ASSESSMENT OF LANDSCAPE CONNECTIVITY OF URBAN GREEN INFRASTRUCTURE FOR BIODIVERSITY MANAGEMENT IN IBADAN

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ABSTRACT

Urban Green Infrastructure (UGI) provides multiple benefits, but these are being greatly eroded by urbanization and declining connectivity, which threaten biodiversity in urban centres. This study therefore investigated the connectivity of green spaces in the Ibadan metropolis, Nigeria, using a combination of geospatial technology and landscape metrics. Landsat 5 TM, 7 ETM+, and 8 OLI-TIRS satellite imageries for 2000, 2005, 2010, 2015, and 2020 were used for land use/land cover change detection. Connectivity analysis was conducted with Fragstats metrics using seven indices: Number of Patches (NP), Mean Patch Area (AREA_MN), Mean Area Perimeter Ratio (PARA_MN), Mean Patch Contiguity Index (CONTIG_MN), Largest Patch Index (LPI), Percentage of Landscape (PLAND), and Area-Weighted Mean Patch Fractal Dimension (AWMPFD). The results showed that in 2000, the built-up area covered about 70.66 km² of the total land (51.97 %), whereas green areas covered about 51.17 km² (37.64 %). By 2020, the built-up area had increased from 51.97 % in 2000 to 69.04 %, to the detriment of other land uses, which decreased drastically over the years. Non-UGI areas accounted for 62.01 % of the total area in 2000 and increased consistently to 77.04 % by 2020. There was also a continual increase in the Number of Patches (NP) in green areas. The study established that UGI connectivity in Ibadan is inadequate, with CONTIG_MN declining from 0.41 in 2000 to 0.13 in 2020, while the Percentage of Landscape (PLAND) decreased from 10.62 in 2000 to 4.04 in 2020, indicating a high degree of fragmentation of green spaces. The findings therefore recommend halting the destruction of UGI in Ibadan to prevent further biodiversity loss and ecological decline in the city.

Keywords: Urban Green Infrastructure, Connectivity, Geospatial Technology, Fragstats Metrics, Fragmentation and Biodiversity

INTRODUCTION

Urban green infrastructure (UGI) is a vital part of urban areas, consisting of vegetation with a high variability of functions, dimensions, and characteristics, such as parks, forests, community gardens, representative green spaces, street trees, green roofs and walls, and service or marginal green areas (Fairbrass *et al*., 2018; Zhang *et al*., 2022; Menconi *et al*., 2023; Hutt-Taylor *et al*., 2024). UGI represents spatial structures that provide benefits from nature to people and aim to enhance nature's ability to deliver multiple valuable ecosystem goods and services, such as clean air and water, carbon sequestration, and mitigation of urban heat (Grover & Singh, 2015; Cheng *et al*., 2021; Zheng & Chen, 2024). UGI has become an important component of human settlements because of the wide range of services it offers, which provide multiple benefits to human beings and other living organisms (Adegun *et al*., 2021; Cho *et al*., 2024; Menconi *et al*., 2024). Engaging in outdoor recreation and visiting available UGI sites benefits public health, significantly influences attitudes and actions that promote nature conservation, and supports environmental protection (Mygind *et al*., 2019; Moreira *et al*., 2021; ONS, 2021; Barragan-Jason *et al*., 2023). UGI also strengthens connections between communities and nature (Silva *et al*., 2018; Pauleit *et al*., 2019; Gong *et al*., 2024; Reinwald *et al*., 2024). It is an indispensable prerequisite for good quality of life in cities, comprising both near-natural and culturally shaped open spaces that safeguard ecosystem services for humans and enhance biodiversity (Federal Agency for Nature Conservation, 2017; Menconi *et al*., 2021; Graffigna *et al*., 2023). When properly planned and managed, UGI can contribute significantly to urban environmental sustainability (Meijering *et al*., 2018; Shackleton *et al*., 2018; Gwedla *et al*., 2019; Russo & Cirella, 2020; Cocks & Shackleton, 2020; Gelan & Girma, 2021; Puchol-Salort *et al*., 2021; Stan, 2022). Furthermore, studies have shown that high-quality green areas in urban spaces encourage physical activity, reduce stress, increase resilience, and improve social interactions (Sugiyama *et al*., 2008; Roe *et al*., 2013). Research also indicates that urban green spaces positively affect property values. To enhance residents' welfare, green infrastructure policies should therefore prioritize the provision of accessible small- and medium-sized parks or forests near residential areas (Cho *et al*., 2024). UGI is recognized as a key strategy for combating climate change, halting biodiversity loss, and preventing many ecological crises in densely populated urban centers (Connop *et al*., 2016; Adegun *et al*., 2021; Lampinen *et al*., 2023). It also provides essential ecosystem services for creating liveable cities, on which human well-being depends (Chikaeze, 2019; Menconi *et al*., 2023; Cho *et al*., 2024; Kulczyk *et al*., 2024).

