AIMS Geosciences

AIMS Geosciences, 10(3): 553–572.
DOI: 10.3934/geosci.2024029
Received: 04 March 2024
Revised: 10 July 2024
Accepted: 19 July 2024
Published: 30 July 2024

http://www.aimspress.com/journal/geosciences

Research article

Spatio-temporal alterations, configurations, and distribution of green areas, along with their sustainability in Parakou, Benin

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Abstract: Green areas (GAs) are swiftly declining in urban areas worldwide, amplifying adverse local climate impacts on the well-being of city residents. Despite this, there is limited empirical research on the changing patterns and distribution of GAs and their vulnerability. This is especially notable in dry tropical cities where these spaces function as vital microclimate areas that control against climate change effects such as flooding and heat islands. This study focused on examining the changing GA coverage, scrutinizing the spatial distribution of different GA categories, and investigating threat factors associated with their perceived sustainability in Parakou. Employing a mixed-methods approach, open-source geospatial data and collected primary data were acquired through on-site observations as well as semi-structured interviews. Data analysis involved the application of geospatial, statistical, and textual techniques. The results indicated that, from 2000 to 2020, the city experienced a loss of 16.48 km² (24.73%) in its GA cover. The predominant land use change observed was the conversion of sparse vegetation (21.86%) into built-up areas. A notable difference ($P < 0.0001$) was observed among GA categories, revealing an aggregated spatial pattern [g (r) > 1] that emphasizes the necessity for tailored strategies to enhance and conserve each GA category within the city. Furthermore, there is a perception of critical degradation in various GA categories, namely city bush, cropland, and forest plantation. The primary causes identified for GA depletion in the city were poor management strategies and lack of planning. These results could provide valuable guidance for policymakers, urban planners, and cityscape architects with a focus on urban sustainability, particularly regarding the development of GAs in the Republic of Benin.

Keywords: green areas; spatio-temporal change; spatial distribution; green area sustainability; urban planning; West Africa

1. Introduction

Cities, complex ecosystems frequently impacted by the environmental consequences of uncontrolled urban growth, suffer from urban expansion invading natural areas, disrupting their configuration and resulting in habitat and species loss [1]. These impacts manifest directly in increased urban heat, air, water, and soil quality degradation, disturbances in land use and cover, biodiversity loss, and climate change, among other issues [2–4]. Urban green infrastructure, encompassing elements such as urban forests, wetlands, parks, street trees, small gardens, green roofs, and walls, serves as a strategic approach to both adapt to and mitigate climate change issues, while concurrently enhancing the overall quality of life [5–7].

Sustainable urban development poses a significant challenge for adaptive planning and management due to rapid environmental degradation and climate impacts [6,8]. In Africa, current patterns of urban expansion have led to severe problems regarding natural resources, particularly impacting biodiversity and quality of life. In the context of sustainability, considerable attention has been given to the role of urban greening landscape behavior [4,9] and its dependence on the state and evolution of city growth.

Despite the increase in built-up areas in cities and towns, they remain highly dependent on nature through ecosystem services and goods' provision, supporting the functioning of their populations [6,10]. Public green areas (GAs), private residential gardens, urban sacred forests, and urban agrosystems are deemed crucial for urban sustainability, particularly when spatially arranged to maximize habitat-patch sizes and minimize isolation from remnants of native habitats in the city [11–13].

Many cities in Benin are grappling with uncontrolled urbanization, leading to events of urban heat and flooding that inevitably impact the health and daily lives of residents [14,15]. Furthermore, the development and careful management of urban vegetation significantly contribute to a country's ability to mitigate and adapt to the heat effect [16,17]. However, few studies have investigated the configuration and spatial pattern changes of GAs, complicating decision-making. Moreover, research has traditionally focused on the (environmental and social) benefits of GAs and their temporal dynamics, highlighting their area loss rather than the factors contributing to it. Therefore, analyzing the effects of urbanization on GAs' structural changes and distribution and factors influencing their depletion in the town of Parakou could contribute to mitigating the risk of GA degradation and improving sustainable urban planning in Benin.

Consequently, this paper addresses the following objectives: 1) Pattern changes (spatiotemporal) of GA cover; 2) structure and distribution of these GAs based on their central point coordinates and landscape metrics parameters such as perimeter, size area, shape index, and edge density; and 3) perception of GA sustainability and contributors to its vulnerability. The study was conducted in Parakou, the third largest town in Benin, located in the central north of West Africa. Parakou was chosen due to its more severe climate challenges, including factors such as temperature, air quality, and rainfall, compared with the first (Cotonou) and second (Porto-Novo) largest towns in Benin [22]. The research output aims to assist urban managers and planners in optimizing the morphological patterns, distribution, and key management of GAs to effectively improve climate change adaptation in Benin.

2. Study area

The study was conducted in the urban areas of Parakou in Benin (West Africa) (Figure 1). Parakou, as noted by Lohnert [18], is the third-largest and fastest-growing city in Benin, divided into three urban sectors or boroughs: 1st, 2nd, and 3rd boroughs (Figure 1). The city is situated in the upper central zone of the country, lying between the northern latitudes 9°15’ and 9°27’ and east longitudes 2°31’ and 2°45’. It features a tropical climate within the guineo-sudanian zone [19]. The annual average rainfall is approximately 1170 mm/year, accompanied by an average temperature of 25 °C [20]. The GA cover in this town primarily consists of shrubs, thickets, and sparsely scattered grass. Additionally, secondary forests, wooded savannahs, and wetlands arising from these vegetation types are prevalent in certain parts of the urban boroughs, despite the escalating threats of urbanization.

