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Geospatial Assessments of Urban Green Space Protection in Abuja City, Nigeria

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Abstract. In the Global South, including Sub-Saharan Africa, several reports have shown that urban planning strategies have failed to protect effectively the new and existing urban green infrastructures. However, while most of those studies did not limit their scales to the implemented urban planned areas, others did not conduct a direct comparison between the observed urban green space and those designated by urban plans. Using Abuja, Nigeria as a case study, urban plan, and Geographic Information Systems/remotely sensed data were combined to assess the urban green space protection within the implemented urban planned areas to support urban strategic actions such as urban policies, planning, and programs for urban environmental sustainability. Supervised classification of land cover was performed on a Sentinel 2 satellite image to assess the spatial patterns of urban green space for 2021. Also, the association between the observed urban green space and that of the urban plan was quantified and compared. Additionally, the level of urban green space protection within individual parks and gardens was investigated. Key findings indicated that while some parks/gardens are moderately protected, others are highly protected. Additionally, the findings showed positive and significant associations between the observed urban green space and land use designated for urban green space by the urban plan. This study showed the effectiveness of the implementation of urban strategic actions for the protection of urban green infrastructures within the implemented urban planned areas in Abuja, Nigeria, which may be the case for other cities in Sub-Saharan Africa and other parts of the world, where such urban strategic actions are being implemented. The findings provided in this study are crucial to support the decision-making process in urban strategic actions on the protection of urban green infrastructures and to improve urban environmental sustainability in Sub-Saharan Africa and other parts of the world.

Keywords. Urban green infrastructure; urban strategic actions; urban planning; urban environmental sustainability; spatial patterns; Sub-Saharan Africa

1. Introduction

Urban green spaces, which are urban land use designated for all kinds of urban green infrastructures, including urban forests, parks, gardens, agriculture, cemeteries, and street greeneries (Kwartnik-Pruc & Trembecka, 2021) contribute to urban environmental sustainability (Zhang et al., 2022; Stan 2022; Cheshmehzangi et al., 2021; Kuklina et al., 2021; Puchol-Salort et al., 2021; Gelan & Girma, 2021; Russo & Cirella, 2020; Narh et al., 2020;

Meijering et al., 2018). In this context, urban environmental sustainability can be regarded as a condition that allows the current and future generations to utilize the services or benefits provided by urban green spaces without jeopardizing the healthy state of urban green ecosystems. Urban green spaces provide environmental benefits, including cooling urban heat (Zhang et al., 2022; Shah et al., 2021; Masoudi et al., 2021), regulating air quality and reducing noise pollution (Misiune et al., 2021; Park et al., 2021; Song et al., 2020; Emechebe & Eze 2019), storm runoff mitigation (Li et al., 2021; Abass et al., 2020; Song et al., 2020; Vargas-Hernández et al., 2018), and climate change mitigation (Nassary et al., 2022; Cheng et al., 2021; Vargas-Hernández et al., 2018). Besides the environmental benefits, urban green spaces provide socio-psychological benefits such as relaxation and alleviation of negative emotions (Dipeolu et al., 2021; Zhu et al., 2021; Park et al., 2021; Sulistyo et al., 2020; Vargas-Hernández et al., 2018). Additionally, they provide economic benefits such as food and fiber availability from urban agriculture and forestry (Zhang et al., 2022; Nassary et al., 2022; Park et al., 2021; Kingsley et al., 2021; Vannozzi Brito & Borelli 2020), Furthermore, they provide cultural benefits such as urban landscape design (Wang, 2022; Park et al., 2021; Puchol-Salort et al., 2021; Sulistyo et al., 2020; Vargas-Hernández et al., 2018) and ethno-cultural identities and values attached to community parks and gardens (Egerer et al., 2019). The services and benefits provided by urban green spaces can be improved and maintained through effective protection of the green infrastructures using urban strategic actions such as urban policies, planning, and programs.

In the Global South, including Sub-Saharan Africa, urban strategic actions re-integrate the establishment of new urban green spaces and the protection of the existing ones into urban development to support urban environmental sustainability. For example, in Nigeria, "Greening Abuja" and "Operation Green Lagos" are urban development programs that were initiated for drastic urban green infrastructures and to ensure the strict implementation of urban plans on urban green spaces in Abuja (Jibril, 2015; Jibril, 2010) and Lagos (Ogunyombo & Odunlami, 2017). In Sub-Saharan Africa, despite urban development strategic actions, including urban planning, most cities have not been able to create and/or protect effectively the new and existing urban green spaces, respectively due to the expansion of urban developments into urban green spaces (Zakka et al., 2017). For example, in Abuja, Nigeria, urban development expands to the detriment of vegetation cover (Enoguanbhor et al., 2019; Mahmoud et al., 2016; Tope-Ajayi et al., 2016; Ade & Afolabi 2013), and this expansion may continue into land designated for protected environmentally sensitive areas and productive forestry if the problem is not put to check (Enoguanbhor, 2021). The degradation of vegetation and other urban green spaces was reported in other Sub-Saharan African urban areas, including Kwale, Nigeria (Matemilola et al., 2018), Mafikeng, South Africa (Munyati & Drummond, 2020), Accra, Ghana (Puplampu & Boafo, 2021) Kumasi, Ghana (Abass et al., 2020; Narh et al., 2020), Addis Ababa, Ethiopia (Mohamed & Worku, 2020), and Dodoma, Tanzania (Kabanda, 2019). Outside Sub-Saharan Africa, Arshad et al. (2022) and Dinda et al. (2021) observed urban expansion to the detriment of urban green spaces in Lahore district as a rapidly urbanizing metropolitan city of Pakistan and Kolkata city of India, respectively.

Previous urban studies (e.g., Puplampu & Boafo, 2021; Narh et al., 2020; Abass et al., 2020; Enoguanbhor, 2021; Mahmoud et al., 2016; Dinda et al., 2021) either did not compare their observed urban green space/vegetation degradation to the land use designated for urban green space by urban plans or they compared them in addition to those areas not covered by urban plans. It can be argued that the reports on the degradation of vegetation and other urban green infrastructures from those previous studies can be associated with the non-availability or non-implementation of urban plans in those areas. This would make it difficult to evaluate the effectiveness of urban planning implementation on urban green space protection in general and those found within the protected parks and gardens in particular. In one of those urban studies, Enoguanbhor (2021) compared the observed urban green space/vegetation to those designated by land use plans but did not investigate the protection level of urban green infrastructures in protected parks and gardens found within the implemented urban planned areas, as well as the relationship/association between the observed urban green space and those designated by the urban plan. In a particular study that assessed the conditions of urban green infrastructures in parks and gardens, Narh et al. (2020) opined on the degradation of urban green infrastructure and concluded that Kumasi as a West African Garden City is without parks and gardens. However, the study did not make a direct comparison between green infrastructures and the urban plan. These existing findings from previous urban studies raise a crucial question: are urban green spaces in parks and gardens found within the implemented urban planned areas protected effectively?

The current study, therefore, aims to integrate urban plan and Geographic Information System (GIS)/remotely sensed data to assess the urban green space protection, including parks and gardens found within the implemented urban planned areas to support urban strategic actions such as urban policies, planning, and programs for urban environmental sustainability. Specifically, the study seeks to:

1. quantify the spatial patterns of urban green space for 2021 and compare the observed green space to those designated by the urban plan;
2. quantify and compare the association between the observed urban green space and that of the urban plan for different urban development phases, and;
3. investigate the level of urban green space protection within individual parks and gardens.