Ecosystem services are the functions provided by GI and natural systems, which are of benefits to society and the economy (Fairbrass *et al*., 2018; Kulczyk *et al.,* 2024) and these include provisioning, regulating, cultural and supporting services (Hassan *et al*., 2005; Riungu *et al*., 2018; Arvidsen *et al*., 2024). Worldwide, cities depend on GI for the provision of these services and UGI provides numerous ecosystem services and has contributed to increasing physical activity, improved in mental health and improved socialization of community residents and biodiversity functions (Hansen *et al*., 2014, Moreira *et al*., 2021; Hannah *et al*. 2023; Cho *et al*., 2024). Cities depend on green infrastructure for the provision of biodiversity on which human survival depends (Zari, 2018; Pauleit *et al*., 2019; Reinwald *et al*., 2024). Biodiversity is a vital component that serves as an essential ecosystem services for liveable, healthy and well-functioning cities which are of immense benefits to the society and the economy (Fairbrass *et al*., 2018; Scheiber, 2022). However, rapid population growth and urbanization been wittnessd in cities of the world have resulted in the conversion of several urban lands into built up structures and in excessive development of the natural ecosystem (Garrah *et al*., 2017; Areola & Ikporukpo, 2018; Weisser *et al*., 2021; Gong *et al*., 2024). This is a major driver of forest fragmentation and the loss of biodiversity (Severijnen, 2018; Kaczorowska & Pont, 2019; Kowarik *et al*., 2020; Kirk *et al*., 2021; WBCSD, 2023). The urban landscapes are experiencing drastic change due to anthropogenic pressures, which include loss of habitats and fragmentation (Graffigna *et al*., 2023). According to Gong *et al.* (2024) intensity of human activities in the urban area causes landscape alterations to occur rapidly presenting, the challenges of public safety and ecological sustainability that can compromise the urban development framework. Presently, report have shown that 60 % of the world's ecosystem are degraded and used unsustainably (MEA, 2005; UNFAO, 2011; WBCSD, 2023), while about 50 % of the world population live in cities at the commencement of 21st century and also 70 % of human population are expected to live in urban areas by 2050 (United Nations Human Settlement Program, 2012; United Nations, 2018; Gong *et al*., 2024).

UGI is becoming grossly inadequate in major Nigerian cities due to rapid population growth and uncontrolled urban development. The biodiversity components and connectivity of UGI are under serious threat from anthropogenic activities (Kowarik *et al*., 2020), resulting in fragmentation and habitat loss. In the context of landscape connectivity in urban settings, the concern is not only with increasing green cover, improving the microclimate, and enhancing other ecological functions, but also with bringing people closer to nature to promote better physical and mental health (Jim & Chen, 2003; Pascual-Hortal & Saura, 2006; Pregitzer *et al*., 2022; Zhao *et al.,* 2023). UGI also contributes to better living environments and enhances economic values such as urban landscape quality and tourism potential (Rudnick *et al*., 2012). Several studies based on urban morphology have demonstrated the influence of UGI distribution and patterns on various aspects, including thermal adaptation, transportation, energy use, cultural services, and ecological networks (Vance & Hedel, 2007; Wickham *et al*., 2010; Lin *et al*., 2024). Conducting a comprehensive inventory of a city's green spaces is an important but challenging prerequisite for improving urban planning and mitigating the ecological impacts of urban expansion (Von Thaden *et al*., 2021). However, despite the recognized value of UGI in urban settings, its crucial role in constructing urban ecological networks is often overlooked and easily altered by urban expansion (Adegun *et al*., 2021; Gong *et al*., 2024). These issues call for a critical assessment of landscape connectivity in urban green infrastructure, particularly for maintaining biodiversity in sub-Saharan cities such as Ibadan, Nigeria, in order to achieve the objectives of the Sustainable Development Goals aimed at creating resilient urban areas. The loss of habitats and UGI poses threats to the physical and psychological well-being of urban residents, as well as to biodiversity itself (Hutt-Taylor *et al*., 2024).

