Assessing urban spatial patterns within the implemented urban planned areas using GIS and remote sensing data

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ABSTRACT

In the developing world, including Sub-Saharan Africa, reports have indicated that urban planning as a strategic instrument has not been able to guide urban spatial patterns and this poses challenges to improving urban environmental sustainability. The current study combined a city land use plan, Geographical Information Systems, and remotely sensed data to evaluate urban spatial patterns within areas where the city plan is reported to have been implemented to support strategic actions for urban environmental sustainability. Focusing on Abuja city, Nigeria, the study deployed a supervised classification on Landsat 8 remotely sensed data to analyze spatial patterns of urban land cover types, computed transition change detections and compared the urban impervious surface to the area of land designated for urban development by the city plan. Key findings indicated that the land areas designated for urban development have not been fully developed and the transition from urban green space is the highest transition from other land cover types to urban impervious surface. The baseline information provided in this study is crucial to inform decision-makers on improving and maintaining the implementation of strategic actions for urban environmental sustainability in Sub-Saharan African cities and other parts of the developing world.

Key Words: *Strategic actions, Urban planning, Urban impervious surface, Urban environmental sustainability, Sub-Saharan Africa and Developing world.*

I. Introduction

Urban spatial patterns have not been guided effectively to improve urban environmental sustainability, despite implementing urban planning and policies as strategic actions for urban development in Sub-Saharan Africa and other parts of the developing world. For example, in Abuja, Nigeria, urban spatial patterns deviate from the land use plans (Gumel et al., 2020; Enoguanbhor et al., 2019; Mahmoud et al., 2016; Ade and Afolabi, 2013) and the situation may continue if the problems are not put under control (Enoguanbhor et al., 2021). Similar unguided urban spatial patterns were

reported for other cities in Sub-Saharan Africa, including Benin City, Nigeria (Agheyisi, 2016), Addis Ababa, Ethiopia (Mohamed et al., 2020); Kumasi, Ghana (Cobbinah et al., 2019); Takoradi and Bolgatanga, Ghana (Biney and Boakye, 2021; Kleemann et al. 2017) and Blantyre City, Malawi (Mawenda et al., 2020). Outside Sub-Saharan Africa, deviated urban spatial patterns from urban plans were reported for Hangzhou and suburban Beijing in China (Wu et al., 2017; Liu et al., 2020) and Araraquara City in the State of Sao Paulo, Brazil (Menzori et al., 2021). Previous urban studies (e.g., Lu et al., 2022; Biney and Boakye, 2021; Koko et al., 2021; Gumel et al., 2020; Liu et al., 2020; Enoguanbhor et al., 2019; Kleemann et al., 2017; Mahmoud et al., 2016; Ade and Afolabi, 2013) either did not compare their observed urban spatial patterns with the land use the urban plan proposed for urban development or they compared them beyond the spatial scope (coverage) of such plans. From this point of view, it can be argued that the non-availability of urban plans in those areas not covered by the plans and/or those areas the plans are yet to be implemented can mislead, generalizing the ineffectiveness of urban planning strategies to guide urban spatial patterns.

The current study, therefore, aims to combine a city land use plan, Geographical Information Systems (GIS), and remotely sensed data to evaluate urban spatial patterns within areas where the city plan is reported to have been implemented to support strategies for urban environmental sustainability. To achieve this aim effectively, this study focuses on specific objectives, including:
a) Analyzing spatial patterns of the urban impervious surface and other land cover types;
b) Computing the transition change detection between the urban impervious surface and other land cover types, and
c) Analyzing and comparing the observed urban impervious surface to the area of land designated for urban development phases I-III by the city plan.

