collected for the years 2000 and 2020 to examine the variation in the topography of the study area. The STRM of 2000 and 2020 were used because they were the available DEM that are from reliable sources while those of 1990 and 2010 were not available. The urban growth pattern of the study locations was determined using the landsat imageries of 1990, 2000, 2010 and 2020. The elevation, slope rise percent, slope degree, relief contours drainage network and landforms were obtained from the DEM imagery of 2000 and 2020. The landsat imageries of the study locations were classified into different major landuse/land cover using the maximum likelihood supervised classification method in the ArcGIS environment.



Source: Edo State Ministry of Land and Surveying, 2024

Figure 1 Benin City Metropolis

The workflow chart for the evolution of landscape change patterns in this study was obtained by using topographical position index (TPI). The Topographic Position Index (TPI) is a geospatial analysis tool used to classify terrain by comparing the elevation of a cell to the average elevation of its surrounding cells within a defined radius (De Reu et al., 2013). This comparison helps in identifying landforms and slope positions, such as ridges, valleys, and slopes. Essentially, TPI highlights whether a cell is higher or lower than its neighbours. Topographic Position Index (TPI) is a topographic position classification identifying upper, middle and lower parts of the landscape.

“TPI measures the difference between elevation at the central point (z0) and the average elevation (ẑ) around it within a predetermined radius (R), where (n) the total number of surrounding points employed in the evaluation”[Wilson and Gallant, 2000; Jenness, 2006; Al-Sababhah, 2023]:

$\hat{Z} = 1/n\mathrm{R}\ 1\ \mathrm{nR} \sum \mathrm{i} \in \mathrm{R}\ \mathrm{Zi}$ ………………………………………………….. Equ 1.

The output of the TPI value is positive when the central point is situated higher than its neighborhood and negative when it is situated lower. The output values mostly range between +1 and −1, and values outside this range may indicate anomalies within the DEM. Moreover, "DEV measures the topographic position of the central point (z0) using TPI, and the standard deviation of the elevation (SD)"

[22]. This can be represented as follows:

$$DEV = z0 - \hat{Z}/SD \quad \text{Equ. 2}$$

TPI is computed with the focal function by Arc GIS tools, as follows:

$$TPI < - \text{focal}(x, w = f, fun = \text{function}(x, \ldots)\ x[5] - \text{mean}(x[-5])) \quad \text{Equ 3}$$

Where positive TPI values point to high areas as ridges, negative values represent lower areas as valleys, and zero value indicates flat areas (Wilson, 2000)

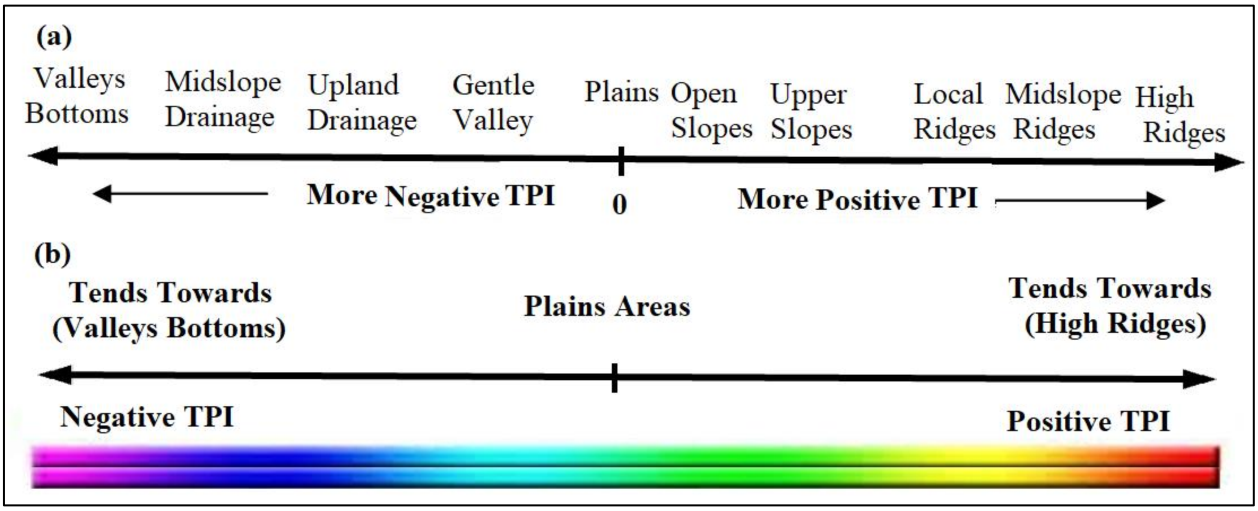
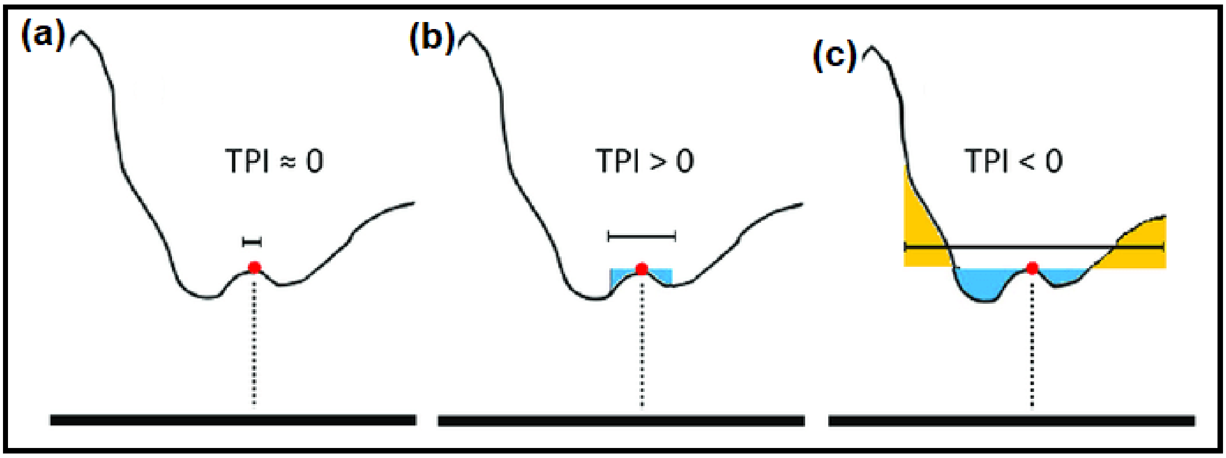


Figure 2(a) Landform types according to TPI values, (b) Positive and negative TPI values



Descriptive statistics were employed for the data analysis.

