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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

Appendix 1

Stakeholder questionnaire. In order to promote sustainability in our settlements at these moments of harmful effects of climate change, this interview is set to appreciate the efficacity of green areas in the cities of Parakou (Benin).

Interviewer Name: ……...…….

Date: Day……...Month……...Year……

City: ……..……and……. **City borough name…**……..……

Language of survey: ……...……...

Table 1. Description of interviewee.

1	Name of interviewee if possible	
2	Age	
3	Gender	1 = male
		0 = female
4	Ethnic	
5	Religion	1 = Christianism
		2 = Islam
		3 = traditionalist
		4 = Other (to specify)
6	Matrimonial	1 = Single
		2 = Married
		3 = Widow
		4 = Divorced
7	Polygamy	1 = Yes
		0 = No
8	School education level	1 = Primary
		2 = Secondary and first cycle
		3 = Secondary and second cycle
		4 = University
		5 = Literacy in local tongue
		9 = Never at school

9	Residence acquisition	1 = Rent 2 = Free lodge 3 = Owner 4 = other (to specify)
10	Main activity	1 = Trade 2 = Agriculture 3 = Transformation of agro-food 4 = Handcraft 5 = Public officer 6 = Private officer 7 = Student 8 = Retired 9 = Other (to specify)
11	Level of monthly income	1 = Less than 40 000 FCFA 2 = Between 40 000 and 80 000FCFA 3 = More than 80 000 FCFA
12	**How many years do you spend in the city**	1 = less than 02 years 2 = between 02 and 05 years 3 = more than 05 years

Table 2. Characteristics of green infrastructure.

13	Type of green infrastructure exists in your location	1 = Street trees 2 = Public gardens 3 = Private garden 4 = Urban park 5 = Community or Sacred forests 6 = Urban cropland 7 = Improved verges 8 = House trees 9 = Green roof 10 = City bush 11 = Urban wetland 12 = Other to specify
14	Main green infrastructures in your location	
15	How would you have rated key aspects of green infrastructures in your location	1 = Poor 2 = Inadequate 3 = Adequate 4 = Excellent 5 = Other to specify
16	Vegetation diversity of green areas in your location	1 = Poor 2 = Inadequate 3 = Adequate 4 = Excellent 5 = Other to specify
17	Management of green areas in your location	1 = Poor

		2 = Inadequate
		3 = Adequate
		4 = excellent
		5 = Other to specify
18	Attractivity of green areas in your location	1 = Poor
		2 = Inadequate
		3 = Adequate
		4 = Excellent
		5 = Other to specify
19	Green area in your house	1 = Yes
		0 = No;
		2 = Neither yes nor no
		If yes, which one
20	Worry about improving housing green areas	1 = Yes
		0 = No
		2 = Neither yes nor no
21	Public participation in green areas development and planning	1 = Yes
		0 = No
		2 = Neither yes nor no
		If yes,
		1 = Maintenance and protection,
		2 = Financial support,
		3 = Technical support,
		4 = Local referendum
		5 =Other to specify
22	Location of dominated green areas	1 = Centre of the city
		2 = Business areas of the city
		3 = Suburbs
		4 = New expansion areas
		6 = Public offices
		7 = Private offices
		8 = Other to specify

Table 3. Knowledge of green infrastructure's importance in the town.

23	**General awareness on the impacts of green areas in town?**	1 = Yes
		0 = No
		2 = Neither yes nor no
24	Currently loss of benefits of green area	1 = Yes
		0 = No
		2 = Neither yes nor no
25	More important benefits lost from green areas in the city in your opinion?	1 = Beauty and aesthetic
		2 = Heat control
		3 = Flood control
		4 = Biodiversity sink
		6 = Air quality