II. Materials and Methods
Study area
The study area is the phase I-III urban development in the Federal Capital City (FCC), Abuja, Nigeria (Figure 01), where the city plan is reported to have been implemented (Gumel et al., 2020). The FCC, Abuja city development was divided into four phases that were later extended to five phases and to be implemented sequentially (Gumel et al., 2020; Enoguanbhor et al., 2019). The FCC, Abuja, is located northeast of the Federal Capital Territory (FCT), Abuja, Nigeria (Figure 01).
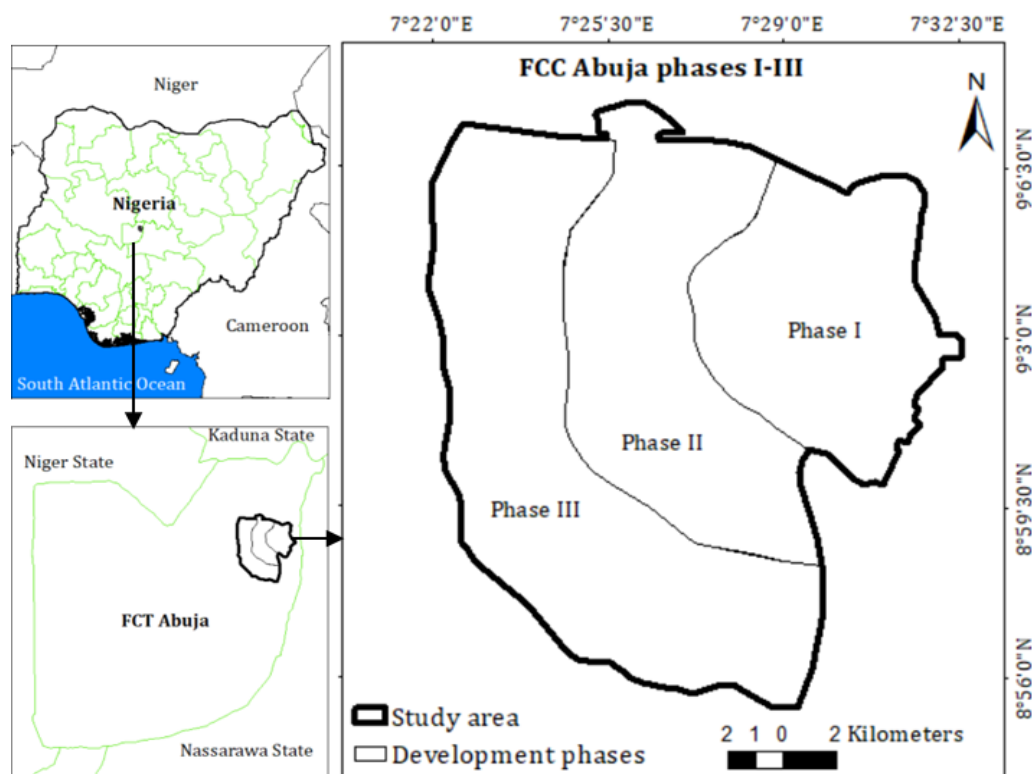

Figure 01. Map of Abuja urban development phases I-III.

The declaration of the FCT, Abuja, in 1976 to develop a new capital city that is free from social and environmental problems associated with the formal capital, Lagos, was followed by the development of urban and regional plans in 1979 (FMITI, 2015; Sufiyan et al., 2015; Abubakar, 2014; Ade and Afolabi, 2013; Ejaro and Abubakar, 2013). The plans were developed by International Planning Association (IPA) to create a functional garden city, preserve the natural environment, including urban green space, improve the accessibility to all areas, rapid national economic growth and others (Enoguanbhor et al., 2022; Jelili et al., 2017; Abubakar, 2014; Fola Consult Ltd 2011; AS&P and Elsworth, 2008;). The city land use plan made provisions for constant and comprehensive reviews every ten years, but only the central area (phase I) was revised in 2008 by Albert Speer & Partner GmbH (Abubakar, 2014), and the plan for phases I-III was reproduced in 2011 by Fola Consult Ltd (Fola Consult Ltd, 2011). The implementation of the urban plan to foster sustainable development started in phase I in the early 1980s before the government seat of power was relocated from Lagos to Abuja in 1991 (Enoguanbhor, 2022; Adama, 2020; Abubakar, 2014; Idoko and Bisong, 2010).

Data collection and analysis
Satellite images captured during West African dry seasons on 02/11/2013 and 09/02/2021 by Landsat 8 (Operational Land Imager) were collected from the United States Geological Survey (USGS) Earth Explorer service (USGS, 2021). The satellite images are 30 m spatial resolution with 11 bands each. The paths/rows of the satellite images are 189/054 and 189/053 for 2013 and 2021, respectively. The reason for collecting this data set is due to the freely accessible data platform and the spatial coverage of the study area. Additionally, we collected the urban land use plan phases I-III from the Department of Urban and Regional Planning, Abuja.

The analysis was performed using ArcGIS version 10.8.1. Supervised classification with a maximum likelihood algorithm was deployed to analyze the spatial patterns of the urban impervious surface and other land cover types (Campbell and Wynne, 2011; Lu et al., 2011; Tso and Mather, 2009). While supervised classification is a process of generating classification training samples using pixels that represent the known geographic features to assign other pixels that represent unknown geographic features to different classes, the maximum likelihood algorithm uses the concept of highest probability to assign pixels to a class of geographic features (Enoguanbhor et al., 2022). The final land cover maps were classified into the urban impervious surface, urban green space, urban bare land/surface and water bodies, as described in Table 01.