The city experiences high population density and boasts one of the fastest growth rates in the north-central region of Benin. Presently, it is inhabited by approximately 408,000 people, with an annual growth change of 4.35, as per the 2023 population and housing census [21]. To accommodate the increasing population and associated socio-economic activities, the urban area has been rapidly expanding. Key economic endeavors in the region encompass trade, farming, tourism, and hospitality-related businesses and activities. The growth of these activities, coupled with competition for land for housing, poses significant potential harm to the city’s natural environment. Previous research [15] indicates a swift depletion of the city’s vegetation cover. A reduction in GA could impact the local climate, recreational pursuits, and the overall well-being of residents [22]. Furthermore, green areas play a crucial role in enhancing the visual appeal of the city and attracting tourists. The degradation of these areas could consequently undermine the tourism potential of the city. Considering these factors, the urban area of Parakou presents an ideal case for scrutinizing the changes in GA cover patterns and their potential liaison on the provision of ecosystem services for the well-being of residents.

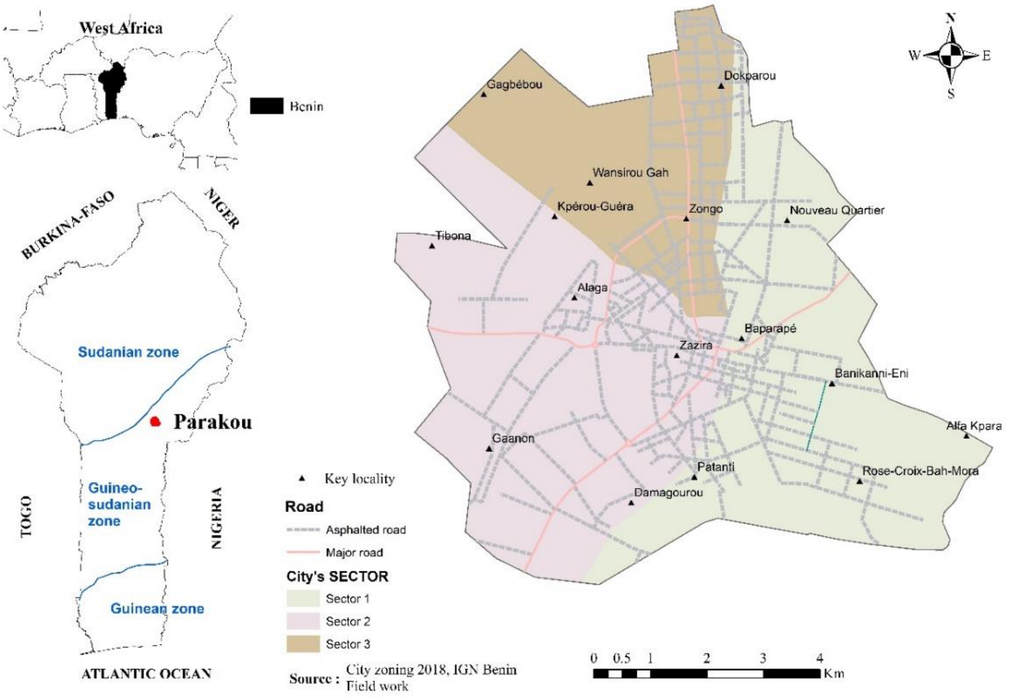

Figure 1. Map showing the study area.

3. Methods

3.1. Land cover dynamics

To analyze the spatiotemporal changes in green areas within the study area, imagery from SPOT 4 and 5 sensors with a spatial resolution of 6 m was utilized for the years 2000 and 2010. For the year 2020, changes were assessed using Google Earth Pro V 7.3 imagery (Landsat/Copernicus) due to its relatively high spatial resolution and global accessibility. The classification process involved supervised classification employing the maximum likelihood algorithm (Spot images), and subsequent accuracy assessments were carried out. Five distinct land cover classes for the city were generated, and the classification output was validated using 100 random ground control points to determine overall Kappa and overall accuracy metrics. Ground control points, representing various land cover types such as buildings, bare land, areas of dense vegetation, and sparse vegetation for each year were recorded using GPS devices through a participatory mapping approach [23]. The accuracy assessment results revealed an overall accuracy of 92% for 2000, 87% for 2018, and 94% for 2020. The Kappa coefficients exceeding 0.9 for each year indicated an acceptable level of agreement [23]. These accuracy assessment outcomes affirm that the land cover classes in the classified maps were accurately identified and classified with minimal class confusion.

3.2. Spatial pattern and distribution of GAs

The study utilized Google Earth images with a spatial resolution of up to 0.6 meters for the city of Parakou, making it feasible to identify and differentiate green areas visually. Remote-sensed images from Landsat/Copernicus in 2022, provided by Google Earth Pro V 7.3, were manually analyzed to identify major green areas across the entire city. August, during the rainy summer season, was chosen for image capture to highlight the greening areas, aiding in visual interpretation.

Green areas, categorized as forest (sacred and gallery forest), wetland, forest plantation (e.g., *Tectona grandis* tree plantation), cropland (agricultural areas), city bush (unmanaged greenery), urban garden (public and private green areas), cemetery, and tree (home, office, and street tree assemblages) were delineated manually. These polygons, saved in keyhole markup language data format, were input into ArcGIS 10.3 for subsequent data creation, including centroid coordinates (X, Y), area (m^2), and perimeter (m) for each green area polygon.

To verify the accuracy of the identified green areas, 100 random coordinates were selected, and field surveys, including area measurements, were conducted. A general regression model, with a regression slope of 0.90, was employed for comparison (Figure 2). This result suggests that reliable information on green areas can be collected through visual interpretation of remotely sensed images.