Figure 3 Elevation values change according to TPI, at three scales: a TPI is zero, b TPI higher than zero, c TPI lower than zero (Wilson, 2000; Al-Sababhah, 2023)

3. Results and Discussions

3.1. Landuse and Land cover Analysis of Benin City from 1990 to 2020

Table 1 shows the landuse/land cover pattern in Benin City of Edo State between 1990 and 2020. In 1990, it is revealed that waterbodies covered 426.58km^2 (16.56%) of total study area, thick vegetation had 1547.75 km^2 (60.09%), farmlands had 407.01 km^2 (15.80%), and built up area had 194.24 km^2 (7.54%) (Figure 4). In 2000, it is shown that waterbodies covered 411.58km^2 (15.98%) of total study area, thick vegetation had 1510.11 km^2 (58.63%), farmlands had 338.21 km^2 (13.13%), and built up area had 315.69 km^2 (12.26%) (Figure 5). In 2010, it is shown that waterbodies covered 358.87km^2 (13.93%) of total study area, thick vegetation had 1418.25 km^2 (55.07%), farmlands had 428.2 km^2 (16.43%), and built up area had 375.27 km^2 (14.27%) (Figure 6). In 2010, it is shown that waterbodies covered 397.45km^2 (15.43%) of total study area, thick vegetation had 1358.66 km^2 (52.75%), farmlands had 412.29 km^2 (16.01%), and built up area had 407.19 km^2 (15.81%) (Figure 7).