Article I. 2. Materials and methods

2.1. Study area

The urban development phase I-II (covering about 171.66 km2) of the Federal Capital City (FCC), Abuja, Nigeria (Figure 1) was chosen for this study because urban planning has been implemented in the area (Enoguanbhor et al., 2022). The urban development of FCC Abuja was initially divided into four (now five) phases to be implemented consecutively and currently; the plan's implementation has gone beyond phases I-II (Gumel et al., 2020). The urban planning implementation started in the early 1980s in phase I before the relocation of the government seat of power from the formal capital, Lagos to Abuja in 1991(Adama, 2020; Sufiyan et al., 2015; Abubakar, 2014; Ejaro & Abubakar, 2013; Idoko & Bisong, 2010). The urban plan was prepared in 1979 by the International Planning Associates (IPA) (FMITI, 2015; Fola Consult Ltd, 2011). The plan made provisions for urban green spaces, including the protection of the natural vegetation and the creation of new urban greeneries across various urban development phases (Abubakar, 2014; Fola Consult Ltd, 2011; AS&P & Elsworth, 2008). Some of the parks and gardens as urban green infrastructures include the National Arboretum, Millennium Park, City Park, Zone 6 Neighbourhood Park, Jabi Recreational Park and Garden, Harrow and Lobito Cr Park, and Eden Park and Garden (Figure 6).

As a fast-growing region, the population of the FCT, Abuja was estimated to be 1.4 million in 2006 with a 9.1% growth rate defined by the National Population Commission, Abuja (Adama, 2020; NBS, 2016). However, the growth rate was estimated at 5.3% in 2015 (Mashi

& Shuaibu 2018). Due to the lack of census data on recent/current population figures in Nigeria, different figures have been projected using different growth rates. Thus, using the 9.1% growth rate, the population of FCT was projected to be 3.6 million in 2016 by NBS (2016) and 3.8 million in 2017 by Enoguanbhor (2019).

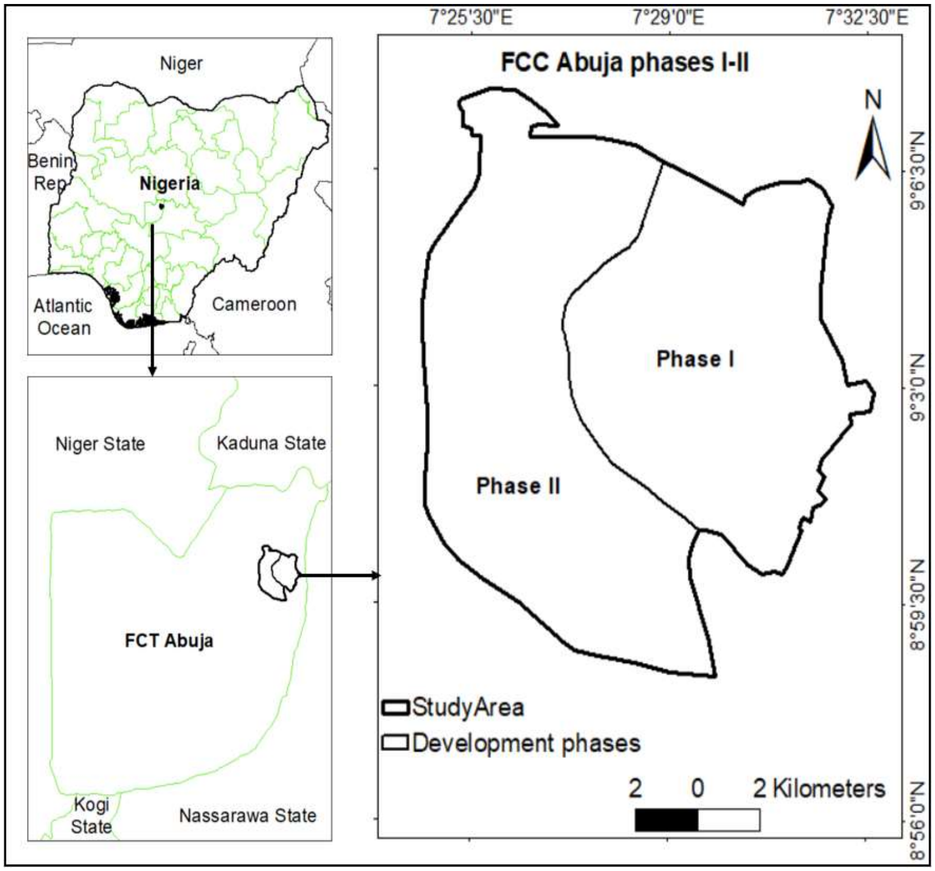

Figure 1. Map of Abuja urban development phases I and II.

2.2. Data collection and analysis

The remotely sensed satellite image captured in April 2021 by the Sentinel 2 satellite of the European Space Agency was collected (ESA, 2021). This dataset was used for this study due to its 10 meters spatial resolution (which is good for the analysis of urban green space), openly accessible, and coverage of the study area. Additionally, a 2011 reproduced version of the urban land use plan phases I-III of Abuja city was collected from the Department of Urban and Regional Planning, Abuja, Nigeria (Fola Consult Ltd, 2011).

The data analysis for the current study was performed using ArcGIS version 10.8.1. and R version 4.1.1. The spatial pattern of urban green space for 2021 was quantified using the supervised classification and maximum likelihood algorithm (Campbell & Wynne, 2011; Lu et al., 2011; Tso & Mather, 2009). The supervised classification uses training samples of known pixels to assign the unknown pixels to different classes and the maximum likelihood algorithm assigns pixels to a class with the highest probability (Enoguanbhor et al., 2022). For the training samples, the Normalize Difference Vegetation Index (NDVI) was used (Kwan et al., 2020) to identify pixel values (2.0 and above) for urban green space. The NDVI is expressed as:

$$\mathbf{NDVI} = \frac{\mathbf{NIR- R}}{\mathbf{NIR+ R}} = \frac{\mathbf{Band\ 8- Band\ 4}}{\mathbf{Band\ 8+ Band\ 4}}$$

where NIR and R denote the near-infrared band (band 8) and red band (band 4) respectively. The final land cover map was classified into green space (urban green infrastructures, including street greeneries, forests, parks, gardens, grasses, etc.) and non-green space. The accuracy assessments of land cover classification were performed using a simple random sampling (Olofsson et al., 2014) of 200 points. The composite Sentinel 2 satellite image was used as referenced data for the computation of different accuracy assessments, including user accuracy (UA), producer accuracy (PA), over accuracy (OA), and kappa coefficient (KC) as described in detail by Enoguanbhor (2021). The UA and PA for the green space were estimated at 87% and 89.7% respectively. The UA and PA of the non-green space were estimated at 90% and 87.4% respectively. The OA and KC of the classification were estimated at 88.5% and 0.89% respectively.

To compare the observed green space to those designated by the urban plan, the observed green space was extracted, the land use designated for urban green space by the urban plan was digitized, and both the observed and the digitized urban green spaces for each of the phases I and II were calculated. Finally, the cartographic GIS overlay (Enoguanbhor et al., 2021) was used to visualize the spatial patterns of the observed and digitized urban green spaces.