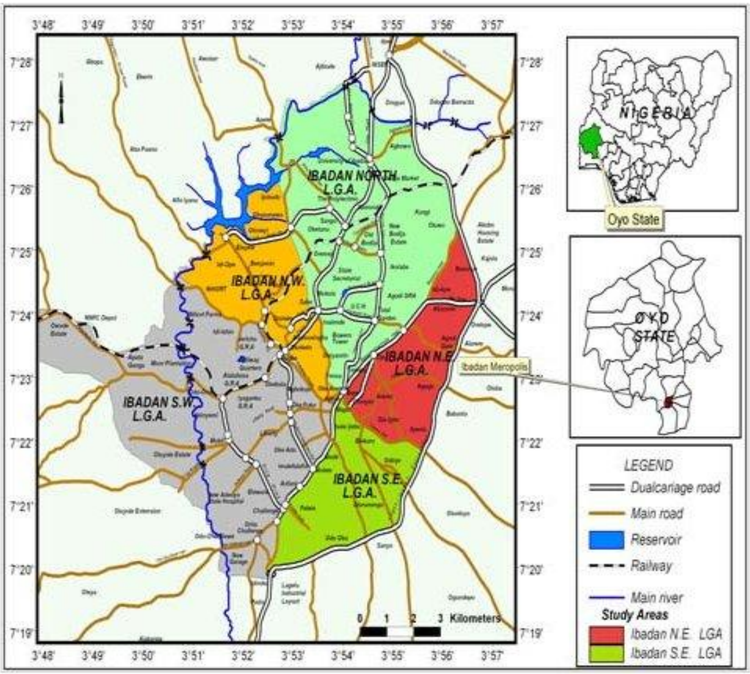
Landscape connectivity, defined as the ease with which organisms move between landscape elements and the number of connections between patches relative to the maximum potential connections (Brierley *et al*., 2006; Aune *et al*., 2011; CIEEM, 2018), faces critical threats from fragmentation and habitat loss (Rudnick *et al.,* 2012). Understanding the composition, quality, and connectivity of green spaces is key to conserving and enhancing the biodiversity assets essential for human well-being in urban environments (Aronson *et al*., 2017; Jennings *et al*., 2017). There are two basic types of connectivity: structural and functional (Auffret *et al*., 2015; Ronan *et al*., 2020). Structural connectivity refers to the physical (Euclidean) distance between patches, regardless of how organisms move across the landscape (Graffigna *et al.,* 2023). Functional connectivity, by contrast, considers movement behavior by estimating routes between patches that are suitable for dispersal. The degree of structural connectivity provided by green areas (such as public parks, private gardens, squares, and orchards) embedded in the urban matrix can offer insights into ecological functioning and the natural processes taking place there (Guo *et al*., 2018; Graffigna *et al*., 2023). Landscape connectivity analysis is in many cases driven by spatial data, and landscape metrics can be measured using spatial models such as Fragstats software (McGarigal, 1995). Spatial metrics are quantitative indices that describe the structure and patterns of a landscape (Herold *et al*., 2003). When integrated with GIS, landscape metrics become useful tools for quantifying spatial land-cover characteristics (Kong *et al.,* 2012; Rafiee *et al*., 2009). They have been widely applied in studies of landscape variability over the years (Sun *et al*., 2020; Liu *et al*., 2021), addressing both ecological and visual values (Sahraoui *et al*., 2021). Fragstats is commonly used to quantify green space patterns using landscape metrics at local scales (Kong & Nakagoshi, 2006; Han *et al*., 2002). It has also been employed in numerous studies analyzing the distribution of green spaces, particularly in relation to ecological networks that consist mainly of green areas (Li *et al*., 2015; Kang *et al*., 2018; Han *et al*., 2022). Over the years, many green areas in Nigerian cities, including Ibadan, have been lost due to changes in land use and land cover. This loss has negatively affected connectivity and reduced the effectiveness of biodiversity functions (Siehr *et al*., 2022; Vilanova *et al*., 2024). Therefore, this study applies Fragstats software as a spatial metric to measure the connectivity of green spaces in the Ibadan urban area, with the aim of improving biodiversity management in the city.