The landscape metrics, including mean patch perimeter, edge density, mean patch size, and shape index of urban green areas, were computed to quantify the pattern and configuration of these spaces (Table 1). An analysis of variance (ANOVA) was applied to assess the significance of these land metric variations. Upon detecting a significant difference through ANOVA, the Student-Neuman-Keuls (SNK) test was implemented using the statistical package “agricolae” to reveal the means.

Furthermore, the spatial distribution analysis of all green areas and each green area category was conducted using the “spatstat” package of R software 4.2.0, employing Ripley’s K method based on green entity center distances. The pair correlation function [24], denoted as g(r), was utilized to examine whether green areas exhibited a regular, random, or aggregative pattern. This normalized measure assessed the average manner in which green areas were perceived with increasing distance (r) within the urban area [25]. The function formula is $g(r) = K'(r)/(2\pi r)$, derived from $\lambda K(r) = E$ (Number of neighbor elements at distance $\leq r$), where $K(r) = \int 2\pi r g(s) s ds$, and $K'(r)$ represents the derivative or second reduced moment of Ripley’s function $K(r)$ [26].

The estimated function g(r) was compared to the theoretical value of the null hypothesis (random distribution of individual green areas). The Monte Carlo procedure, involving 500-point simulations, was employed to establish rejection envelopes for the null hypothesis at the 0.05 threshold. The null hypothesis is rejected if, for any distance r, the value of g(r) falls outside the envelope resulting from the simulations [27]. The key interpretation is as follows: $g(r) = 1$ indicates a random distribution, $g(r) > 1$ indicates an aggregate distribution, and $g(r) < 1$ indicates a regular distribution.

Table 1. Landscape metrics used to quantify GA pattern [28].

Metric	Description	Equation
Mean perimeter (km)	The average perimeter of all GA of each category in the city	$\frac{10^{-3}}{n} \times \sum_{i=1}^{n} e_i$
Mean size area (km^2)	The average area of all GA of each category in the city	$\frac{1}{10^{-6} \times n} \times \sum_{i=1}^{n} a_i$
Edge density (km/km^2)	Total length of all edge segments in each category of GA per km^2	$\frac{10^{-3}}{A} \times \sum_{i=1}^{n} e_i$
Shape index	Value of the index	$\frac{1}{4n} \times \sum_{i=1}^{n} \frac{e_i}{\sqrt{a_i}}$

ai represents the area of patch i, ei represents the length of the edge (or perimeter) of patch i, A represents the total area of the city, and n represents the total number of patches.

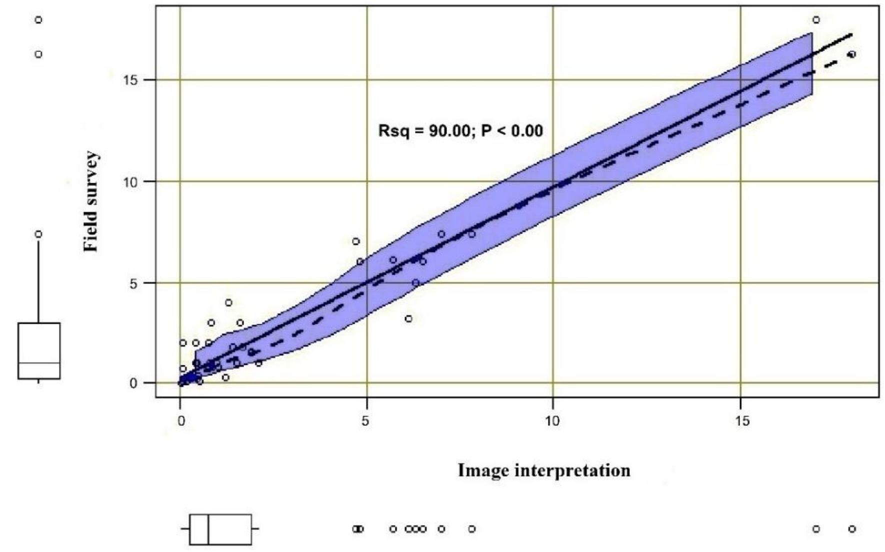

Figure 2. Comparison of the GA area obtained by visual interpretation of Google Earth images and field survey measurement.

Note: The dots represent the matched-pair comparison between values from the visual interpretation of images and field survey on the same GA category. Solid lines indicate the linear regression, dashed lines show the local lowess-type regression curve, and the blue band shows the full regression curve.

3.3. Questionnaire survey

A cross-sector survey was undertaken to collect data on the perceived sustainability of green areas and the factors contributing to their depletion. This survey utilized a semi-structured questionnaire designed to capture socioeconomic characteristics including age, gender, ethnicity, religion, marital status, polygamy, educational background, residence acquisition, primary activity, monthly income, and urban and living duration (see Appendix 1). Purposely, the questionnaire sought information on residents' perceptions of GA ecosystem services, GA sustainability, and factors influencing their vulnerability. Specifically, the survey aimed to gather information on the perception of green area degradation risk, with questions such as: "How concerned are you about the degradation or loss of green areas in your community? (1—concerned, 2—not concerned), and "What are the main factors or activities that you believe contribute to the degradation and benefit loss of green areas? (1—Insufficient maintenance, 2—Mismanagement of green area, 3—Lack of green area planning, 4—Limited size of green area, 5—Limitations in the diversity and density of green areas). Interviews were conducted randomly with both female and male participants using the Kobo Collect application. Upon approaching each randomly selected resident, a courteous greeting was extended, and the purpose of the interaction was clearly communicated to encourage willingness to participate in the survey. The sample size for this segment of the study was determined as 400 using Dagnelie's infinite sample size estimation formula [22]. The 400 interviewees were proportionally distributed across city sectors or sub-cities based on the population size of each sector: 1st sector (179), 2nd sector (112), and 3rd sector (109).