The association between the observed urban green space and that of the urban plan for different urban development phases was quantified and compared using the Euclidean distance and simple linear regression modeling (Fotang et al., 2021). The Euclidean distance, which is based on Pythagoras' Theorem is used to calculate the distance from a particular point to another point of feature (Yenisetty & Bahadure, 2021) and was used to generate parameters for the simple linear regression modeling. The simple linear regression modeling can be expressed as:

$$\mathbf{Y = \beta_0 + \beta_1 X + \varepsilon}$$

where Y is the dependent variable (the observed urban green space), X is the independent variable (land use designated for urban green space by the urban plan), $\beta 0$ and $\beta 1$ are intercept and coefficient respectively and ε represents the random error terms.

Finally, the level of urban green space protection within individual parks and gardens was investigated by digitizing eight selected parks/gardens and calculating the observed green space within the parks/gardens using geoprocessing tools. Figure 2 shows the materials and methods applied for the current study.

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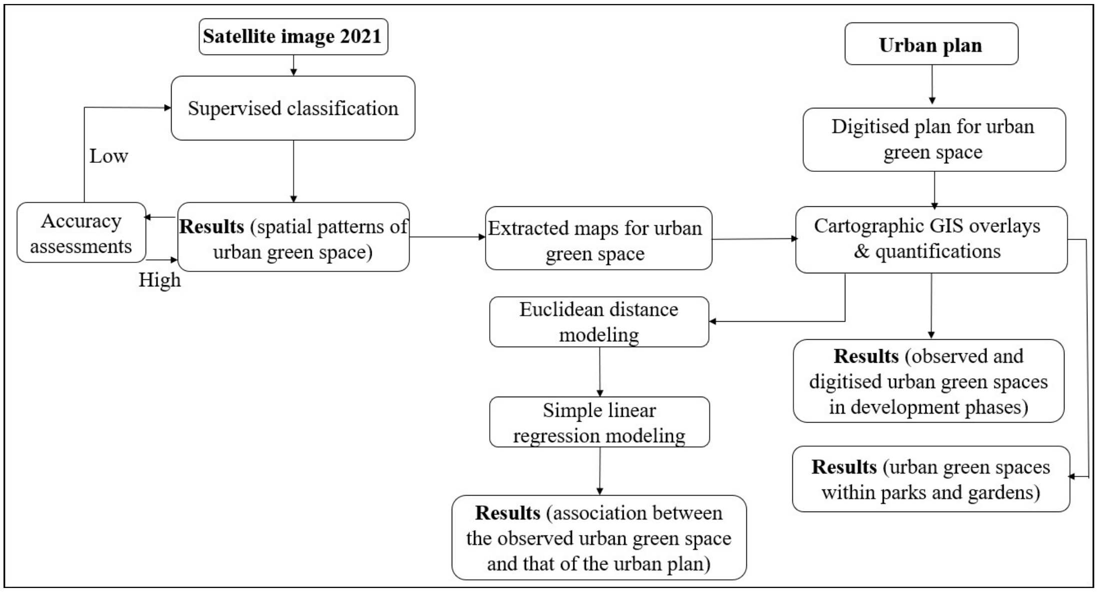

Figure 2. Methods for assessing urban green space protection.

3. Results

The results (Tables 1 and 2, and Figure 3) showed the quantified spatial patterns and comparison of the observed urban green space to those designated by the urban plan. While the observed green space is 23.3%, the non-green space is 76.67% (Table 1) and the land use designated for urban green space by the urban plan is 20.48% of the total area (Table 2). The comparison between the observed green space and those designated by the urban plan showed that in phase I, the observed green space is 11.78% and the land use proposed for urban green space by the urban plan is 8.35%. In phase II, while the observed green space is 11.55%, the land designated for urban green space by the urban plan is 12.13%.

Table 1. Calculated area of 2021 land cover types.

Land cover classes	**Area km^2**	**% of the study area**
Green space	40.05	23.33
Non-green space	131.60	76.67
Total	**171.66**	**100**

Table 2. Calculated areas of the observed green space and that of the urban plan.

Urban development phases	**Observed green space**	**Land use designated for green space by the urban plan**
Area km^2	**Area km^2 (% of the study area)**	**Area km^2 (% of the study area)**
Phase 1 (77.31)	20.23 (11.78%)	14.34 (8.35%)
Phase II (94.35)	19.82 (11.55%)	20.83 (12.13%)
Total (171.66)	**40.05 (23.33%)**	**35.17(20.48%)**

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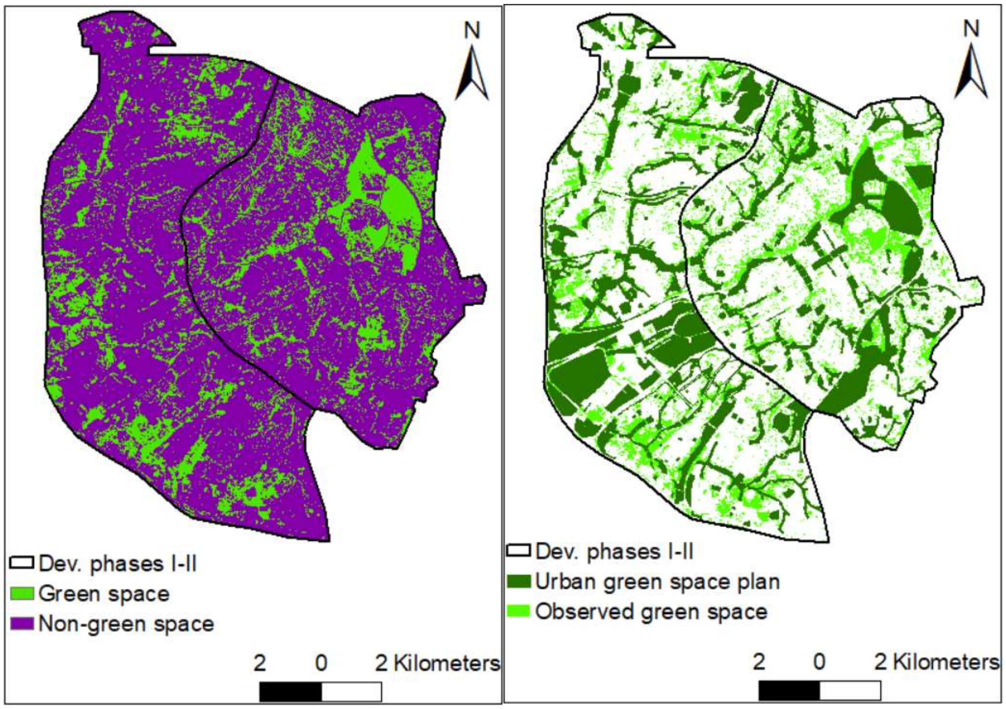

Figure 3. Spatial patterns of the observed urban green space for 2021 and that of the urban plan.

The results (Table 3 and Figure 4) showed the association between the observed green space and those designated by the urban plan at the level of urban development phases. In phases, I and II, the observed green space and those designated for urban green space are significantly and positively associated at 0.41 and 0.39 coefficients respectively. The standard errors of 0.07 and 0.05 for phases I and II, respectively indicated good models' fit.

Table 3. The association between the observed green space and that of the urban plan.