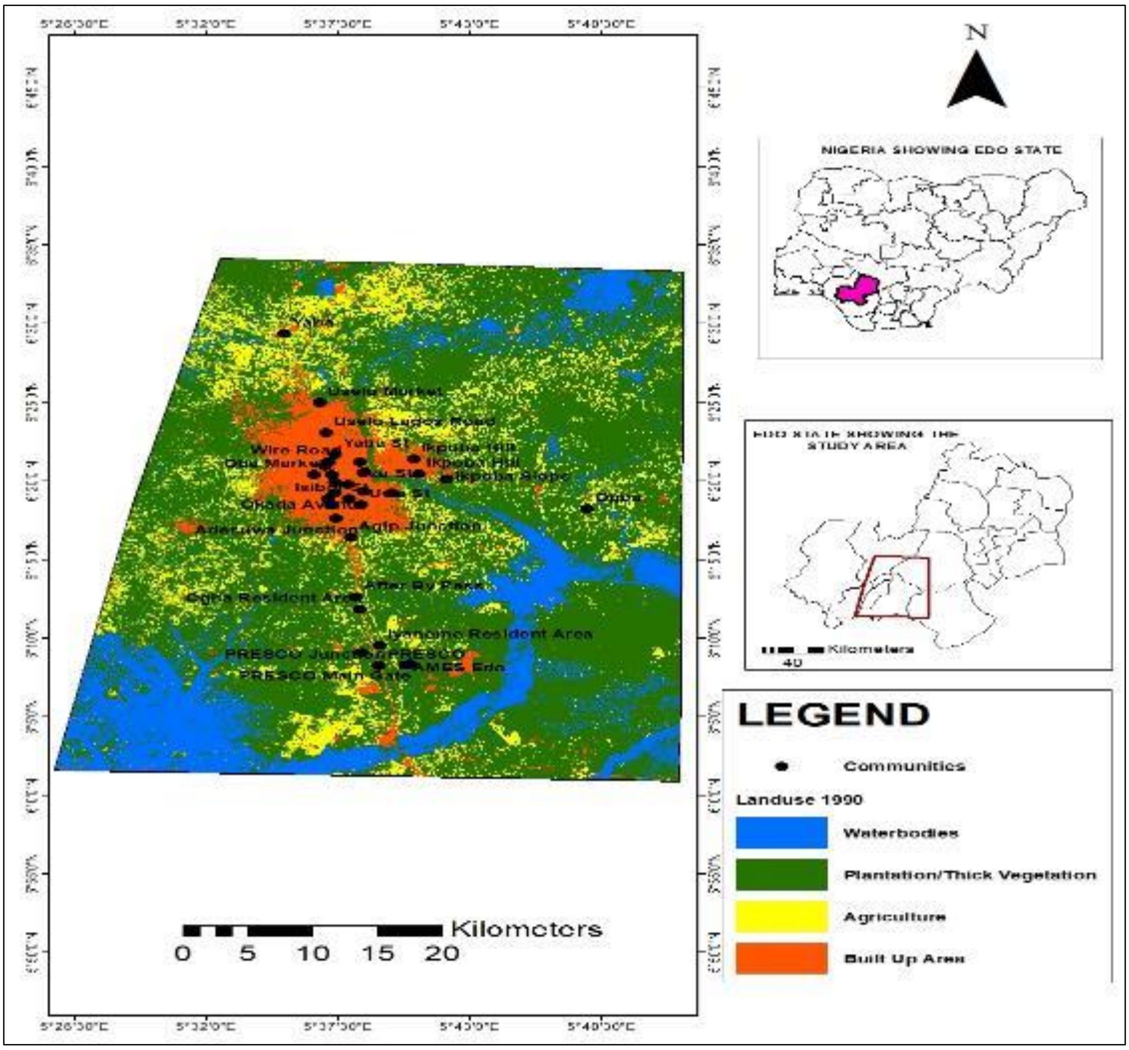


Figure 4 Landuse/Land cover of Benin City in 1990

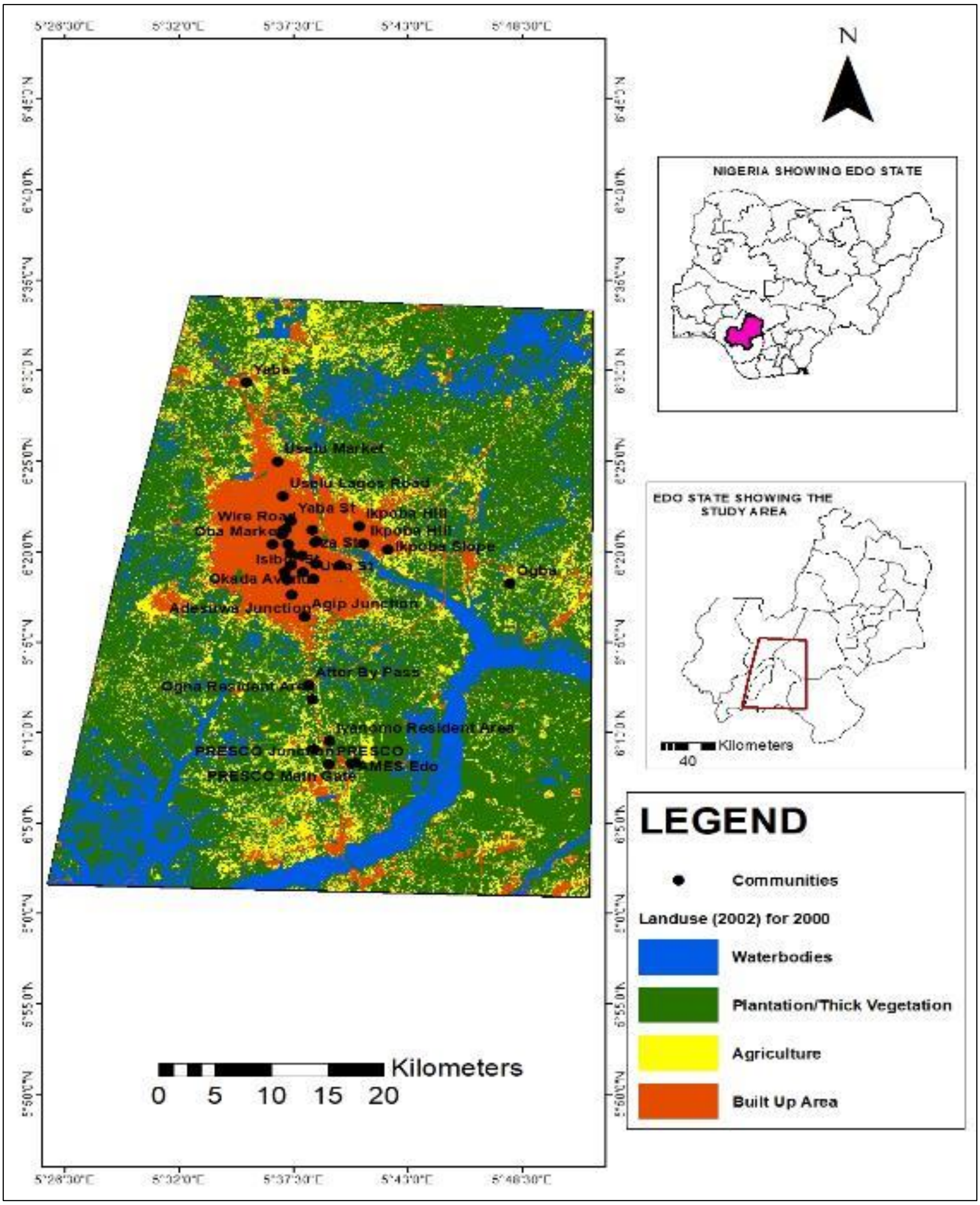


Figure 5 Landuse/Land cover of Benin City in 2010

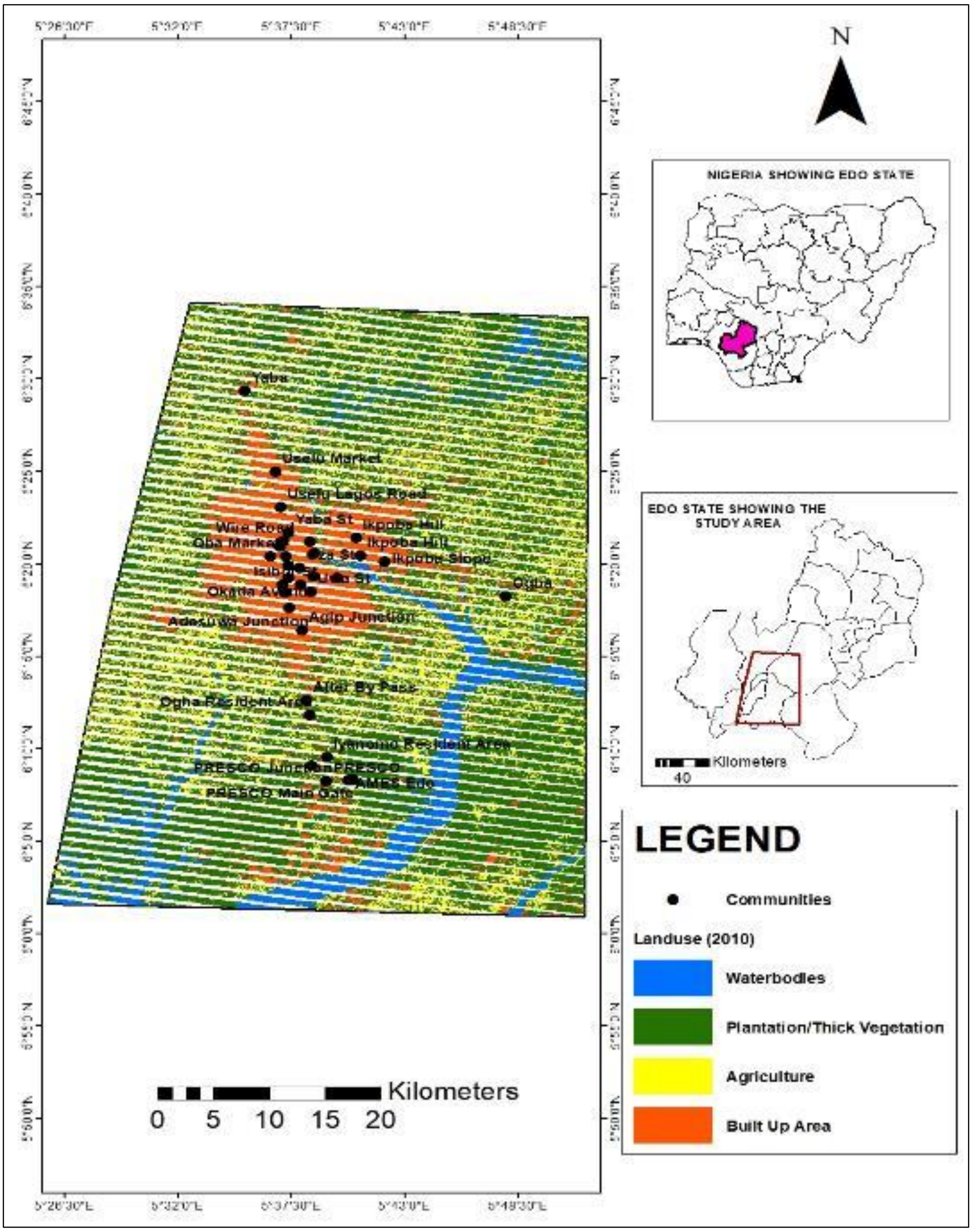


Figure 6 Landuse/Land cover of Benin City in 2010

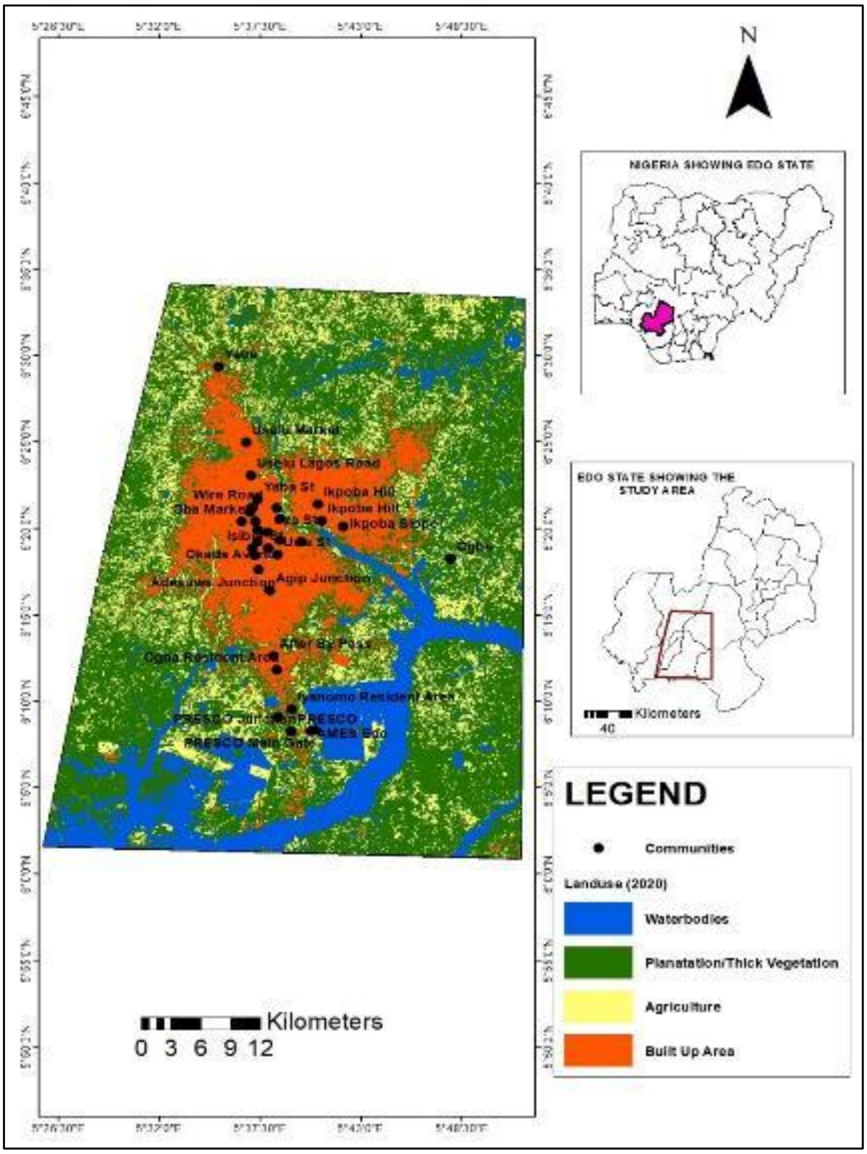


Figure 7 Landuse/Land cover of Benin City in 2020

Table 1 Landuse change from 1990 to 2020 in Benin and Environs

Landuse	**1990**		**2000**		**2010**		**2020**	
	Areal coverage (km²)	Percentage (%)	Areal coverage (km²)	Percentage (%)	Areal coverage (km²)	Percentage (%)	Areal coverage (km²)	Percentage (%)
Waterbodies	426.58	16.56	411.58	15.98	358.87	13.93	397.45	15.43
Thick Vegetation	1547.75	60.09	1510.11	58.63	1418.25	55.07	1358.66	52.75
Farmlands	407.01	15.80	338.21	13.13	423.2	16.43	412.29	16.01
Built Up Area	194.25	7.54	315.69	12.26	375.27	14.57	407.19	15.81
Total	2575.59	100.00	2575.59	100.00	2575.59	100.00	2575.59	100.00