MATERIALS AND METHODS

Study Area

The city of Ibadan is located on latitude 7°25′ to 7°42′N and longitude 3°51′ to 3°9′E (Fig. 1), in Oyo State, southwest, Nigeria. It covers 3,080 km^2 with a current metro population of about 4004,000 inhabitants (Ibadan, Nigeria Population, 2024). The area is underlain by Precambrian basement complex rocks mainly of the granite, quartzite and migmatite types and also minor rock types such as pegmatite, aplite and diorite (Ajayi *et al*., 2012).

Fig. 1: Map of the Study Area



It is on a central range of hills and river valley plains with an elevation of 227m above sea level (City of Ibadan, 2013). A very intensive system of rivers and streams such as R. Ogunpa, R. Ona, R. Kudeti, R. Ogbere, R. Alaro and R. Alapata drain the area (Murphy, 1998). It experiences the hot humid climate where annual average temperature ranges between 25 °C and 35°C (Alo & Nwatu, 2018), a mean annual rainfall above 1,505 mm and relative humidity between 60 % and 80 % (Raheem & Adeboyejo, 2016).

Data and Pre-Processing

Land cover data from 2000 to 2020, collected at five-year intervals, were utilized for this study and were sourced from remote sensing monitoring data. Landsat Thematic (TM) for 2000, 2005 and 2010 and Operational Land Imager (OLI) for 2015 and 2020 were obtained from United State Geological Survey Global Visualization Viewers (USGS-GLOVIS). The dataset has a spatial resolution of 30 m and has been widely applied and validated in different scientific research (Zhang *et al*., 2023; Gong *et al*., 2024). Before the LULC classification the imageries has undergone preprocessing such as atmospheric correction and orthorectification. Geometric corrections of collected images were done by Google Earth Images. The Landsat data were pre-referenced with Universal Transverse Mercator (UTM) projection system and WGS-84 datum. The LULC types were categorized into four classes: built-up, green area, bare land, and water bodies (Table 1). The location of LULCs were based on high-resolution images of Google Earth, and then confirmed by ground truthing. The ArcGIS 10.5 software was used for processing the data.

Table 1: Description of land use classes

Serial No	Land Use Class	Description
A	Built up area/Transport	Built up areas used for residential, commercial, manufacturing, institutions, transportation, communities, and utilities.
B	Green area	Areas covered with soft landscape elements such as urban forests, woodlands, trees, bush, shrub, grasslands, parks, gardens, greenways, playgrounds, sports fields, etc.
C	Bare surface	These are bare lands, quarry sites, open spaces, etc.
D	Waterbodies	These are water features such as rivers, streams, lakes, ponds, fountains, etc.

Source: Adapted from Anderson *et al.* (1976)

Land use/land cover classification

For the 2000, 2005 and 2010, Landsat TM data bands no. 1–5 and 7 were used for land use mapping, while for the Landsat OLI data 2015 and 2020, bands no. 1–7 were used. The supervised image classification technique with maximum likelihood algorithm was used to show the changes of land use/land cover over time in the study area. The accuracy of the classification was done using an error matrix i.e. the Kappa coefficient (K) (Foody, 1992) for land use map of all four years under consideration. The Kappa index which indicates the presence of misclassification. The Kappa coefficient in this study ranged from 0.72-0.83 representing an accurate classification (Landis & Koch, 1977).

Landscape Patterns Analysis

Based on the existing published research and the knowledge of the study area seven landscape metrics were to capture the pattern of UGI within the Ibadan Metropolitan Area: Number of patches into (NP), mean patch area (AREA_MN), mean area perimeter ratio (PARA_MN), mean patch contiguity index (CONTIG_MN), largest patch index (LPI), percentage of landscape (PLAND) and area weighted mean patch area (AWMPFD). The land use land cover analysis obtained from geographic information system analysis served as input into the Fragstats software for the production of connectivity analysis.