Urban development Phases	**Coef.**	**P-value**	**Std. error**
Phase I	0.41	0.00***	0.07
Phase II	0.39	0.00***	0.05

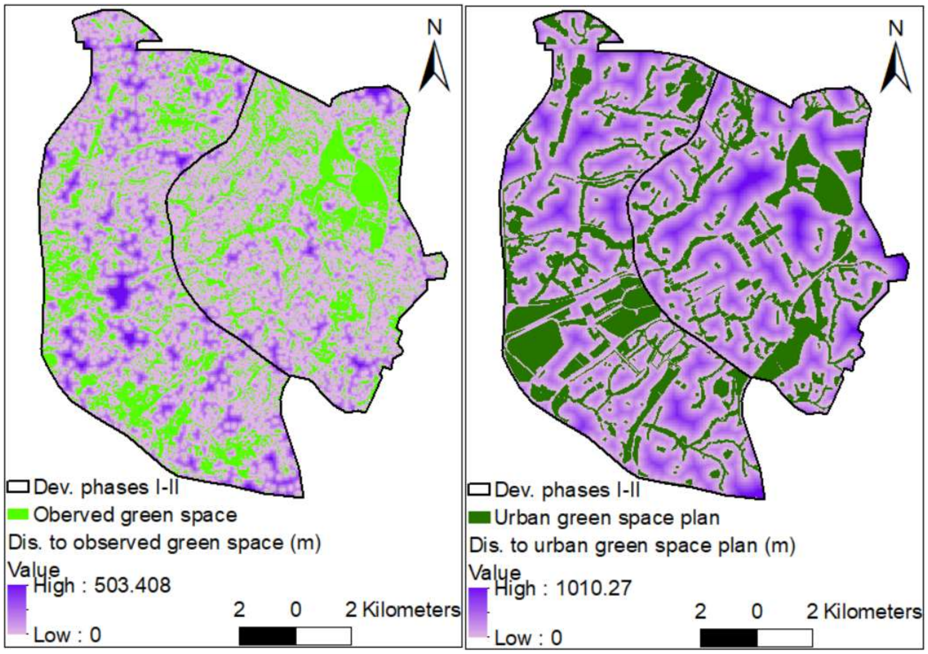

Figure 4. Maps showing the Euclidean distance to the observed green space and land use designated for urban green space by the urban plan.

The results (Figures 5 and 6) showed the level of urban green space protection within individual parks and gardens. The highly protected parks/gardens are the National Arboretum (96.20%), followed by Millennium Park (95.83%), City Park (91.18%), Zone 6 Neighbourhood (90.20%), and Julius Berger Neighbourhood Park (80.00%). The Jabi Recreational Park and Garden and Harrow and Lobito Cr Park are moderately protected by 50.00% and 55.56% respectively.

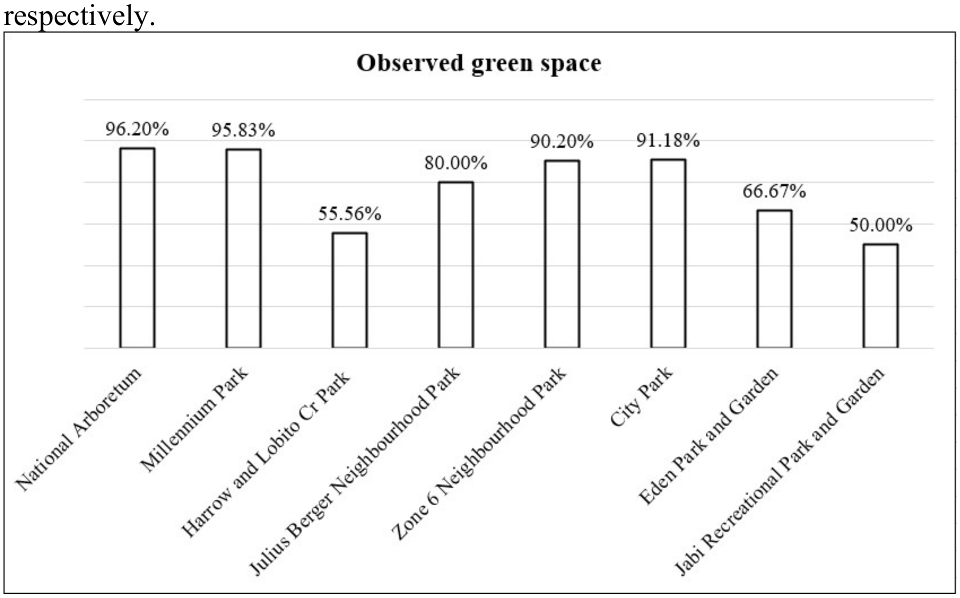

Figure 5. The observed green space within individual parks and gardens.

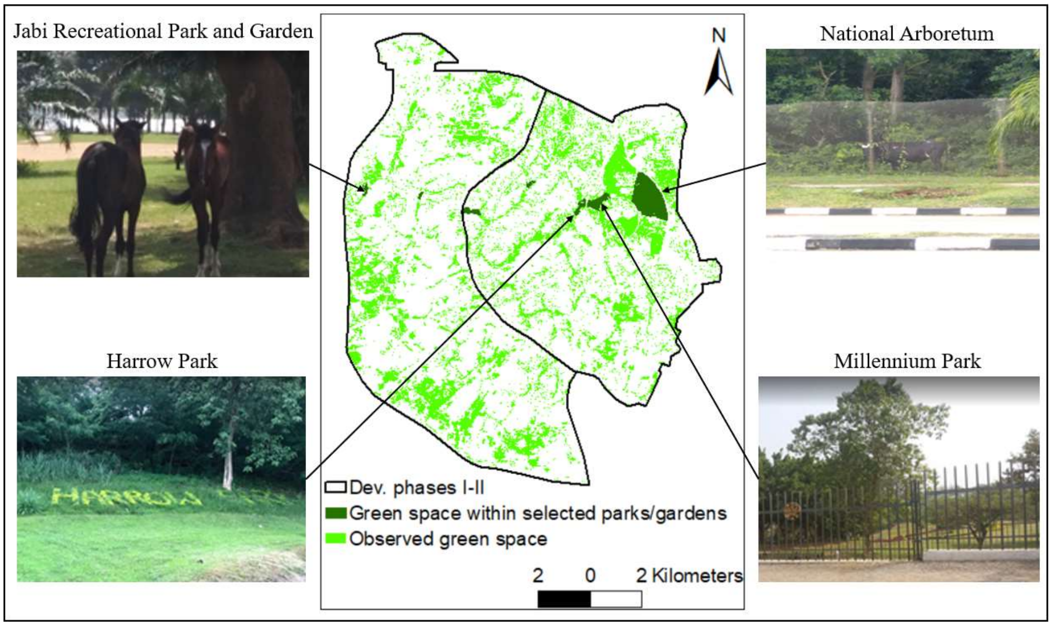

Figure 6. Map showing individual parks and gardens.

4. Discussion

This study provides the first comprehensive geospatial assessments of urban green space protection, including parks and gardens, found within the implemented urban planned areas to support urban strategic actions such as urban policies, planning, and programs for urban environmental sustainability in Abuja, Nigeria.