4. Results

4.1. Land cover dynamics of the urban area of Parakou during 2000–2020

This section presents the spatial representation and statistics of the diverse land cover classes identified in the study area spanning 20 years (2000–2020). The identified land cover classes encompass dense vegetation (sacred forest, gallery forest, and forest plantation), sparse vegetation, which includes city bush, croplands, green cemetery, urban gardens, and home trees assemblage, as well as wetlands and built-up areas such as buildings, bare land, grey surfaces, and other concrete areas. Figure 3 illustrates the land cover maps for the urban area of Parakou in the years 2000, 2010, and 2020.

From the land cover maps (Figure 3), statistics, including the area of coverage and the percentage share of total land cover for each specific class, were computed. The findings reveal that in the year 2000, dense vegetation, sparse vegetation, and wetlands occupied 6.27 km^2 (9.40%), 23.20 km^2 (34.82%), and 1.67 km^2 (2.50%), respectively, of the urban land area (Table 2, Figure 4). Dense vegetation cover in 2010 amounted to 6.49 km^2 (9.75%), indicating a 3.51% increase; by 2020 it declined (33.9%) to 4.29 km^2 (6.44%). Similarly, areas occupied by sparse vegetation and wetlands experienced declines of 44.48% and 3.59% in 2010, and 31.74% and 19.87% in 2020, respectively. However, the built environment's area sharply increased from 35.49 km^2 (53.25%) in 2000 to 46.86 km^2 (68.07%) in 2010, and further to 51.97 km^2 (78%) in 2020. The expansion of covered built-up areas can be observed at 32.04% in 2010 and 10.90% in 2020 (Table 2).

Table 2. Area of coverage of land cover classes and change from 2000 and 2010 to 2020 with the year 2000 as the base land cover change.

	Area of cover (km^2)			Change in cover	
Land Cover class	2000	2010	2020	2010	2020
Dense vegetation	6.27	6.49	4.29	+3.51 %	−33.9 %
Sparse vegetation	23.20	13.17	9.08	−31.05 %	−31.74 %
Built-up areas	35.49	45.36	51.97	+27.81 %	+10.90 %
Wetlands	1.67	1.61	1.29	−3.59 %	−19.87 %
Total	66.63	66.63	66.63	−	−

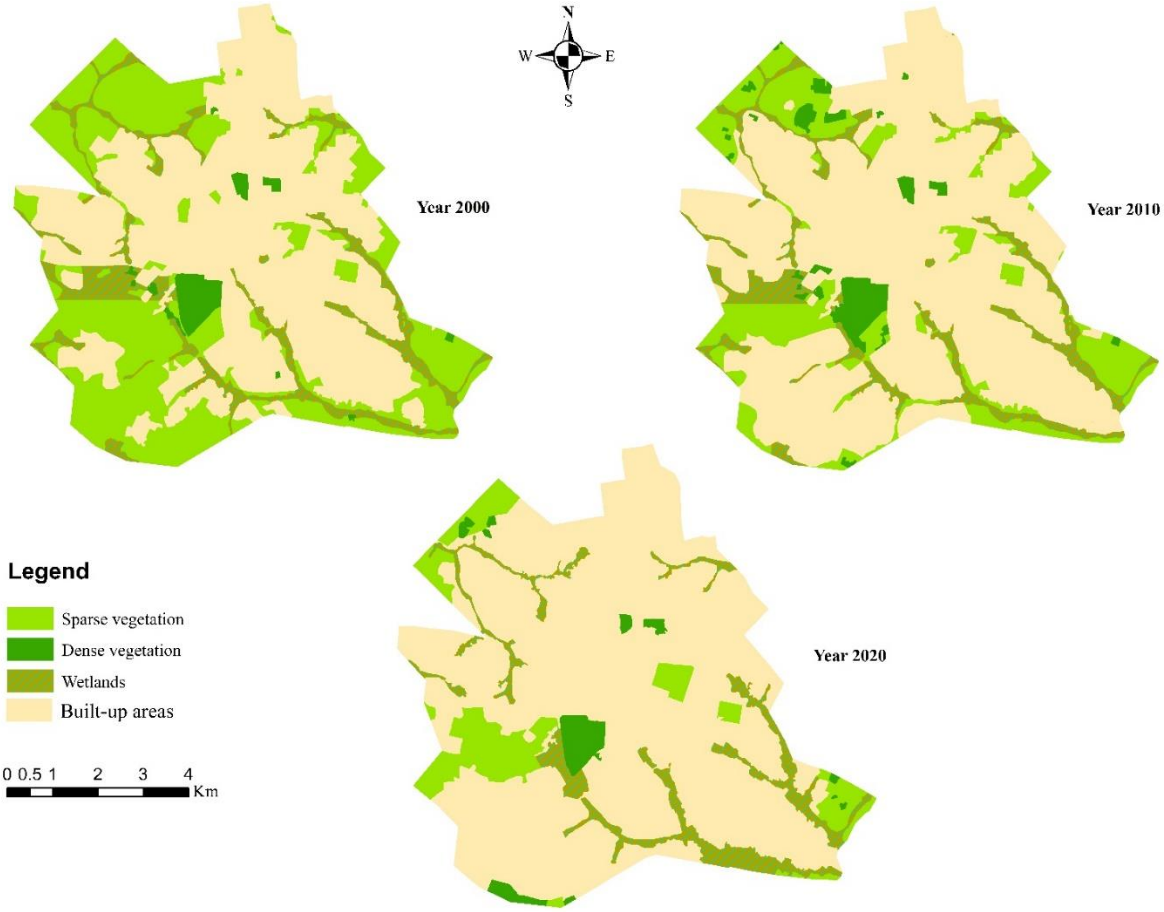

Figure 3. Land cover (LC) map for the years 2000, 2010, and 2020.