Table 2: Introduction and definition of landscape metrics

Abbreviation	Name	Definition	Formula	Range	Unit
NP	Number of patches	Number of patches in the landscape, or total number of patches for a particular class	$NP = n_i$	>0	-
AREA_MN	Mean patch area	The mean area of patches of a certain class	$\frac{\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}}{n_i}$	>0	Ha
PARA_MN	Mean area perimeter ratio	The simple measure of shape complexity, but without standardization to a simple Euclidean shape	$PARA = \frac{P_{ij}}{a_{ij}}$	>0	-
CONTIG_MN	Mean patch contiguity index	Mean contiguity in patches per class	$\left[\frac{\frac{\sum_{r-1}^{x} c_{ijr}}{a_{ij}}}{\vartheta - 1}\right]$	0≤CONTIG≤1	-
LPI	Largest patch index	The area of the most giant patch divided by the total area of the landscape multiplied by 100	$\frac{A^2}{\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}^2}$	0<LPI≤100	%
PLAND	Percentage of landscape	Percentage of the area of each class	$PLAND = P_1 = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	0<PLAND≤100	%
AWMPFD	Area weighted mean patch area	The fractal dimension of a patch equals two times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m²).	$AWMPFD = \sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(\frac{21n(.25p_{ij})}{1na_{ij}}\right)\left(\frac{a_{ij}}{A}\right)\right]$	1≤AWMPFD≤2	None

RESULTS AND DISCUSSION

Land use/land cover change

The results of the classification of land use for year 2000 to 2020 as extracted using geospatial techniques are presented in Fig. 2 (Busari & Adedeji, 2024). During the study period significant changes were witnessed in the proportion and pattern of land use/land cover. For instance in year 2000, Ibadan built-up area covered about 70.66 km² of the total land amounting to 51.97 %, whereas green area covered about 51.17 km² (37.64 %). At the same period, bare surface was about 13.64 km² (10.04 %), while water bodies covered about 0.49 km² (0.36 %). Rapid population growth and urban expansion brings about an increase in land use type such as built-up area for housing, industrialization, recreation, education, and transportation among others. Thus by 2020, the built-up area increased from 51.97 % in the year 2000 to 69.04 % at the detriment of other land uses that decreased drastically over the years (Table 3, Fig. 2). Erstwhile green areas like Samonda, Alalubosa, and Bower Tower downslope were converted into residential and commercial properties. These findings were corroborated by studies such as Barlow *et al*. (2018) and Akingbade *et al*. (2022) that urbanization has led to the degradation and consequent alteration of ecosystem which is responsible for environmental deterioration of the greens.

Table 3: Land use/Land cover change 2000-2020

Year	2000		2005		2010		2015		2020	
Land use	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)
Built-up	70.66	51.97	75.85	55.79	77.50	57.00	91.27	67.13	93.87	69.04
Green Area	51.17	37.64	47.53	34.97	48.00	35.30	31.56	21.96	31.07	22.84
Bare Surface	13.64	10.04	12.15	8.94	12.41	9.13	12.84	10.69	10.91	8.03
Water bodies	0.49	0.36	0.42	0.31	0.40	0.30	0.30	0.22	0.12	0.09
TOTAL	135.96	100.00	135.96	100.00	135.96	100.00	135.96	100.00	135.96	100.00

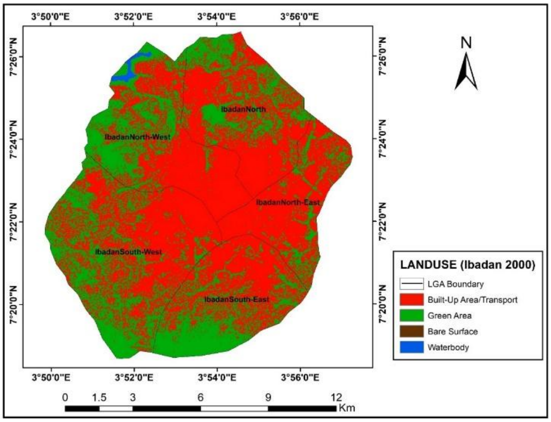
Changes in the UGI Based on Land Use

Urban expansion generates different landscape patterns through the interaction of local ecosystems and land-use decisions (Richards & Belcher, 2020). A curious look at the results of the land use/land cover change analysis show that UGI areas consistently occupied about half of the total study area since 2000 increasing from 70.66 sqkm to 93.87 sqkm in 2020 (Fig. 2). The non-UGI accounted for 62.14 % of the total area and consistently increases over the study period to 77.48 % by 2020. This is an indication that UGI in the study area has been markedly altered by urban expansion and other anthropogenic activities. During study period, UGI decreased between 2000 and 2005, increased between 2005 and 2010 and later decreased between 2005 to 2020 (Table 3). The UGI diminished drastically from 51.17 sqkm to 31.07 sqkm which is significant in proportion from 20 years prior by 2020.