The landuse change and percentage change of Benin City is presented in Table 2. From 1990 to 2000, the analysis showed that thick vegetation reduced by 37.64 km^2 (23.61%), and waterbodies reduced by 15.0 km^2 (3.52%) while the spatial extent of farmlands increased by 68.80 sq km (16.90%), and built up area increased by 121.44 sq km (62.52%).

From 2000 to 2010, the analysis showed that thick vegetation reduced by 91.86 km^2 (6.08%), and waterbodies reduced by 52.71 km^2 (12.81%) while the spatial extent of farmlands increased by 84.99 sq km (25.13%), and built up area increased by 59.58 sq km (18.87%).

From 2010 to 2020, the analysis showed that thick vegetation reduced by 59.59 km^2 (4.20%), and farmlands reduced by 10.91 km^2 (2.58%) while the spatial extent of waterbodies increased by 38.58 sq km (10.75%), and built up area increased by 31.92 sq km (8.51%).

In a nutshell, from 1990 to 2020 , it was discovered that thick vegetation reduced by 189.09 km^2 (12.22%) and waterbodies reduced by 29.13 km^2 (6.83%) while the spatial extent of farmlands increased by 5.28 sq km (1.30%), and built up area increased by 212.94 sq km (109.62%).

Table 2 Landuse change and percentage change between 1990 and 2020 in Benin City and Environs

Landuse	**1990**	**2000**	**Rate of Change**	**Percentage of Change (%)**
Waterbodies	426.58	411.58	-15	-3.52
Thick Vegetation	1547.75	1510.11	-37.64	-2.43
Farmlands	407.01	338.21	-68.8	-16.90
Built Up Area	194.25	315.69	121.44	62.52
Total	2575.59	2575.59		
Landuse	2000	2010		
Waterbodies	411.58	358.87	-52.71	-12.81
Thick Vegetation	1510.11	1418.25	-91.86	-6.08
Farmlands	338.21	423.2	84.99	25.13
Built Up Area	315.69	375.27	59.58	18.87
Total	2575.59	2575.59		
Landuse	2010	2020		
Waterbodies	358.87	397.45	38.58	10.75
Thick Vegetation	1418.25	1358.66	-59.59	-4.20
Farmlands	423.2	412.29	-10.91	-2.58
Built Up Area	375.27	407.19	31.92	8.51
Total	2575.59	2575.59		
Landuse	1990	2020		
Waterbodies	426.58	397.45	-29.13	-6.83
Thick Vegetation	1547.75	1358.66	-189.09	-12.22
Farmlands	407.01	412.29	5.28	1.30
Built Up Area	194.25	407.19	212.94	109.62
Total	2575.59	2575.59		

3.2. TPI Analysis and Landform Evolution in Benin City

The TPI range of Benin City is presented in Table 3 and displayed in Figure 8 for the year 2000 and Figure 9 for the year 2020. The TPI gradient of Benin City in 2000 was between -11.55 m to 13.22m. It is shown that from -11.55 to -1.64 covered a spatial extent of 90.72 sq km (3.58%), from -1.63 m to -0.76m covered 396.44 sq km (15.63%), -0.75m to -0.09m covered 703.42 sq km (27.74 %), from -0.10m to 0.98m covered 1016.66 sq km (40.09%) and from 0.99m to 13.22m covered 328.49 sq km (12.95%). In the year 2020, the TPI ranged from -31.33m to 27.33m. It is shown that from -31.33m to -12.00m covered 129.16 sq km (5.05%); from -11.99m to -3.72 m covered 255.46 sq km (9.99%); from -3.71m to 1.56m covered 1366.84 sq km (53.47%) and from 1.57m to 7.77m covered 611.7sq km (23.93%) and from 7.78 m to 27.33m covered 193.33 sq km (7.56%).

Table 3 Topographic Position Index (m) of Benin City (2000-2020)

2000			**2020**		
TPI (m)	Area (sq km)	Percentage (%)	TPI (m)	Area (sq km)	Percentage (%)
-11.55- -1.64	90.72	3.58	-31.33- -12.00	129.16	5.05
-1.63 - - 0.76	396.44	15.63	-11.99 - - 3.72	255.46	9.99
-0.75 - -0.09	703.42	27.74	-3.71 – 1.56	1366.84	53.47
-0.10 – 0.98	1016.66	40.09	1.57 – 7.77	611.7	23.93
0.99 – 13.22	328.49	12.95	7.78 – 27.33	193.33	7.56
Total	2535.73	100.00	Total	2556.49	100.00