4.1. Findings

The findings on the level of urban green space protection (Figures 5 and 6) indicate that five parks/gardens are highly protected, including the National Arboretum, Millennium Park, City Park, Julius Berger Neighbourhood Park, and Zone 6 Neighbourhood Park. This indicates an effective urban planning implementation for the protection of urban green infrastructures in those parks and gardens. This result differs from those of Narh et al. (2020) who opined on the degradation of greeneries in parks and gardens of Kumasi, Ghana. Other parks/gardens e.g., the Jabi Recreational Park and Garden, Harrow and Lobito Cr Park, and Eden Park and Garden are moderately protected, indicating an intervention to improve their protection and prevent the urban green infrastructures from degradation. This finding is similar to the report from Narh et al. (2020) who opined that interventions are required to stop the degradation of urban greeneries in parks and gardens of Kumasi, Ghana.

The findings on the association between the observed urban green space and that of the urban plan for different urban development phases (Table 3 and Figure 4) show positive and significant associations in both phases I and II. This indicates a high level of urban planning implementation on urban green infrastructures in the study area. This result is similar to the report from Liu et al. (2022) who opined that greening policies are positively associated with urban green space spatial patterns in Shanghai and Xuchang urban areas in China.

Furthermore, the findings on spatial patterns of urban green space and the comparison to those designated by the urban plan (Tables 1 and 2 and Figure 3) show that while the green space covers about 23.33% of the study area, land use designated for urban green space by the urban plan covers about 20.48%. This indicates that the observed green space is above the urban planning target within the study area. However, while the protection is above the urban planning target in phase I, it is below the target in phase II (Table 2). This could be due to the encroachments of urban developments into land use designated for urban green spaces as reported by Zakka et al. (2017); Enoguanbhor (2021), resulting from challenges facing urban planning, including lack of good coordination, lack of political will, and insufficient funding (Enoguanbhor et al., 2021).

4.2. Implications of the findings

An important implication of the findings is the clarification that implementations of urban strategic actions for the protection of urban green infrastructures in parks and gardens found within the implemented urban planned areas are still effective to a large extent, despite the encroachments of urban developments into urban green spaces in Abuja as reported by Zakka et al. (2017) and Enoguanbhor (2021). Urban development may be encroaching into urban green spaces but without a direct comparison with the plan, it is difficult to ascertain whether the encroached green spaces were initially reserved for urban green infrastructures or not by the urban plan. The encroachments of urban development into land use designated for urban green space by the urban plan can be prevented with strict implementation of the urban plan on urban green infrastructures. Considering the high-level protection of five out of eight parks/gardens and the positive association between the general observed urban green spaces and those designated by the urban plan show the effectiveness of urban plan implementation on urban green infrastructures. A similar situation may be the case in other Sub-Saharan African cities and across other parts of the Global South if a direct comparison is conducted between the observed urban green space and those designated by the urban plan, particularly within the implemented urban planned areas. This shows that with effective implementation of the urban plan on urban green space protection, there are possibilities for sustaining various services/functions provided by urban green infrastructures, including environmental functions (Nassary et al., 2022; Zhang et al., 2022; Esmail et al., 2022; Shah et al., 2021; Masoudi et al., 2021; Misiune et al., 2021; Park et al., 2021; Song et al., 2020; Emechebe & Eze, 2019; Li et al., 2021; Abass et al., 2020; Cheng et al., 2021; Vargas-Hernández et al., 2018), socio-psychological services (Dipeolu et al., 2021; Zhu et al., 2021; Park et al., 2021; Vargas-Hernández et al., 2018), economic services (Zhang et al., 2022; Park et al., 2021; Kingsley et al., 2021; Vannozzi Brito & Borelli, 2020), and cultural services (Wang, 2022; Park et al., 2021; Puchol-Salort et al., 2021; Vargas-Hernández et al., 2018; Egerer et al., 2019).

Another implication of the current study is the need for effective monitoring of the implementation of the strategic urban policies, planning, and programs on urban green space protection at all levels of urban development phases, especially in phase II to ensure the achievement of urban planning targets on urban green infrastructures. While considering the entire scale of the study area, the observed urban green spaces are above the urban planning targets, but in phase II, they are below the urban planning targets. Also, the moderate protection of three out of eight parks/gardens shows the need to improve the implementation of urban planning on urban green infrastructures in those parks/gardens. Improving the implementation of urban planning would help to sustain various services/functions provided by urban green infrastructures in those parks/gardens. For effective implementation of the urban plan on urban green infrastructures and monitoring, such spatial information is crucial for decision-makers in strategic urban actions, including urban policies, planning, and programs for protecting the existing and creating new urban green infrastructures for urban environmental sustainability.

The general implication of the current study is the combination of the applied methodological approach of direct comparison between the observed urban green spaces and those designated by the urban plan, particularly in the implemented urban planned areas. The results obtained from the various combined methods (e.g., the comparative and association analyses of the observed urban green space and the plan, as well as the protection levels of various parks/gardens) show the effectiveness of urban green space protection in the context of urban planning, opposing the general views from several urban scholars (e.g., Puplampu & Boafo, 2021; Abass et al., 2020; Narh et al., 2020; Enoguanbhor, 2021; Mahmoud et al., 2016; Dinda et al., 2021) who opined that urban green space/vegetation undergo degradation despite the implementation of urban planning as an urban strategic action.

By applying the combined methods to obtain new findings, this paper provides new insights into the effectiveness of urban planning implementation on urban green space protection, particularly within the implemented urban planned areas, which can be used to justify the effectiveness beyond the case study to other cities found in Sub-Saharan Africa and other parts of the Global South. Thus, this paper contributes to urban planning as a strategic instrument for providing and protecting urban green infrastructures and improving urban environmental sustainability.

4.3. Limitations and recommendations

This study is limited by the number of parks/gardens analyzed due to the lack of data on other parks/gardens in the study area. However, the analysis of eight parks/gardens in this study can be used to guide certain decisions regarding the protection of other parks/gardens that were not analyzed. Another limitation of the study can be attributed to the pixel classification error of the remotely sensed data. Although the classification accuracy assessments of the green space land cover type are high, the inability to obtain 100% accuracies indicates some misclassifications of land cover types, which may have little impact on the results. Furthermore, the urban plan used for this study was last revised (particularly phase I) in 2008 (Abubakar, 2014) and was reproduced in 2011 (Fola Consult Ltd, 2011), indicating some changes that might have occurred and were accepted by urban planners but were not updated on the plan and this may have some impact on the results. For example, it was not all identified parks and gardens are represented in the plan.

Based on the findings and the limitations of this study, the following recommendations are put forward: First, there should be continuous effective monitoring of the urban planning implementations on urban green space protection to improve the protection of those individual parks/gardens that require urgent interventions to attain and sustain the urban planning target on the protection. Second, the urban plan should be revised with detailed information on all urban green infrastructures, including the individual parks/gardens, especially on all accepted changes that have occurred over the decades. This would make it easier to identify all urban green infrastructures on the plan and compare them to a real-world situation. Finally, future research should be conducted using the revised urban plan and if possible, a higher spatial resolution of satellite data for spatial and temporal assessments of the protection of urban green infrastructures, including the parks/gardens that were not investigated in this study.