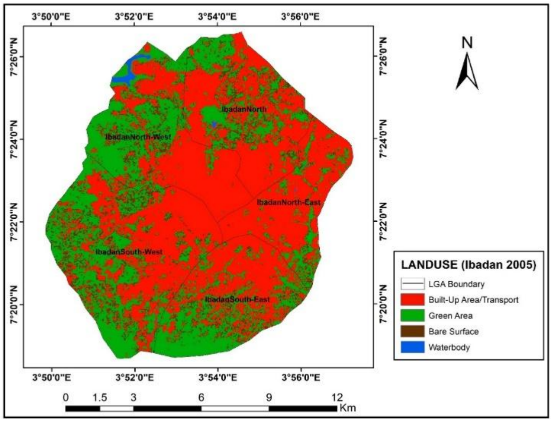
Landscape Pattern

Land cover maps at the class level were used to calculate landscape metrics in the FRAGSTATS software. These landscape metrics according to Gong *et al*. (2024) indicated a trend towards reduced heterogeneity and decreasing diversity of UGI at the landscape scale. Table 4 displays the results of landscape metrics over the past 20 years as well as a five-year forecast. The highest rate of urban growth is observed between 2010 and 2015 with an increase in the built up area of about 13.77 % within 5 years (Table 4). In the built-up areas, the number of patches (NP) declined from 1143 in 2000 to 349 in 2020. The anticipated NP metrics in 2025 will be 177 showing further decline. The decrease in the number of built-up patches indicates that disjointed patches will progressively come together to create single patches. This is a reflection of the built-up land cover type's expansion and development in the research area. Yang & Liu (2005) have shown that landscape pattern is more fragmented around city centres and along coastlines, where urbanization and human economic activities are more concentrated. During the research period, NP in bare land decreased from 3097 in 2000 to 1284 in 2020. Moreover, NP of the green area class increased as the year progress, which is an indication of more fragmentation and loss of vegetation. In the green area, the NP measure increase from 1991 in 2000 to 2844 in 2020 and is expected to increase to 2912 by 2025. The continuous rise of number of patches (NP) in the green area could be an indication of fragmented and heterogeneous process of urban growth taking place in the study area (Olayiwola & Fakayode, 2019). At the same time there is the continuing development of scattered and fragmented urban patches in the study area due to a development of small and irregular built up patches around the periphery of the city and in peri-urban regions.

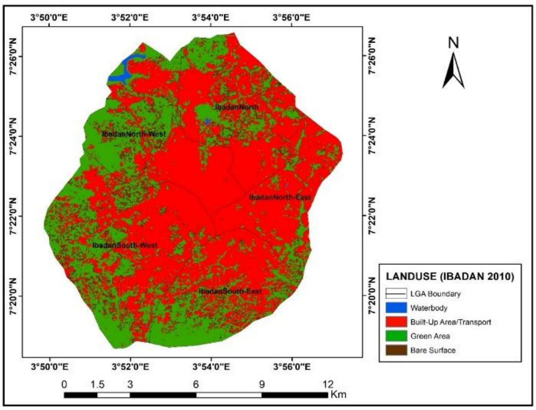
Fig. 2: Land use analysis between 2000-2020