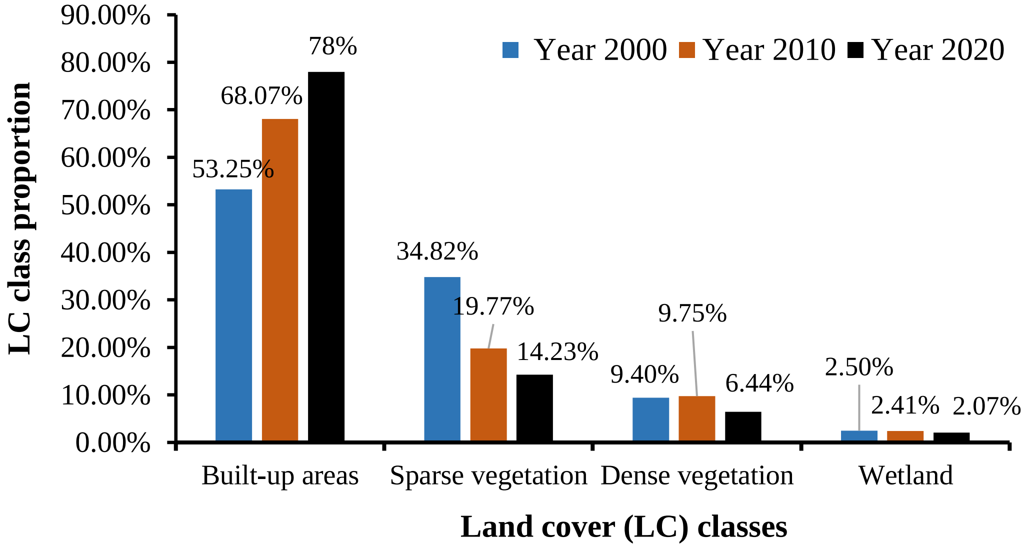

Figure 4. Proportion occupied by the land cover classes over the city area.

Between 2000 and 2010, as well as from 2010 to 2020, a substantial portion of Parakou's urban area, specifically 83.52% and 88.95%, respectively, remained unchanged (see Table 3), despite noticeable alterations among the land cover classes during these periods. The urban sections exhibiting no change predominantly included the built-up areas and green areas in the north-western and south-eastern sections of the urban area (Figure 3).

The analysis indicates that 14.51% and 7.35% of the land cover previously characterized by sparse vegetation underwent conversion to built-up land cover between 2000 and 2010 and between 2010 and 2020, respectively. Moreover, 1.11% of sparse vegetation cover transitioned to dense vegetation from 2000 to 2010, with no substantial change observed from 2010 to 2020. It was also noted that there was no conversion from wetland to dense and sparse vegetation between 2000 and 2010, although some conversions occurred from 2010 to 2020 at rates of 0.03% and 0.16% for dense vegetation and sparse vegetation classes, respectively.

In general, each GA class (dense vegetation, sparse vegetation, and wetlands) underwent conversion to built-up areas in the studied city during the research period. The annual loss of these green areas over the 20 years was calculated by dividing the total area of land cover class changes in green areas to built-up areas by 20 years. The results revealed that each year, Parakou's urban area lost 0.82 km^2 of its GA cover to built-up land cover.

Table 3. Statistics generated from the change detection map of Parakou (2000, 2010 to 2020).

Land cover class conversion	Change in cover (km^2)	
	2010 (%)	2020 (%)
Dense vegetation to sparse vegetation	0.38 (0.57%)	0.61 (0.91%)
Dense vegetation to built-up areas	0.13 (0.19%)	1.62 (2.43%)
Sparse vegetation to dense vegetation	0.74 (1.11%)	0.00 (0%)
Sparse vegetation to built-up areas	9.67 (14.51%)	4.90 (7.35%)
Wetland to dense vegetation	0.00 (0%)	0.02 (0.03%)
Wetland to sparse vegetation	0.00 (0%)	0.11 (0.16%)
Wetland to built-up areas	0.06 (0.09%)	0.1 (0.15%)
No conversion areas	55.65 (83.52%)	59.27 (88.95%)

4.2. Variation of spatial pattern of GAs

A total of 14.52 km^2 (21.79%) of the urban area in Parakou was covered with GAs, as shown in Table 4. The largest GA category was cropland, with a cumulative area of 4.06 km^2 (6.15%), followed by plantations and city bushes with 3.34 km^2 (5.01%) and 2.43 km^2 (3.65%), respectively. Cemeteries represented the smallest GA category, with a cumulative area of 0.17 km^2 (0.15%) in the urban area (Table 4).

The ANOVA results indicated a significant difference (P-value ≤ 0.000) between green area categories (Table 5). In this study, wetlands exhibited the greatest perimeter, while no significant difference was recorded between the remaining GA categories (Table 6). Concerning area size, forests (0.36 ± 0.24 km^2) and plantations (0.31 ± 0.27 km^2) presented the greatest values, while the remaining GA categories showed no significant difference (Table 6).

The forest category had the highest values for the shape index (2.66 ± 2.47) and edge density (0.40 ± 0.40), while the tree category gathered the lowest values, specifically 0.47 ± 0.46 and 0.02 ± 0.02, respectively (Table 6).

Table 4. Number of GA units, cumulative area, and cover proportion of GA.

GA units	Number	Cumulative area (km^2)	Cover %
Cemetery	3	0.17	0.15
City bush	39	2.43	3.65
Cropland	41	4.06	6.15
Forest	4	1.06	1.59
Wetlands	16	1.30	1.95
Plantation	10	3.34	5.01
Trees	27	1.62	2.43
Urban garden	33	0.54	0.83
Total	173	14.52	21.79

Table 5. Summary of ANOVA model on GA configuration parameters.