The topographic position index showed that

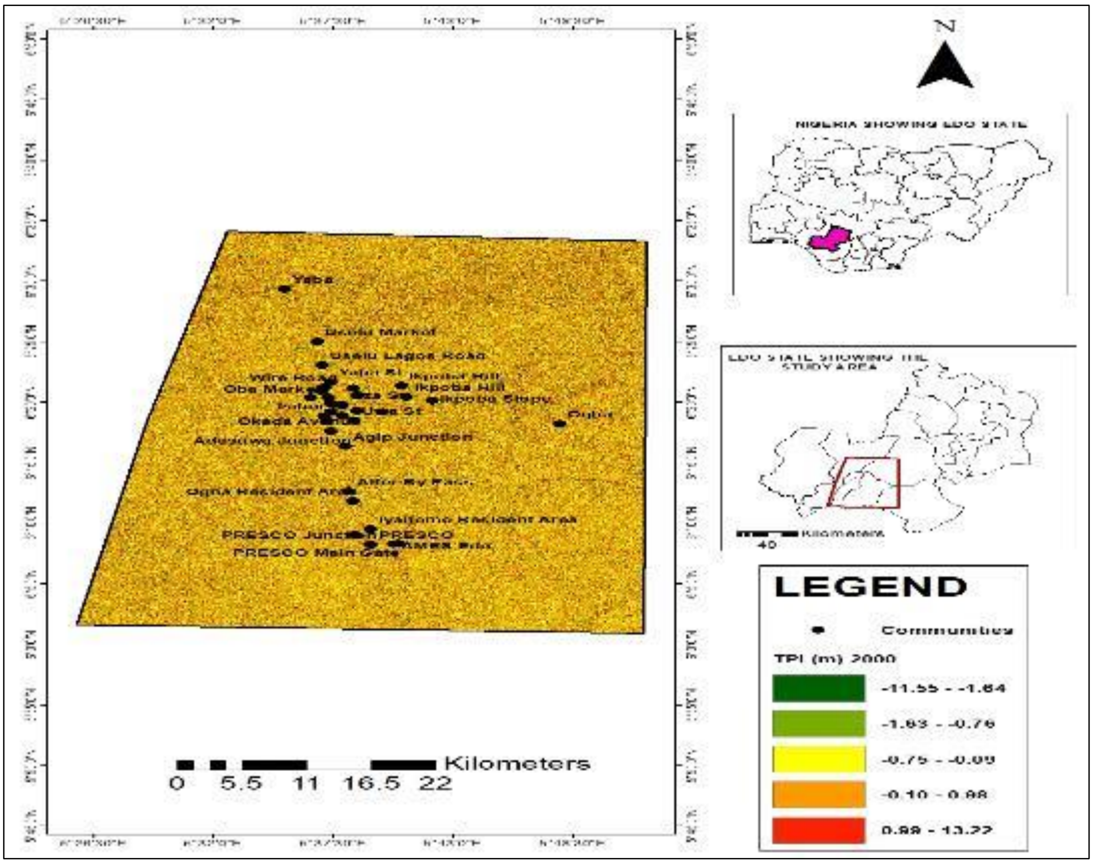


Figure 8 Topographic Position Index of Benin City Metropolis in 2000

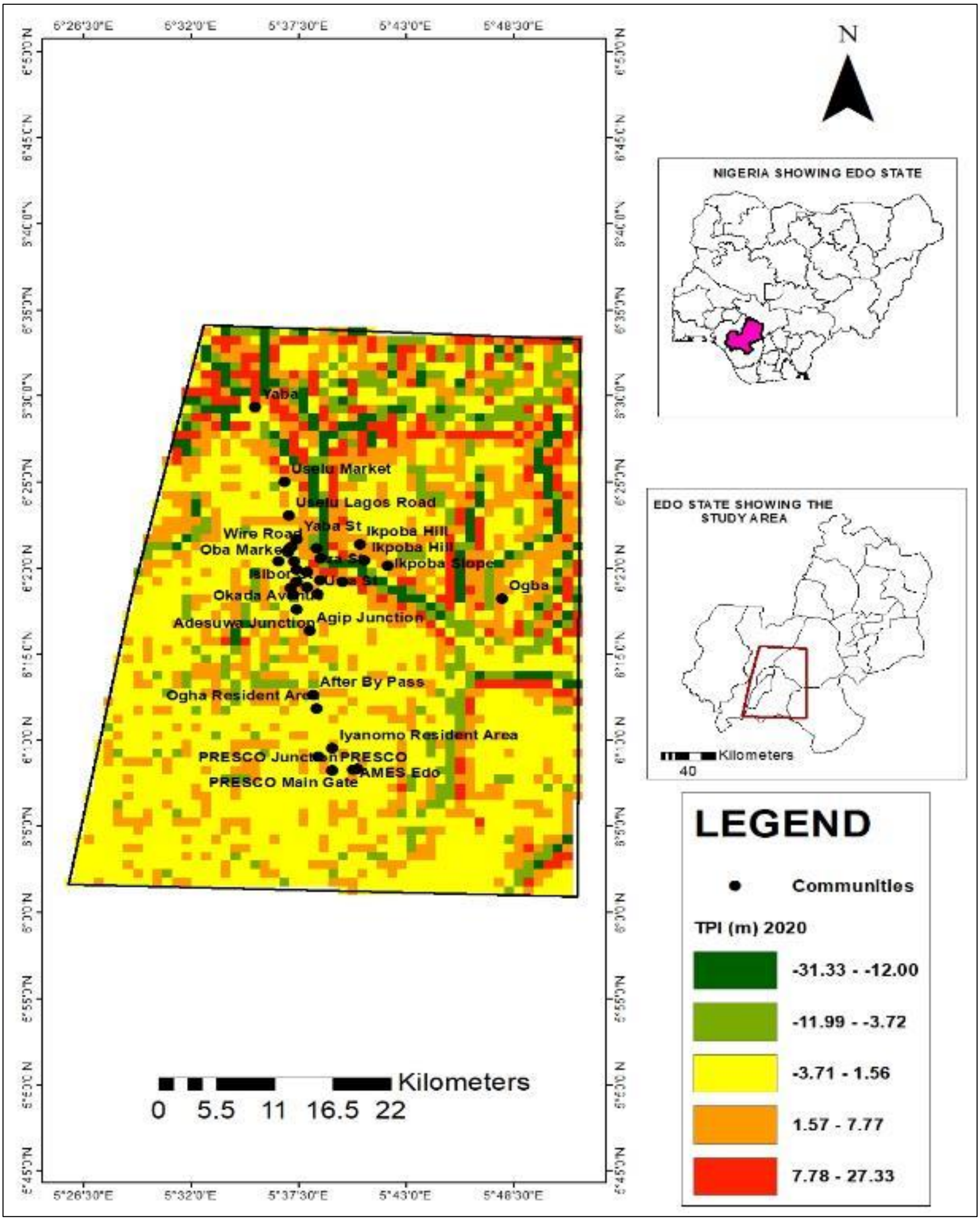


Figure 9 Topographic Position Index of Benin City in 2020

Table 4 presents the landforms evolution between 2000 and 2020 in Benin City and also displayed in Figure 10 for the year 2000 and Figure 11 for the year 2020. It is observed that the valley covered a spatial extent of 487.16 sq km (19.21%), flat surfaces/middle slope covered 703.42 sq km (27.74%), upper slope covered 1016.66 sq km (40.09%) and peak/hill covered 328.49 sq km (12.95%). In the year 2020, the landform evolution revealed valley covering 384.62 sq km (15.10%), flat surfaces/middle slopes covering 1366.9 sq km (53.66%) and peak/hill covered 795.62 sq km (31.24%).

Table 4 Landforms Evolution between 2000 and 2020 in Benin City

2000			2020		
Landforms	Area (Sq km)	Percentage (%)	Landforms	Area (Sq km)	Percentage (%)
Valley	487.16	19.21	Valley	384.62	15.10
Flat Surfaces/Middle Slope	703.42	27.74	Flat Surfaces/Middle Slope	1366.9	53.66
Upper Slope	1016.66	40.09	Peak/Hill	795.62	31.24
Peak/Hill	328.49	12.95			0.00
Total	2535.73	100.00		2547.14	100.00