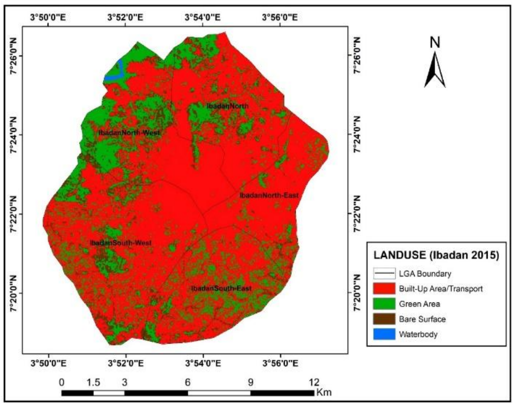
Land use for year 2000



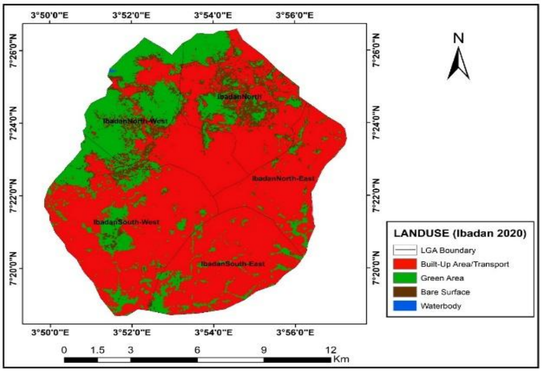
Land use for year 2005



Land use for year 2010



Land use for year 2015



Land use for year 2020

It is important to note that some of the findings of this study are consistent with the findings of Saeedal & Aysan (2020). Adewale & Olayinka (2019) carried out a landscape metrics analysis of land use patterns and changes in suburban local government areas of Ibadan, Nigeria. Though their landscape metrics of interest were slightly different from the ones examined in this study, there were similarities in few common metrics as their study revealed that the NP in 2017 was 809 for the built-up areas, whereas in this study, the NP of built-up area in 2015, the closest study year to 2017, was 898 (Table 4). Disruptors may have separated the patches of green areas into smaller patches as a result of their effect.

The development of residential spaces and the extension of the city, including green area and bare land, are indicated by the increase in the number of patches of green area and the reduction in built-up patches. Furthermore, in the last decades the urban expansion rate has been considerably higher exceeding what is needed to sustain population growth (Liu *et al.* 2020) and this is generating principally negative impacts on biodiversity. This demand for urban construction has placed growing pressure on biodiversity conservation (Guo *et al*., 2018; Hyseni *et al*., 2021).

One of the indicators that showed the mean patch size was AREA-MN. The level of interspersion is indicated by the lowering of this metric. The built-up class has seen a rise in this statistic, whereas greenspace and bare land have seen a drop. The level of the metric for the built-up area in 2000 was 7.42 and 12.90 in 2020. The decline of this measure in the green and bare land areas indicated a drop in the mean of these patch types, indicating a drop in the level of interspersion classes. In the year 2000, the average patch size in the green area class was 14.73 which declined to 6.17 in 2020.

The mean area perimeter ratio (PARA-MN) is a basic measure of the shape's complexity because it displays the circumference to area ratio. The closer the shape is to the rotating state, the smaller the ratio. As a result, based on the numbers of the metric in the classes, it was discovered that there is a marked decrease in the green area and built-up classes while bare land increased. The CONTIG-MN measure is one of the metrics for determining the degree of landscape patch integrity as well as the degree of landscape fragmentation. When the patches are entirely distributed and fragmented, the metric is 0. Contiguity is stated to be at its highest level when the landscape is formed by only one type of patch. Between 2000 and 2020, the built-up and bare land classes both increased. Green areas, on the other hand, decreased from 2000 (0.41) to 2020 (0.13), demonstrating increased contiguity and decreased interspersion in these classifications.

Table 4: Land classes based on landscape metrics

Metrics	LULC	2000	2005	2010	2015	2020	2025
NP	Built-Up	1143	1043	902	898	349	177
	Bare land	3097	2975	2702	1793	1284	1007
	Green Area	1991	2312	2505	2692	2844	2912
AREA_MN	Built-Up	7.42	8.47	9.59	11.45	12.90	14.68
	Bare land	4.23	3.43	2.39	1.38	0.98	0.45
	Green Area	14.73	12.73	10.45	8.45	6.17	4.70
PARA-MN	Built-Up	1215.29	1015.23	1002.68	987.79	876.03	748.55
	Bare land	1195.68	1278.68	1320.21	1504.39	1799.49	1873.46
	Green Area	1242.11	1142.12	1053.55	1010.23	968.17	742.65
CONTIG-MN	Built-Up	0.12	0.34	0.65	0.76	0.79	0.85
	Bare land	0.14	0.17	0.19	0.20	0.24	0.25
	Green Area	0.41	0.24	0.19	0.15	0.13	0.11
LPI	Built-Up	59.06	68.05	78.00	82.03	85.82	91.64
	Bare land	17.14	13.51	8.06	3.08	2.14	1.54
	Green Area	13.75	11.61	9.35	4.17	2.14	1.17
PLAND	Built-Up	62.36	67.36	83.78	97.79	96.04	98.31
	Bare land	27.02	29.02	36.23	48.94	66.92	69.26
	Green Area	10.62	9.62	7.22	6.27	4.04	2.46
AWMPFD	Built-Up	1.42	1.33	1.33	1.33	1.29	1.23
	Bare land	1.32	1.31	1.13	1.12	1.28	1.17
	Green Area	1.24	1.12	1.31	1.31	1.15	1.21