Variable	Df	F-value	P-value
Perimeter (m)	8	14.24	< 0.000***
Area (km^2)		8.37	
Shape index		13.44	
Edge density		16.51	

Note: Significance codes: ns = no significant, *** = 0.001, ** = 0.01, * = 0.05.

Table 6. Mean, standard deviation (Std), and difference category.

GA category	Perimeter (km)	Size area (km^2)	Shape index	Edge density (km/km^2)
Cemetery	1.17 ± 0.34^a	0.06 ± 0.01^a	1.22 ± 0.22^b	0.08 ± 0.02^a
City bush	1.2 ± 1.02^a	0.08 ± 0.12^a	1.18 ± 0.28^{bc}	0.08 ± 0.07^a
Cropland	0.59 ± 0.55^a	0.14 ± 0.18^a	0.55 ± 0.45^{bc}	0.04 ± 0.04^a
Forest	1.13 ± 0.44^a	0.36 ± 0.24^b	2.66 ± 2.47^a	0.40 ± 0.40^b
Wetland	2.33 ± 1.33^b	0.11 ± 0.18^a	0.95 ± 0.47^{bc}	0.06 ± 0.04^a
Plantation	1.05 ± 1.26^a	0.31 ± 0.27^b	0.56 ± 0.48^{bc}	0.07 ± 0.09^a
Trees	0.34 ± 0.31^a	0.05 ± 0.03^a	0.47 ± 0.46^c	0.02 ± 0.02^a
Urban garden	0.33 ± 0.24^a	0.02 ± 0.02^a	0.95 ± 0.46^{bc}	0.02 ± 0.02^a

Note: Means with the same letter are not significantly different (SNK test).

4.3. Spatial patterns and distribution of GAs

The spatial patterns of green areas are presented in Figure 5. An aggregative distribution of the points (central point of GA) is observed. Moreover, g(r) >1 was obtained, confirming that GA individuals were effective in the aggregative pattern (Figure 6).

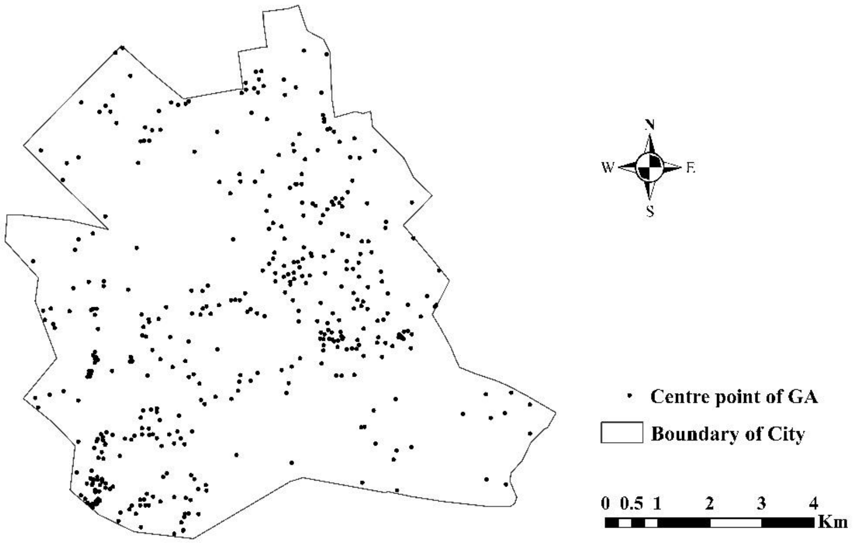

Figure 5. Map of the spatial pattern of GA in the study city.

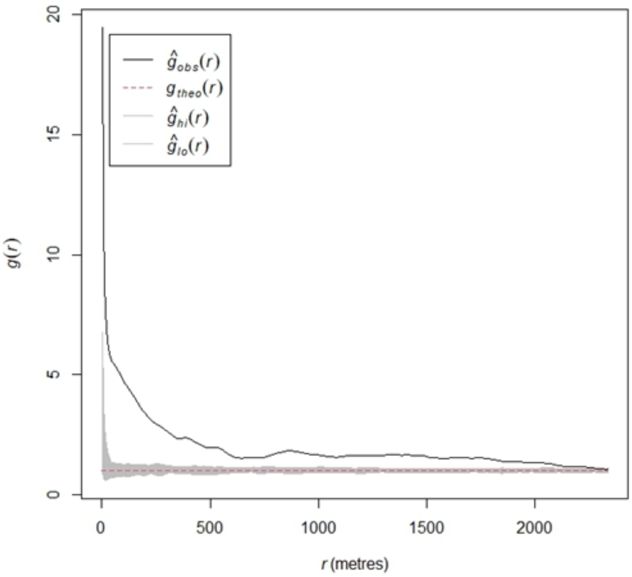

Figure 6. Graphs showing the spatial distribution of GA in the study city.

4.4. Background characteristics of respondents

Of all surveyed individuals, 61.0% were male. The age group of 25–44 years constituted 65.0% of the study's surveyed population. The predominant religion was Christianity, practiced by 54% of the respondents. The majority of respondents were married (69%), with monogamous couples making up 79.7%. Observations revealed that a significant portion of the surveyed population had completed senior high secondary school (33.3%), and the majority reported a monthly income ranging between 71.63 USD and 143.25 USD (see Appendix 2). Furthermore, a notable proportion of people in the city were renting their residences (55.7%). Lastly, a substantial 67.0% of the population had a stay duration in the city exceeding 10 years.