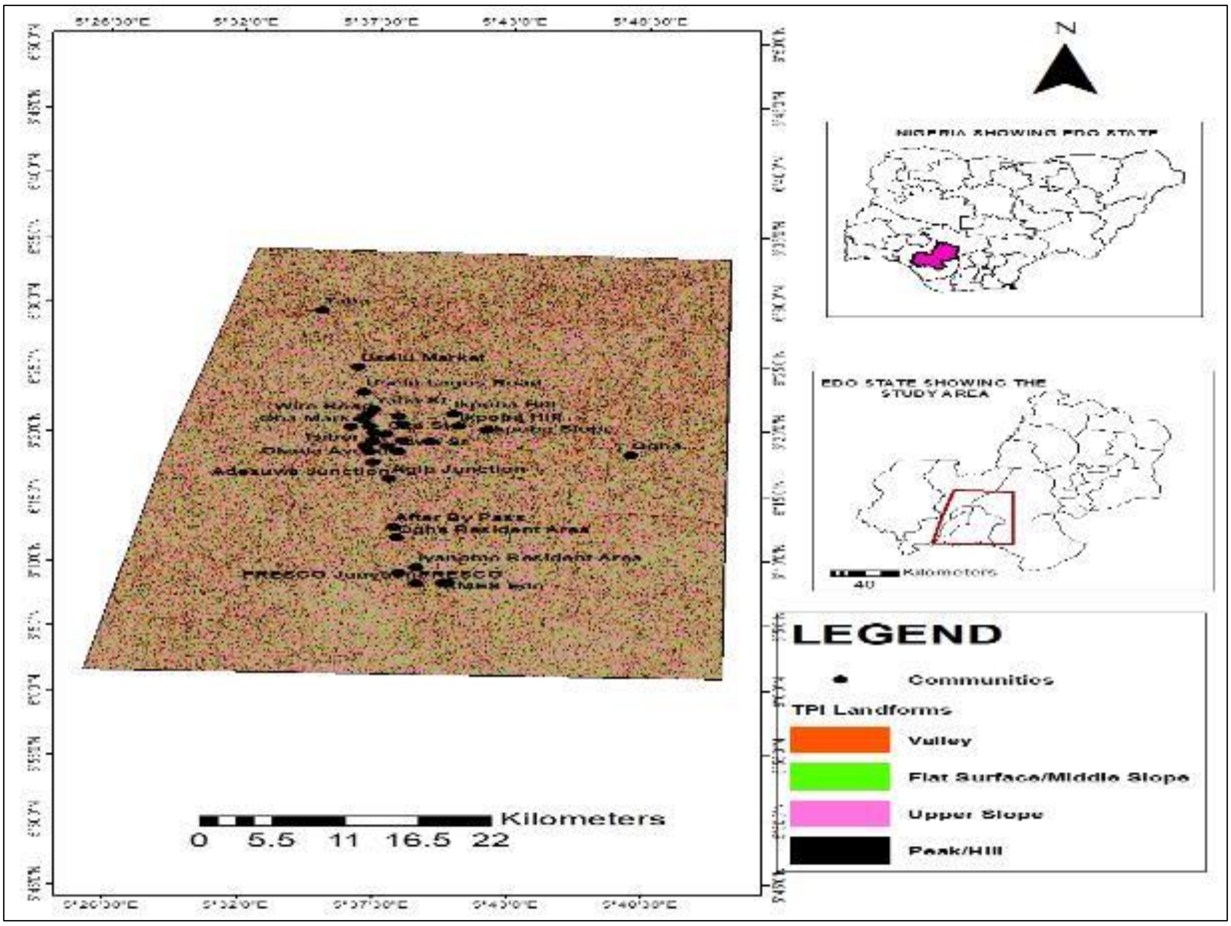


Figure 10 Landforms Evolution between in Benin City in 2000

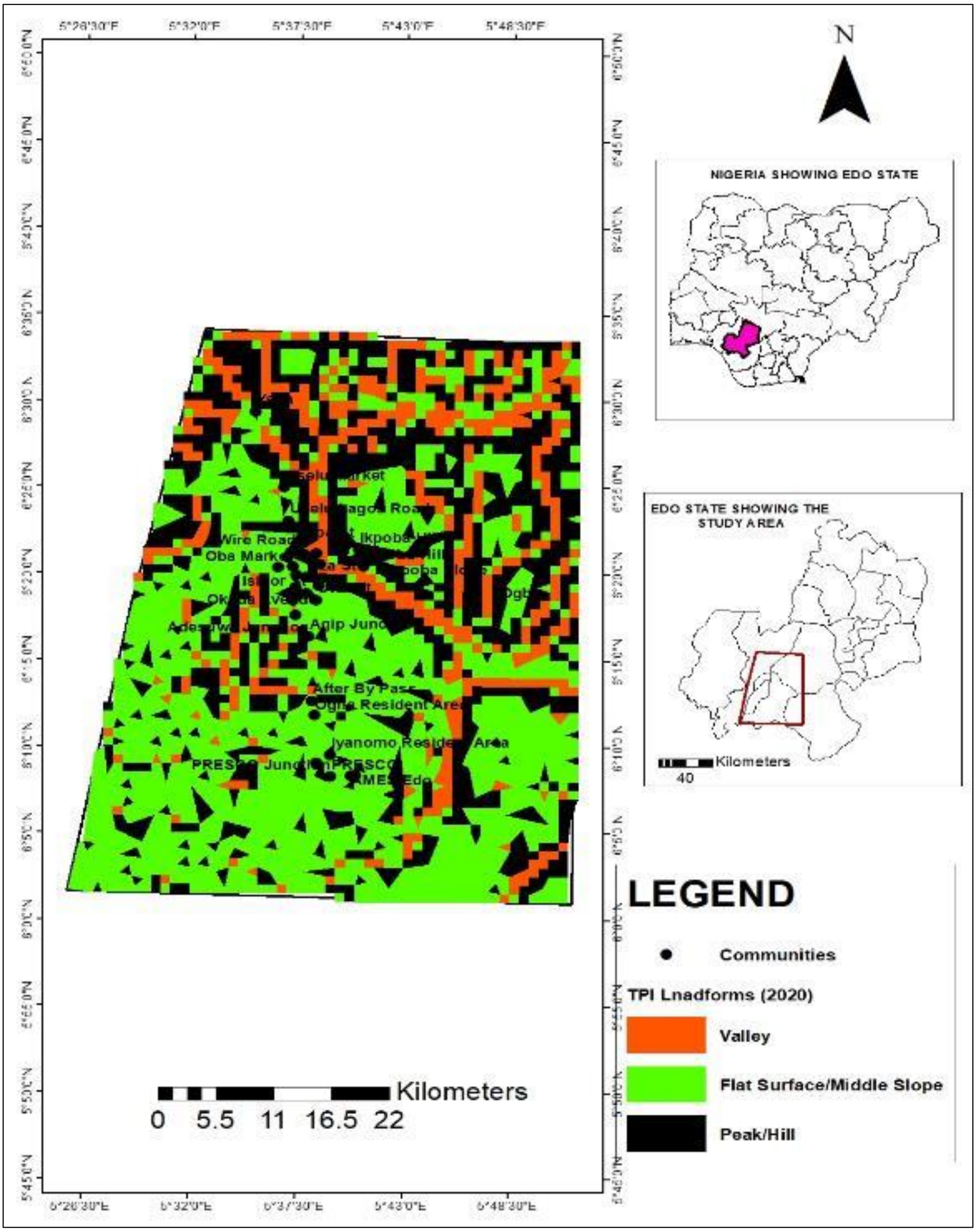


Figure 11 Landforms Evolution between in Benin City in 2020

4. Discussion of Findings

The urban expansion over the years in the Capital Cities of States in the South south region of Nigeria has altered the topographic nature of these places. Findings showed that the evolution of landforms in the Capital Cities of South south States had basically produced valleys, flat surface/middle slope, upper slope, and peak/hills or peak/ridges. Among all these landforms, the flat surface/middle slope was found to be the largest landforms evolving in the South south region. This is in agreement with the of De Reu et al (2013) whereby the middle slope/flat area was the largest category, with percentages ranging between 63.28% (100 m) and 69.97% (1500 m). Each of the other four categories (valley, lower slope, upper slope and ridge) represented between 5% and 10%. No wonder Wang et al., (2023) and Peng et al., (2017) reported that urbanization often manifests as significant alterations in the landscape, both in terms of amount and spatial layout, for example, the expansion of impervious surface and the retreat of the natural surface. These alterations change original ecological functions and processes, and the increase impermeability of the cities significantly (Liu et al., 2019; Mao et al., 2019).

Similarly, Wang et al (2023) noted that urbanization significantly alters the Topographic Position Index (TPI) of urban areas by changing land cover and altering natural drainage patterns. Urban expansion, with its associated increase in impervious surfaces and engineered drainage systems, can lead to a homogenization of the TPI, potentially reducing the natural variability of the landscape. Furthermore, urban development can alter the spatial distribution of topographic features, impacting how water flows and how landforms are shaped. Jiang et al (2024) also reported that the expansion of urban areas can significantly alter landscape patterns, with construction land often concentrated in low-lying areas and forest land in higher topographic areas. This shift in land use can further influence the TPI by altering the distribution of different land cover types and their associated topographic characteristics. The changes in landscape patterns resulting from urban expansion are a significant driver of alterations to the urban and surrounding ecological environment (Das et al., 2021; Wei et al., 2022).

5. **Conclusion and Recommendations**

The study concluded that the landuse and land cover change over time has affected the evolution of landforms pattern in Benin City; and in most areas, erosion has deeply taken place which has reduced the heights of some parts of the topography. It is recommended that the urban growth or sprawl evidently demonstrated in Benin City should be controlled under the supervision of the Town Planning Offices at the State level and Local Government Areas levels to ensure that the environment is prevented against unwanted environmental hazards.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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