5. Conclusions

This study presented geospatial assessments of urban green space protection, including parks and gardens found within the implemented urban planned areas to support urban strategic actions such as urban policies, planning, and programs for urban environmental sustainability. The findings showed that the protection of urban green space is above the urban planning target within the study area. Although, while the protection is above the urban planning target in phase I, it is below the target in phase II. The results on the association between the observed green space and that of the urban plan for different urban development phases indicated positive and significant associations in both phases I and II. The study showed a high level of urban green space protection in the National Arboretum, Millennium Park, City Park, Julius Berger Neighborhood Park, and Zone 6 Neighborhood Park. However, the findings suggest additional efforts on implementing strategic urban policies, planning, and programs to improve the protection of other parks/gardens, including the Jabi Recreational Park and Garden, Harrow and Lobito Cr Park, and Eden Park and Garden.

Despite the encroachments of urban developments into urban green spaces as reported by previous studies, this study clarified that implementations of urban strategic actions, including urban policies, planning, and programs for the protection of urban green infrastructures, particularly within the implemented urban planned areas are still effective in Sub-Saharan Africa in particular and which may be the case for other parts of the Global South in general. The various services that are provided by urban green infrastructures, including environmental, socio-psychological, economic, and cultural services as reported by previous studies would be sustained if the urban planning implementation and monitoring are maintained or improved effectively. Interventions are, therefore, required to improve the protection of other parks/gardens that are moderately protected.

The combination of various methods e.g., the comparative and association analyses between the observed urban green space and those designated by the urban plan, as well as the protection levels of various parks/gardens as demonstrated by the current study, is crucial to provide new insights into urban green space protection in the context of urban planning implementation. This provides objective information to inform a critical debate on the role and effectiveness of urban planning implementation on urban green infrastructures, particularly within the implemented urban planned areas. Such information can be useful to support the decision-making process in urban strategic actions and to improve urban environmental sustainability in Sub-Saharan Africa and other parts of the Global South. Thus, this paper contributes to urban planning as a strategic instrument, which is used to protect the existing and provide new urban green spaces for urban environmental sustainability. Future research is required for spatial and temporal assessments of the protection of urban green infrastructures (including the parks/garden that were not investigated in this study) using the revised urban plan and higher spatial resolution remotely sensed data.

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References

[1] A. Kwartnik-Pruc and A. Trembecka, "Public Green Space Policy Implementation: A Case Study of Krakow, Poland," *Sustainability,* vol. 13, p. 538, 2021. https://doi.org/10.3390/su13020538

[2] Y. Zhang, J. P. Smith, D. Tong and B. L. Turner II, "Optimizing the co-benefits of food desert and urban heat mitigation through community garden planning," *Landscape and Urban Planning,* vol. 226, p. 104488, 2022. https://doi.org/10.1016/j.landurbplan.2022.104488

[3] M.-I. Stan, "Are public administrations the only ones responsible for organizing the administration of green spaces within the localities? An assessment of the perception of the citizens of Constanța municipality in the context of sustainable development," *Technium Social Sciences Journal,* vol. 31, pp. 58 - 74, 2022. https://doi.org/10.47577/tssj.v31i1.6510

[4] A. Cheshmehzangi, C. Butters, L. Xie and A. Dawodu, "Green infrastructures for urban sustainability: Issues, implications, and solutions for underdeveloped areas," *Urban Forestry & Urban Greening,* vol. 59, p. 127028, 2021. https://doi.org/10.1016/j.ufug.2021.127028

[5] V. Kuklina, O. Sizov and F. Fedorov, "Green spaces as an indicator of urban sustainability in the Arctic cities: Case of Nadym," *Polar Science,* vol. 29, p. 100672, 2021. https://doi.org/10.1016/j.polar.2021.100672

[6] P. Puchol-Salort, J. O'Keeffe, M. van Reeuwijk a and A. Mijic, "An urban planning sustainability framework: Systems approach to blue green urban design," *Sustainable Cities and Society,* vol. 66, p. 102677, 2021. https://doi.org/10.1016/j.scs.2020.102677

[7] E. Gelan and Y. Girma, "Urban green infrastructure accessibility for the achievement of SDG 11 in rapidly urbanizing cities of Ethiopia," *GeoJournal,* 2021. https://doi.org/10.1007/s10708-021-10404-7

[8] A. Russo and G. T. Cirella, "Edible Green Infrastructure for Urban Regeneration and Food Security: Case Studies from the Campania Region," *Agriculture,* vol. 10, p. 358, 2020. http://dx.doi.org/10.3390/agriculture10080358

[9] S. N. Narh, S. A. Takyi, M. O. Asibey and O. Amponsah, "Garden city without parks: an assessment of the availability and conditions of parks in Kumasi," *Urban Forestry & Urban Greening,* vol. 55, p. 126819, 2020. https://doi.org/10.1016/j.ufug.2020.126819

[10] J. V. Meijering, H. Tobi and K. Kern, "Defining and measuring urban sustainability in Europe: A Delphi study on identifying its most relevant components," *Ecological Indicators,* vol. 90, p. 38–46, 2018. https://doi.org/10.1016/j.ecolind.2018.02.055

[11] A. Shah, A. Garg and V. Mishra, "Quantifying the local cooling effects of urban green spaces: Evidence from Bengaluru, India," *Landscape and Urban Planning,* vol. 209, p. 104043, 2021. https://doi.org/10.1016/j.landurbplan.2021.104043

[12] M. Masoudi, P. Y. Tan and M. Fadaei, "The effects of land use on spatial pattern of urban green spaces and their cooling ability," *Urban Climate,* vol. 35, p. 100743, 2021. https://doi.org/10.1016/j.uclim.2020.100743

[13] I. Misiune, J. P. Julian and D. Veteikis, "Pull and push factors for use of urban green spaces and priorities for their ecosystem services: Case study of Vilnius, Lithuania,"

Urban Forestry & Urban Greening, vol. 58, p. 126899, 2021. https://doi.org/10.1016/j.ufug.2020.126899

[14] M. S. Park, S. Shin and H. Lee, "Media frames on urban greening in the Democratic People's Republic of Korea," *Forest Policy and Economics,* vol. 124, p. 102394, 2021. https://doi.org/10.1016/j.forpol.2020.102394

[15] P. Song, G. Kim, A. Mayer, R. He and G. Tian, "Assessing the Ecosystem Services of Various Types of Urban Green Spaces Based on i-Tree Eco," *Sustainability,* vol. 12, p. 1630, 2020. https://doi.org/10.3390/su12041630

[16] L. C. Emechebe and C. J. Eze, "Integration of Sustainable Urban Green Space in Reducing Thermal Heat in Residential Area in Abuja," *Environmental Technology & Science Journal,* vol. 10, pp. 24-32, 2019. http://repository.futminna.edu.ng:8080/jspui/handle/123456789/6826

[17] C. Li, M. Liu, Y. Hu, R. Zhou, W. Wu and N. Huang, "Evaluating the runoff storage supply-demand structure of green infrastructure for urban flood management," *Journal of Cleaner Production,* vol. 280, p. 124420, 2021. https://doi.org/10.1016/j.jclepro.2020.124420

[18] K. Abass, D. Buor, K. Afriyie, G. Dumedah, A. Y. Segbefi, L. Guodaar, E. K. Garsonu, S. Adu-Gyamfi, D. Forkuor, A. Ofosu, A. Mohammed and R. M. Gyasi, "Urban sprawl and green space depletion: Implications for flood incidence in Kumasi, Ghana," *International Journal of Disaster Risk Reduction,* vol. 51, p. 101915, 2020. https://doi.org/10.1016/j.ijdrr.2020.101915

[19] J. G. Vargas-Hernández, K. Pallagst and J. Zdunek-Wielgołaska, "Urban Green Spaces as a Component of an Ecosystem," in *Handbook of Engaged Sustainability*, S. Dhiman and J. Marques, Eds., Springer, Cham., 2018, pp. 1-32.