The LPI index shows which patch is the largest in total. According to this indicator, if the largest patch class shrinks, it could be a factor in land fragmentation. In this study, in 2000, the green area class was 13.75 but decline in 2005 to 11.61, the further to 9.35 in 2010 and then drastically to 2.14 in 2020. The amount of the measure in the bare land class declined from 17.14 in 2000 to 2.14 in 2020. In the built-up class, this index increased from 59.06 in 2000 to 85.82 in 2020, indicating a relationship between the patches that created a larger patch. The increasing intensity of buildings in the area increased the LPI of the built-up area leading to a tremendous urbanization pressure over the other land uses (Akintunde *et al.,* 2019). This is aggravated the demand for more houses due to the increasing population, consequently leading to the creation new built-up areas at the urban peripheral areas. Generally in urban landscapes, vegetation patches usually decrease in size and quality along a gradient from periurban rural areas toward the urban center (Williams & Newbold, 2020; Von Thaden *et al*., 2021). The class percentage of the entire landscape is represented by the PLAND measure. The expansion of both land covers is shown by an increase in this metric in both the built-up and bare land classes. This statistic accounted for 62.36 percent of the built-up class in 2000. In 2020, it was 96.04. The reduction in class fragmentation and the establishment of new built-up regions are represented by the growth in the number and density of built-up patches. During the study period, the percentage of the landscape covered by the green area class declined due to the consumption of the green ecosystem by other land uses and land covers. 10.62, 9.62, 7.22, 6.27, and 4.04 were the scores, respectively. In 2000, 2005, 2010, 2015, and 2020, the outcomes of this metric on the bare land landscape were 27.02, 29.02, 36.23, 48.94, and 66.92, respectively. Over the same period, AWMPFD results across the terrain did not change considerably during the study period. AWMPFD in the built-up area was 1.42 in 2000 and 1.23 in 2020 while in the green areas; AWMPFD was 1.24 in 2000 and 1.15 in 2020. Higher values were however obtained 2010 and 2015 (1.31). The higher value obtained in during the period shows that the geometry of urban patches is getting more complex over time and the prevalence of fragmented low density development in the fringe areas (Wang *et al.* 2019; Akintunde *et al.,* 2019) having effects on biodiversity. The degree to which the landscape facilitates movement among landscape tracts defines the amount of connectivity (Lepczyk *et al*., 2017; Ronan *et al*., 2020).

The landscape connectivity of Ibadan has been badly affected by anthropogenic forces which continues to reduce the green infrastructure available in the city for various ecosystem services and benefits of humans. The ecological linkage in Ibadan remains weak and fragmented, and this connectivity reduces the effectiveness in sustaining biodiversity, restricting species movement and ecosystem resilience. A coherent, ecologically integrated green infrastructure network is imperative for sustaining biodiversity and promoting environmental resilience in Ibadan's rapidly evolving urban landscape.

CONCLUSION

This study assessed landscape connectivity of urban green infrastructure for biodiversity management in Ibadan, Nigeria. Seven indices of the spatial metrics were used in evaluating the connectivity of these green spaces. Landscape connectivity is low in the city and could be attributed to biodiversity loss caused by anthropogenic activities. It was established that green areas continued to decrease in size from 2000 to 2020 thus leading to reduction in patch sizes and increase in fragmentation. Findings indicate that the number of patches (NP) in the green areas has continued to increase due to urban expansion; there is a noticeable trend towards a reduction in the number of patches in other landscape types. In fact the internal composition of UGI has undergone multifarious spatiotemporal changes during over the study period. This empirical evidence reviewed that existing green spaces in the city need to be effectively managed to halt further degradation of the biodiversity that provides ecosystem services on which human life and organisms well-being depend. Future planning should not only focus on preventing the loss of UGI area but also emphasizes the internal structure and characteristics of UGI. This study have provided valuable insights into how to plan UGI in a rapidly growing city like Ibadan and would help planners and administrators develop a crucial strategy for urban centres to address ecological crises. Therefore, to avoid these ecological crises and reduce unsustainable city expansion, the UGI in urban centres should received significant attention from managers and landscape designers. Efforts should be made towards planting and preserving urban trees, particularly large-stature trees that will address climate change by cooling the environment via transpiration, shading buildings and paved surfaces to reduce energy usage, and storing carbon with high permanence. Furthermore, the negative impact of urbanization on biodiversity can be buffered by blue (e.g., rivers, ponds) and green (e.g., parks, forests) spaces which should be connected by corridors, so that organisms may disperse between sites

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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