		7 = Sound control
		8 = Other to specify
26	Main causes of the given loss of benefit?	1 = Weak density green infrastructure
		2 = Size of green space
		3 = Weak diversity of green infrastructures
		4 = Unplanning of green infrastructure
		5 = Lack of management or green infrastructure
		6 = Other to specify
27	Possibility of restoring some benefits	1 = Yes
		0 = No
		2 = Neither yes nor no
28	If yes, give the key actions	
29	Kind of green areas most interesting in urban environmental control	1 = Street trees
		2 = Public gardens
		3 = Private garden
		4 = Urban park
		5 = Urban cropland
		6 = Improved verges
		7 = House trees
		8 = Green roof
		8 = Other to specify
30	Will you contribute to the development of green areas in your locality?	1 = Yes
		0 = No
		2 = Neither yes nor no
31	If No, give the primary reasons.	
32	Which kind of contribution?	1 = Financial by subscription
		2 = Manpower volunteer
		3 = Information awareness
		4 = Self tree plantation
		5 = Self home garden management
		6 = Security and protection of public green infrastructures
		7 = Other to specify

Table 4. Knowledge and practice of green infrastructure management and planning.

33	Is there any program for urban greening development?	1 = Yes
		0 = No
		2 = Neither yes nor no
34	If yes, specify	
35	Are there planning spaces for greening in your location?	1 = Yes
		0 = No
		2 = Neither yes nor no

36	Do you have knowledge of institutions in charge of green infrastructure management?	1 = Yes 0 = No 2 = Neither yes nor no If Yes, Specify them
37	What are the two main institutions that close questions on greening in the city?	1 = NGOs (to specify) 2 = Town hall 3 = University 4 = Environmental office 5 = Heath office 6 = Other to specify
38	Is there good cooperation between institutions?	1 = Yes 0 = No 2 = Neither yes nor no
39	If Yes, specify their relationship or collaboration	
40	What are the attributions of each in greening planning and development	1 = Installation of new greening in the city 2 = Maintenance and protection of green infrastructures 3 = Financial support, 4 = Technical support 5 = Communication, awareness and education 6 = Other to specify
41	Cooperation attitude of institutions with local communities	1 = Yes 0 = No 2 = Neither yes nor no
42	Is there any community association for greening planning and development	1 = Yes 0 = No 2 = Neither yes nor no
43	Level of involvement of the community association in the management of the green areas	1 = High 2 = Medium 3 = Low 4 = Other to specify
44	Specify the stages of community involvement in green area management	
45	Main challenges for green area planning and management	1 = Lack of fund 2 = Lack of understanding 3 = Default of communication 4 = Lack of new technology 5 = Other to specify
46	Main strategies taken to face these challenges	

Appendix 2. Profile of the surveyed residents.

Variables	City of Parakou (N = 400)
Gender	
Male	244 (61.0%)
Female	156 (39.0%)
Age	
15-24	88 (22.0%)
25-44	260 (65.0%)
45-64	45 (11.3%)
≥65	7 (1.7%)
Religion	
Christianism	216 (54.0%)
Islam	139 (34.7%)
Traditional	45 (11.3%)
Matrimonial	
Single	114 (28.5%)
Married	276 (69.0%)
Divorced	10 (2.5%)
Widower	0 (0.0%)
Polygamy	
Yes	81 (20.3%)
No	319 (79.7%)
Education	
Tertiary	107 (26.7%)
Senior High School	133 (33.3%)
Junior High School	80 (20.0%)
Primary School	34 (8.5%)
Literacy	4 (1.0%)
None	42 (10.5%)
Residence	
Owner	107 (26.8%)
Tenant	223 (55.7%)
Free accommodated	70 (17.5%)
Activity	
Agriculture	18 (4.5%)
Own business	72 (18.0%)
State employment	2 (0.5%)
Private employment	41 (10.3%)
Trade	48 (12.0%)
Student	219 (54.7%)
Pension	0 (0.0%)
Monthly income (USD)	
Less than 71.63	102 (25.5%)
71.63 to 143.25	176 (44.0%)
More than 143.25	122 (30.5%)

Living duration in cities (Year)	
Less than 5	16 (4.0%)
5 to 10	116 (29.0%)
More than 10	268 (67.0%)