[20] E. K. Nassary, B. H. Msomba, W. E. Masele, P. M. Ndaki and C. A. Kahangwa, "Exploring urban green packages as part of Nature-based Solutions for climate change adaptation measures in rapidly growing cities of the Global South," *Journal of Environmental Management,* vol. 310, p. 114786, 2022. https://doi.org/10.1016/j.jenvman.2022.114786

[21] Y. D. Cheng, J. R. Farmer, S. L. Dickinson, S. M. Robeson, B. C. Fischer and H. L. Reynolds, "Climate change impacts and urban green space adaptation efforts: Evidence from U.S. municipal parks and recreation departments," *Urban Climate,* vol. 39, p. 100962, 2021. https://doi.org/10.1016/j.uclim.2021.100962

[22] A. A. Dipeolu, E. O. Ibem, J. A. Fadamiro, S. S. Omoniyi and R. O. Aluko, "Influence of green infrastructure on residents' self-perceived health benefits in Lagos metropolis, Nigeria," *Cities,* vol. 118, p. 103378, 2021. https://doi.org/10.1016/j.cities.2021.103378

[23] X. Zhu, M. Gao, R. Zhang and B. Zhang, "Quantifying emotional differences in urban green spaces extracted from photos on social networking sites: a study of 34 parks in three cities in northern China," *Urban Forestry & Urban Greening,* vol. 62, p. 127133, 2021. https://doi.org/10.1016/j.ufug.2021.127133

[24] B. W. Sulistyo, Antariksa, Surjono and L. Hakim, "The Cultural Meaning Effect to Functional Vitality of a Historical Site was Developed into Urban Public Green Open Space," *Technium Social Sciences Journal,* vol. 14, pp. 688-694, 2020. https://techniumscience.com/index.php/socialsciences/article/view/2188

[25] J. Kingsley, M. Egerer, S. Nuttman, L. Keniger, P. Pettitt, N. Frantzeskaki, T. Gray, A. Ossola, B. Lin, A. Bailey, D. Tracey, S. Barron and P. Marsh, "Urban agriculture as a nature-based solution to address socio-ecological challenges in Australian cities," *Urban Forestry & Urban Greening,* vol. 60, p. 127059, 2021. https://doi.org/10.1016/j.ufug.2021.127059

[26] V. Vannozzi Brito and S. Borelli, "Urban food forestry and its role to increase food security: A Brazilian overview and its potentialities," *Urban Forestry & Urban Greening,* vol. 56, p. 126835, 2020. https://doi.org/10.1016/j.ufug.2020.126835

[27] B. Wang, "Comprehensive evaluation of urban garden afforestation based on PLS-SEM path," *Physics and Chemistry of the Earth,* vol. 126, p. 103150, 2022. https://doi.org/10.1016/j.pce.2022.103150

[28] M. Egerer, C. Ordóñez, B. B. Lin and D. Kendal, "Multicultural gardeners and park users benefit from and attach diverse values to urban nature spaces," *Urban Forestry & Urban Greening,* vol. 46, p. 126445, 2019. https://doi.org/10.1016/j.ufug.2019.126445

[29] I. U. Jibril, "Planning and Land Administration Challenges in Developing New Cities:- The Abuja Experience in Nigeria," Sofia, 2015.

[30] I. U. Jibril, "The Return of the Greens in Abuja, Nigeria's New Capital City," Sydney, 2010.

[31] O. E. Ogunyombo and D. Odunlami, "Exploring the Awareness-Perception Profile of Operation Green Lagos Campaign in Lagos, Nigeria," *Covenant Journal Communication (CJOC),* vol. 4, no. 2, p. 33-54, 2017. https://journals.covenantuniversity.edu.ng/index.php/cjoc/article/view/758

[32] S. D. Zakka, A. S. Permana, M. R. Majid, A. Danladia and P. E. Bako, "Urban Greenery a pathway to Environmental Sustainability in Sub Saharan Africa: A Case of Northern Nigerian Cities," *International Journal of Built Environment and Sustainability,* vol. 4, pp. 180-189, 2017. https://doi.org/10.11113/ijbes.v4.n3.211

[33] E. C. Enoguanbhor, F. Gollnow, J. O. Nielsen, T. Lakes and B. B. Walker, "Land Cover Change in the Abuja City-Region, Nigeria: Integrating GIS and Remotely Sensed Data to Support Land Use Planning," *Sustainability,* vol. 11, no. 5, p. 1313, 2019. https://doi.org/10.3390/su11051313

[34] M. I. Mahmoud, A. Duker, C. Conra, M. Thiel and H. S. Ahma, "Analysis of Settlement Expansion and Urban Growth Modelling Using Geoinformation for Assessing Potential Impacts of Urbanization on Climate in Abuja City, Nigeria," *Remote Sensing,* vol. 8, no. 3, p. 220, 2016. https://doi.org/10.3390/rs8030220

[35] O. O. Tope-Ajayi, O. H. Adedeji, C. O. Adeofun and S. O. Awokola, "Land Use Change Assessment, Prediction Using Remote Sensing, and GIS Aided Markov Chain Modelling at Eleyele Wetland Area, Nigeria," *Journal of Settlements and Spatial Planning,* vol. 7, no. 1, pp. 51-63, 2016. https://doi.org/10.19188/06JSSP012016

[36] M. A. Ade and Y. D. Afolabi, "Monitoring urban sprawl in the Federal Capital Territory of Nigeria using Remote Sensing and GIS techniques," *Ethiopian Journal of Environmental Studies and Management,* vol. 6, pp. 82-95, 2013. http://dx.doi.org/10.4314/ejesm.v6i1.10

[37] E. C. Enoguanbhor, Urban land dynamics in the Abuja city-region, Nigeria: integrating GIS, remotely sensed, and survey-based data to support land use planning, Berlin: Humboldt-Universität zu Berlin, 2021. https://doi.org/10.18452/23620

[38] S. Matemilola, O. H. Adedeji and E. C. Enoguanbhor, "Land Use/Land Cover Change in Petroleum-Producing Regions of Nigeria," in *The Political Ecology of Oil and Gas Activities in the Nigerian Aquatic Ecosystem*, P. E. Ndimele, Ed., Elsevier, 2018, pp. 257-276. https://doi.org/10.1016/B978-0-12-809399-3.00017-3

[39] C. Munyati and J. H. Drummond, "Loss of urban green spaces in Mafikeng, South Africa," *World Development Perspectives,* vol. 19, p. 100226, 2020. https://doi.org/10.1016/j.wdp.2020.100226

[40] D. A. Puplampu and Y. A. Boafo, "Exploring the impacts of urban expansion on green spaces availability and delivery of ecosystem services in Accra metropolis," *Environmental Challenges,* vol. 5, p. 100283, 2021. https://doi.org/10.1016/j.envc.2021.100283

[41] A. Mohamed and H. Worku, "Simulating urban land use and cover dynamics using cellular automata and Markov chain approach in Addis Ababa and the surrounding," *Urban Climate,* vol. 31, p. 100545, 2020. https://doi.org/10.1016/j.uclim.2019.100545