Table 01. Urban land cover classes.

Urban land cover types	Description
Urban impervious surface	Buildings, roads, etc.
Urban green space	Urban green infrastructures such as parks, forests, gardens, grasses and street greeneries.
Urban bare land/surface	Bare soil, rocks, etc.
Water bodies	Lakes, rivers, etc.

Accuracy assessments of the classified maps were evaluated by randomly sampling 222 points (Olofsson et al., 2014) and composite Landsat images for 2021 and 2013 were used as referenced data for the assessments. User accuracy (UC), producer accuracy (PA), and overall accuracy (OA) were calculated as described by Enoguanbhor et al. (2019). The accuracy assessments are presented in Table 02.

Table 02. Accuracy assessments.

Urban land cover classes	2021			2013		
	UA	PA	OA	UA	PA	OA
Urban green space	89.8 %	91.4%		88.9%	92.3%	
Urban impervious surface	91.4%	92.4%	90.1%	90.2%	87.3%	88.7 %
Urban bare land/surface	90.0%	83.3%		88.3%	86.9%	
Water bodies	85.0%	94.4%		85.0%	85.0%	

The pixels-based transition change detection was deployed to compute the transition between the urban impervious surface and other land cover types (Enoguanbhor et al., 2019) and was cross-

89

checked through the polygon-based transition method. The observed urban impervious surface in the urban development phases I-III was extracted and calculated for 2013 and 2021. Land areas allocated for urban development by the urban plan for phases I-III were calculated from the urban plan. The calculated areas of the observed urban impervious surface in the urban development area phases I-III were compared to those designated by the urban plan. Figure 02 shows the schematic diagram of research materials and methods adopted for assessing urban spatial patterns under urban plan implementation.
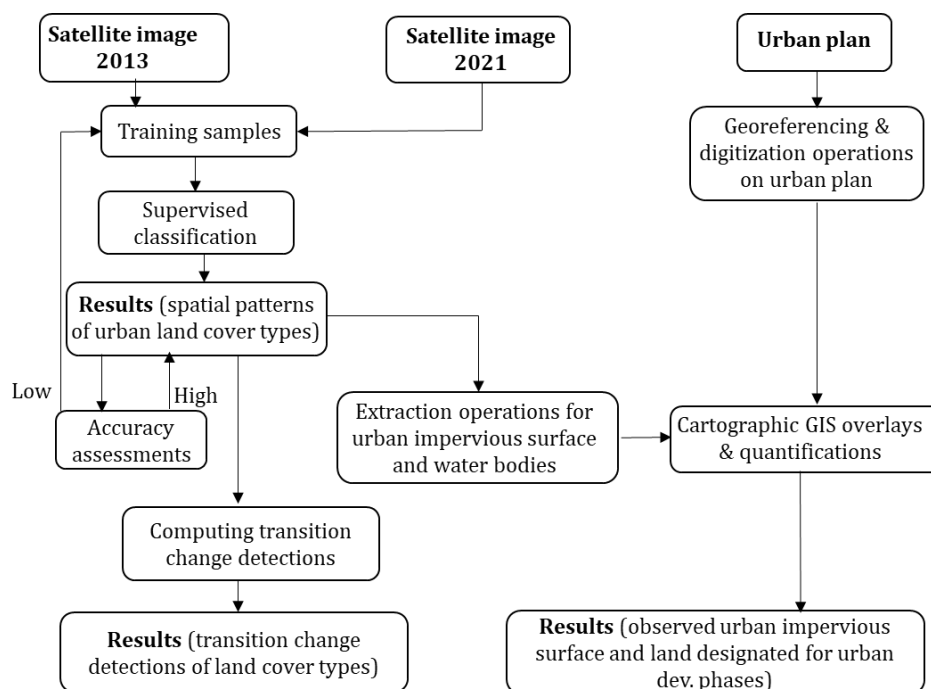
Figure 02. Materials and methods for assessing urban spatial patterns under urban plan implementation.