4.5. *Perception of determinants of GA sustainability*

When questioned about the ability of existing green areas to consistently provide long-term ecosystem services in their neighborhoods, a majority (81.23%) of the participants expressed that those green areas in their vicinity had experienced a decline in service provision. Regarding the long-term existence of green areas in their areas, respondents noted that trees (home, office, and street tree assemblages) (84.4%) and urban gardens (82.1%) were predominantly sustainable, while city bushes (86.3%), plantations (83.8%), and croplands (79.6%) were deemed critically endangered in their localities (Table 7).

The investigation of the primary causes influencing GA sustainability revealed that respondents primarily perceived mismanagement (37.5%) and a lack of planning (29.0%) as the key contributors (Table 8). Only 14.75 % of respondents cited limitations in the diversity and density of green areas as a determinant of GA decline in Parakou.

Table 7. GA sustainability perceived by respondents.

GA category	Response	Percentage (%)
Tree	Yes	84.4
	No	11.3
	Neither yes nor no	4.3
Garden	Yes	82.1
	No	17.6
	Neither yes nor no	1.3
Forest	Yes	57.8
	No	42.3
	Neither yes nor no	0.0
Wetland	Yes	33.0
	No	61.9
	Neither yes nor no	5.10
Cemetery	Yes	61.3
	No	28.2
	Neither yes nor no	10.5
Plantation	Yes	16.3
	No	83.8
	Neither yes nor no	0.0
Cropland	Yes	11.0
	No	79.6
	Neither yes nor no	9.4
City bush	Yes	10.5
	No	86.3
	Neither yes nor no	3.2

Table 8. Cause of GA depletion.

Cause of GA depletion	Percentage (%)
Mismanagement of GA	37.5
Lack of GA planning	29.0
Limited size of GA	18.75
Limitations in the diversity and density of GAs	14.75

5. Discussion

5.1. Changing influence on GA

The urban areas of Parakou experienced a significant reduction in green vegetation (both sparse and dense) and wetlands between 2000 and 2020, as evidenced by the trend analyses. This decline was primarily attributed to the transformation of these natural features into built-up environments, particularly noticeable from the central part of the city, demonstrating the notable influence of urbanization on the conversion of various land covers, such as wetlands, grasslands, linear GA, fallow land, forestlands, and farmlands, into grey infrastructure. Gashu & Egziabher [29], Mandal et al. [30], and Duku et al. [23] affirmed that the escalating population and infrastructure development in the metropolis were responsible for the loss of GA to the built environment.

Change detection analysis from 2000 to 2010 revealed a 1.11% conversion of sparse vegetation cover to dense vegetation, attributable to afforestation efforts, particularly in the northwestern part of Parakou. This shift was linked to the demand for trees (*Tectona grandis*, *Khaya senegalensis*, and *Gmelina arborea*) for artistic purposes, firewood, and charcoal burning [15,31]. However, a substantial greening conversion, including shifts from dense to sparse vegetation, wetland to sparse, and overall transformation into built-up areas, occurred from 2010 to 2020. This transformation was associated with the rising population and urbanization during that period, aligning with insights from Essel [32] and Namwinbown [33], who emphasized the impact of rapid urbanization and population growth on diminishing green areas. Thus, Parakou experienced a population increase from approximately 141,000 in 2000 to 223,000 in 2010 and 338,000 in 2020, contributing to the urban sprawl according to UN-DESA [21].

The study predominantly identified a growing trend in the transformation of GA into built-up areas. This has the potential to adversely affect green area patterns and distribution and urban ecosystem services, as highlighted by Sharma et al. [34]. Additionally, the quality of GAs may degrade, hindering their capacity to support biodiversity, as noted by Namwinbown [33]. The research findings disclosed an annual loss of 0.82 km² of GA cover to built-up land cover within the city. Consequently, the substantial encroachment on these GAs implies their diminished value in the physical landscape of the study area. This underscores the need for heightened attention from city authorities to improve the environmental sustainability of the city through the maintenance and management strategy of each GA category. For sustainable planning and management of green areas in Benin, it is crucial to understand how changes impact the patterns, distribution, and loss risks of green areas in general, as well as specific categories of green areas, particularly in the face of climate change threats.

5.2. Spatial pattern and distribution of GA

The GA in the city under study can be classified into several categories, namely forest (including sacred forest and gallery forest), wetland, forest plantation, cropland, city bush, green cemetery, urban garden, and various tree assemblages (found in homes, offices, and along streets). Comparable categories of green areas, such as trees, forest plantation, and agricultural land, were identified in studies conducted in Thailand [35], Democratic Republic of the Congo (involving wetlands, croplands, gardens, and cemeteries) [36], and Italy (involving crop and cultivated areas, gardens, and forest parks) [37]. However, the specific inclusion of city bushes in this study may be attributed to the unique characteristics of the field. City bushes, being unsustainable, are common in the study cities and are susceptible to disappearance at any time [38].

The proportion of GAs in the city was determined to be 21.79%, which can be compared to the findings of Zakka et al [39], who reported an average GA cover of 24.4% in Kumasi in Ghana from 2000 to 2010. This finding can generally demonstrate how important the green area loss risk was in the study area. The ANOVA test indicated a significant difference among GA categories within the study city, aligning with conclusions drawn in previous studies like Fu et al. [40], where the authors explored optimized urban vegetation configurations for heat reduction. This specific observation highlights the need to understand residents' opinions on both the degradation state of each category of GA and the factors driving this degradation. It is also crucial to gather their perspectives on the strategies needed for the conservation of these GA.

The forest and plantation categories exhibited larger size areas, likely due to the majority of forests being sacred or gallery forests, where settlement access is restricted by traditional prohibitions (sacred forests) or heightened flood risks (gallery forests). The study suggests that specific strategies or actions are needed for the development or conservation of each GA category. Furthermore, it calls for additional research on the current city to uncover the relationship between GA configuration and climate effects mitigation and adaptation, a gap highlighted by Fu et al. [40], particularly in urban areas of the southern hemisphere, especially in developing countries experiencing significant population growth.