[42] T. Kabanda, "Land use/cover changes and prediction of Dodoma, Tanzania," *African Journal of Science, Technology, Innovation and Development,* vol. 11, no. 1, p. 55–60, 2019. https://doi.org/10.1080/20421338.2018.1550925

[43] S. Arshad, S. R. Ahmad, S. Abbas, A. Asharf, N. A. Siddiqui and Z. u. Islam, "Quantifying the contribution of diminishing green spaces and urban sprawl to urban heat island effect in a rapidly urbanizing metropolitan city of Pakistan," *Land Use Policy,* vol. 113, p. 105874, 2022. https://doi.org/10.1016/j.landusepol.2021.105874

[44] S. Dinda, N. D. Chatterjee and S. Ghosh, "An integrated simulation approach to the assessment of urban growth pattern and loss in urban green space in Kolkata, India: A GIS-based analysis," *Ecological Indicators,* vol. 121, p. 107178, 2021. https://doi.org/10.1016/j.ecolind.2020.107178

[45] E. C. Enoguanbhor, F. Gollnow, B. B. Walker, J. O. Nielsen and T. Lakes, "Simulating Urban Land Expansion in the Context of Land Use Planning in the Abuja City-Region, Nigeria," *GeoJournal,* 2022. https://doi.org/10.1007/s10708-020-10317-x

[46] I. A. Gumel, P. Aplin, C. G. Marston and J. Morley, "Time-Series Satellite Imagery Demonstrates the Progressive Failure of a City Master Plan to Control Urbanization in Abuja, Nigeria," *Remote Sensing,* vol. 12, p. 1112, 2020. https://doi.org/10.3390/rs12071112

[47] O. Adama, "Abuja is not for the poor: Street vending and the politics of public space," *Geoforum,* vol. 109, p. 14–23, 2020. https://doi.org/10.1016/j.geoforum.2019.12.012

[48] I. Sufiyan, A. M. Buhari, U. S. Abubakar and A. Y. Ubangari, "An Overview of the Functions of Abuja Geographic Information System (AGIS) As a Tool for Monitoring Growth and Development in Abuja Nigeria," *Journal of Environmental Science, Toxicology and Food Technology,* vol. 9, pp. 17-24, 2015.

[49] I. R. Abubakar, "Abuja city profile," *Cities,* vol. 41, p. 81–91, 2014. https://doi.org/10.1016/j.cities.2014.05.008

[50] S. Ejaro and A. Abubakar, “The challenges of rapid urbanization on sustainable development of Nyanya, Federal Capital Territory, Abuja, Nigeria,” *Journal of Applied Sciences and Environmental Management,* vol. 17, pp. 299-313, 2013. http://dx.doi.org/10.4314/jasem.v17i2.13

[51] M. A. Idoko and F. E. Bisong, “Application of Geo-Information for Evaluation of Land Use Change: A Case Study of Federal Capital Territory-Abuja,” *Environmental Research Journal,* vol. 4, no. 1, pp. 140-144, 2010. http://dx.doi.org/10.3923/erj.2010.140.144

[52] FMITI (Federal Ministry of Industry, Trade and Investment). “Resettlement and social audit: Abuja technology village project,” FMITI, Abuja, 2015.

[53] Fola Consult Ltd, *Federal Capital City: revised land use plan - 2011 phases I, II & III,* Abuja: Federal Capita Development Authority, 2011.

[54] AS&P (Albert Speer & Partner GmbH) and D. Elsworth, “Federal Capital City of Abuja: Review of the Abuja Master Plan - Master Plan for Abuja North Phase IV- West/Structure Plan for Abuja North Phase IV-East Urban Area,” AS&P - Albert Speer & Partner GmbH, Frankfurt am Main, 2008.

[55] NBS (Nigerian Bureau of Statistics), “Population, 2006-2016,” NBS, Abuja, 2016.

[56] S. A. Mashi and H. S. Shuaibu, “People and sustainable land management: assessment of stakeholders knowledge of the nature of landuse/cover change in Abuja, Nigeria,” *GeoJournal,* vol. 83, p. 545–562, 2018. https://doi.org/10.1007/s10708-017-9782-y

[57] ESA (European Space Agency), “Copernicus Open Access Hub,” 2021. [Online]. Available: https://scihub.copernicus.eu/dhus/#/home [Accessed 10 07 2021].

[58] J. B. Campbell and R. H. Wynne, Introduction to Remote Sensing, Fifth ed., New York: The Guilford Press, 2011.

[59] D. Lu, Q. Weng, E. Moran, G. Li and S. Hetrick, “Remote Sensing Image Classification,” in *Advances in Environmental Remote Sensing: Sensors, Algorithms, and Applications*, Q. Weng, Ed., Boca Raton, Tailor & Francis Group, 2011, pp. 219-240.

[60] B. Tso and P. M. Mather, Classification methods for remotely sensed data, Second, Ed., Boca Raton: CRC Press, 2009.

[61] C. Kwan, D. Gribben, B. Ayhan, J. Li, S. Bernabe and A. Plaza, “An Accurate Vegetation and Non-Vegetation Differentiation Approach Based on Land Cover Classification,” *Remote Sensing,* vol. 12, p. 3880, 2020. https://doi.org/10.3390/rs12233880

[62] P. Olofsson, G. M. Foody, M. Herold, S. V. Stehman, C. E. Woodcock and M. A. Wulder, “Good practices for estimating area and assessing accuracy of land change,” *Remote Sensing of Environment,* vol. 148, p. 42–57, 2014. https://doi.org/10.1016/j.rse.2014.02.015

[63] E. C. Enoguanbhor, F. Gollnow, B. B. Walker, J. O. Nielsen and T. Lakes, “Key Challenges for Land Use Planning and its Environmental Assessments in the Abuja City-Region, Nigeria,” *Land,* vol. 10, no. 5, p. 443, 2021. https://doi.org/10.3390/land10050443

[64] C. Fotang, U. Bröring, C. Roos, E. C. Enoguanbhor, P. Dutton, L. R. D. Tédonzong, J. Willie, Y. G. Yuh and K. Birkhofer, “Environmental and anthropogenic effects on the nesting patterns of Nigeria–Cameroon chimpanzees in North-West Cameroon,” *American Journal of Primatology,* 2021. http://doi.org/10.1002/ajp.23312

[65] P. T. Yenisetty and P. Bahadure, "Assessing accessibility to ASFs from bus stops using distance measures: Case of two Indian cities," *Land Use Policy,* vol. 108, p. 105567, 2021. https://doi.org/10.1016/j.landusepol.2021.105567

[66] J. Liu, L. Zhang, Q. Zhang, C. Li, G. Zhang and Y. Wang, "Spatiotemporal evolution differences of urban green space: A comparative case study of Shanghai and Xuchang in China," *Land Use Policy,* vol. 112, p. 105824, 2022. https://doi.org/10.1016/j.landusepol.2021.105824

[67] B. A. Esmail, C. Cortinovis, L. Suleiman, C. Albert, D. Geneletti and U. Mörtberg, "Greening cities through urban planning: A literature review on the uptake of concepts and methods in Stockholm," *Urban Forestry & Urban Greening,* vol. 72, p. 127584, 2022. https://doi.org/10.1016/j.ufug.2022.127584