III. Results

The spatial patterns of urban impervious surface and other land cover types for 2013 and 2021 (Table 03 and Figure 03) showed that the observed urban impervious surface was 29.3% of the total area in 2013 and increased to 48.8% in 2021. The urban impervious surface was majorly distributed in the northeast in 2013. Contrarily, the urban green space was 56.6% in 2013, decreased to 31.6% in 2021 and was majorly distributed in the southwest in 2013. At the same time, urban bare surface increased from 13.7% in 2013 to 19.2% in 2021 and majorly distributed in the southwest in 2021. Water bodies covered 0.4% of the total area during the same period and were majorly distributed in the northwest in 2013 and 2021.

Table 03. Calculated area of urban land cover types in 2013 and 2021.

Urban land cover classes	2013	2021
	Area km² (% of the study area)	Area km² (% of the study area)
Urban green space	175.3 (56.6%)	97.8 (31.6%)
Urban impervious surface	90.8 (29.3%)	151.2 (48.8%)
Urban bare land/surface	42.3 (13.7%)	59.6 (19.2%)
Water bodies	1.3 (0.4%)	1.1 (0.4%)
Total	309.7 (100%)	309.7 (100%)

The results of the transition change detection of the urban impervious surface and other urban land cover types from 2013 to 2021 (Figure 04) showed that the largest transition that occurred between urban impervious surface and other land cover types is urban green space (42.0 km²), followed by urban bare land (29.1 km²). The lowest transition between the urban impervious surface and other land cover types is the transition from water bodies (0.1 km²). No transition from the urban impervious surface to water bodies.
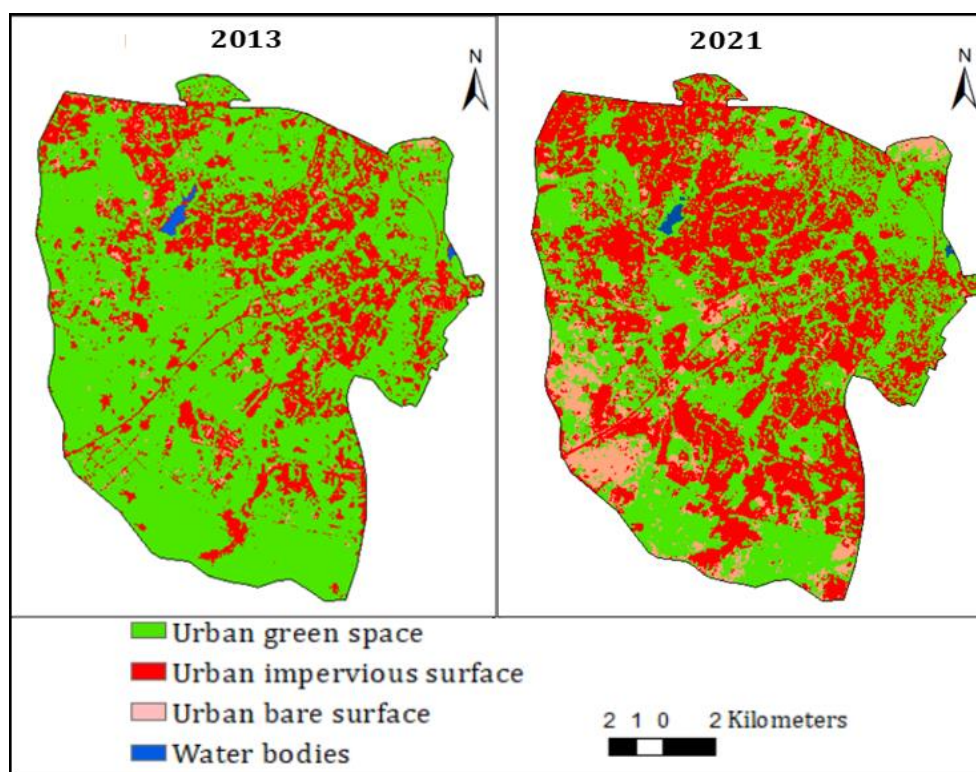
90

Figure 03. Spatial patterns of urban land cover types in 2013 and 2021.