The spatial pattern of GA demonstrated an aggregative distribution, echoing similar findings in Alam et al. [41] regarding the unequal distribution of green areas, such as parks and playgrounds, in Gulberg town (Pakistan). According to Liang et al. [42], the distribution of GA depends on various factors, including area development within the city. Past research by Fangnon [43] on the municipality of Seme (Benin, West Africa) highlighted an uneven distribution of GA with varying densities in the city's boroughs due to historical, social, economic, political, recreational, and cultural functions. The current study's findings can first be justified by the irregular urbanization in each sector of Parakou, characterized by diverse urbanization levels and histories [44]. Second, this result could be supported by the weakness of effective urban planning policies that prioritize GA development and conservation. Moreover, these findings offer valuable insights into the distribution (uneven distribution) of urban ecosystem services in the city [45] and can support decision-making and planning for inclusive GA benefits for residents. Finally, the configuration and distribution of green areas (GA) and the provision of ecosystem services should impact residents' opinions on the degradation risk of each GA category and the factors driving this threat.

5.3. Perception of GA sustainability

Given the limited available evidence on the enduring presence of GA and their impact on the well-being of urban residents, particularly in Benin, this study delves into people's perceptions concerning the factors that influence the sustained existence of various types of GA. Trees (home, office, and street tree assemblages) (84.4%) and urban gardens (82.1%) were primarily perceived as sustainable in the urban area of Parakou. This perception is justified by the fact that these types of GA mainly result from public or private establishment and planning, benefitting from substantial maintenance efforts. A similar conclusion was reached by Kim et al. [46] when investigating the perception of informal GA in Ichikawa, Japan. In contrast, city bushes (86.3%), plantations (83.8%), and croplands (79.6%) were considered critically endangered. This particular perception may be explained by the fact that these categories of GA are typically not regarded as part of urban-planned green areas within the study area's context. Therefore, they typically serve as the final stage in the transition from urban non-built areas to built-up areas. Moreover, wastelands (such as city bush) with semi-natural vegetation were identified as contributors to urban green ecosystems but were publicly perceived as abandoned and empty GA [47,48]. Regarding croplands and plantations, they often face hazards such as tree and crop harvesting, potentially leading to their conversion into other classes (built-up or bare areas). In Parakou, croplands (traditional agriculture) are predominantly transformed into settlement areas. A similar conclusion was drawn by Behera et al. [49], indicating a decrease in agricultural land due to an increase in settlement areas in Chilika Lake, India.

When examining the factors contributing to the vulnerability of GA, individuals notably highlighted the core issues of mismanagement and a lack of planning strategy. This discovery aligns with the findings of Sinxadi & Campbell [50], who observed that inadequate management strategies and poor enforcement of land-use regulations are significant contributors to the prevalence of GA loss in their study region in South Africa. In Parakou, a previous study identified the absence of effective greenery management and planning strategies as the primary cause of the diminished benefits of GA for residents [22], providing additional support for the current results. The implications of these findings are considerable for planning practitioners as well as other professionals and policymakers involved in urban planning and socio-economic development, both within the studied city and beyond.

6. Conclusions

The analysis unveiled various spatiotemporal alterations in the land cover of the urban area of Parakou from 2000 to 2020. The average annual rate of change during this period indicated a loss of 0.82 km² of green areas to built-up or grey areas. This trend was initiated in the central portion of the city and gradually extended toward its peripheries. Noteworthy land cover transformations included the conversion of both dense and sparse vegetation as well as wetlands into built-up areas. These changes underscore the impact of intensified physical development attributed to urbanization, a lack of rigor in enforcing development controls, and the absence of nature-based design principles in housing and infrastructure development.

This study also investigates the spatial pattern and distribution of green areas (GA) in the city, categorizing them into various categories such as forests, wetlands, plantations, croplands, city bushes, cemeteries, gardens, and tree assemblages. The analysis reveals significant differences among these

GA categories, underscoring the importance of tailored strategies for their development, improvement, or conservation based on specific configurations. Additionally, the study notes a clustered distribution of GA, likely influenced by the irregular urbanization process in the city. This finding is expected to offer valuable insights into the distribution of ecosystem services provided by these areas in the city.

Concerning the sustainability of GA in the city, only tree assemblages and urban gardens were largely perceived as persistent, while city bushes, plantations, and croplands were considered critically endangered in this locality. Consequently, inadequate management and planning strategies were identified as major factors contributing to the vulnerability of GA in the studied city. These results could provide valuable guidance for policymakers, urban planners, and cityscape architects with a focus on urban sustainability, particularly regarding the development of GA in the Republic of Benin.

Author contributions

Akakpo Bokon Alexis: Conceptualization, Methodology, Data curation, Formal analysis, Validation, Writing: original draft, Writing: review & editing, Visualization; Padonou Elie Antoine: Formal analysis, Validation and Review of the manuscript; Okhimamhe A. Appollonia: Review and validation of the manuscript; Umaru T. Emmanuel: Review of the manuscript; Azihou F. Akomian: Formal analysis, Validation and Review of the manuscript; Ibrahim Haruna: Review of the manuscript; Orekan A. O. Vincent: Review and validation of the manuscript and Sinsin A. Brice: Review of the manuscript. All authors read the final manuscript.

Acknowledgments

This research work was fully supported by West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) under the Doctoral Research Programme (DRP) of Climate Change and Human Habitat (CC-HH). We also thank the reviewers for their valuable contributions to the quality of the paper.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest.

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