Figures 05 and 06 show the comparison between the observed urban impervious surface and the land area designated for urban development phases I-III by the urban plan and the overlays of the urban impervious surface in 2013 and 2021, respectively. While about 80.7% of the land was designated for development by the urban plan, about 29.3% developed as the urban impervious surface in 2013 and increased to about 48.8% in 2021. In phase I, 20.2% was designated for urban development, but 10.4% and 14.1% of the land were developed as urban impervious surfaces in 2013 and 2021, respectively. In phases II and III, similar development trends were observed as the land designated for urban development are higher than the observed urban impervious surface for 2013 and 2021 (Figure 06).
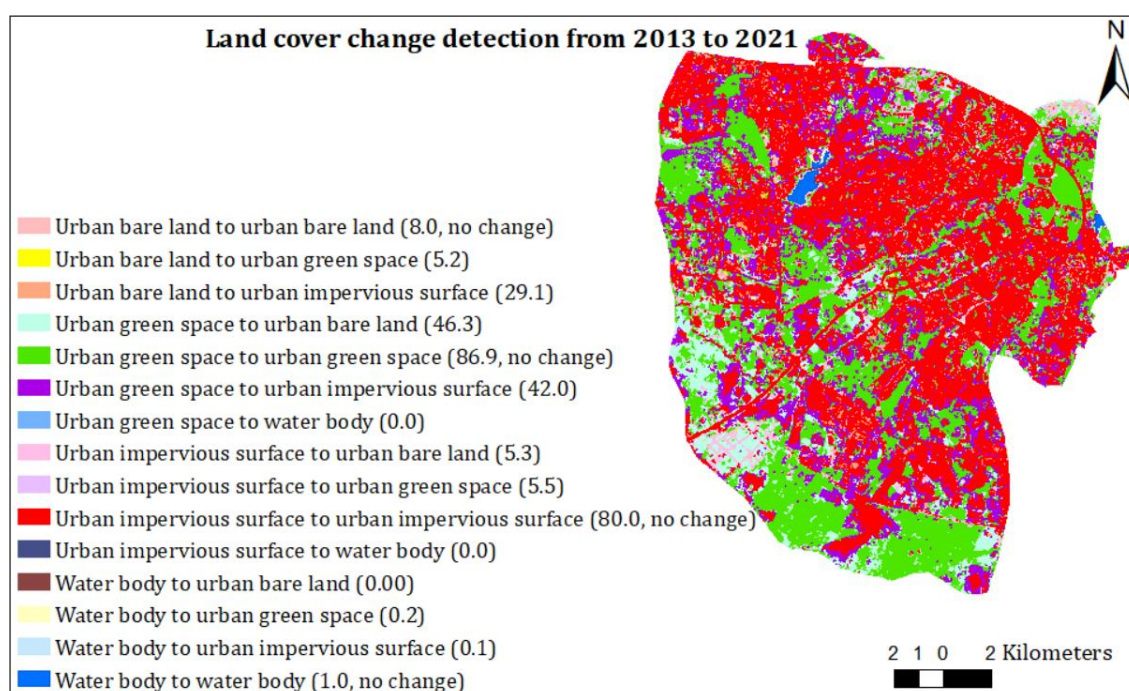

Figure 04. Land cover transition change detection from 2013 to 2021, with transitioned land area, shown in parentheses in km²
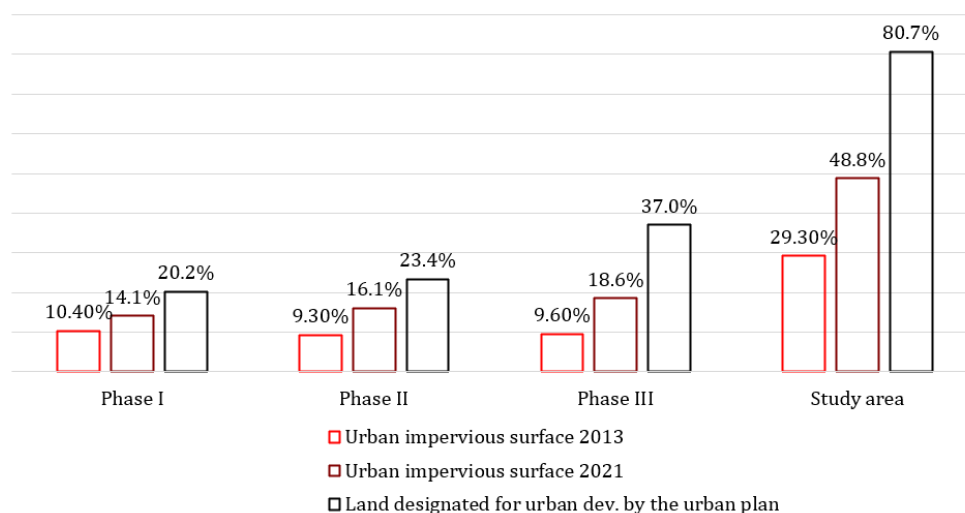
Figure 05. Percentage area of the urban impervious surface land cover and land use proposed for urban development by the city plan.
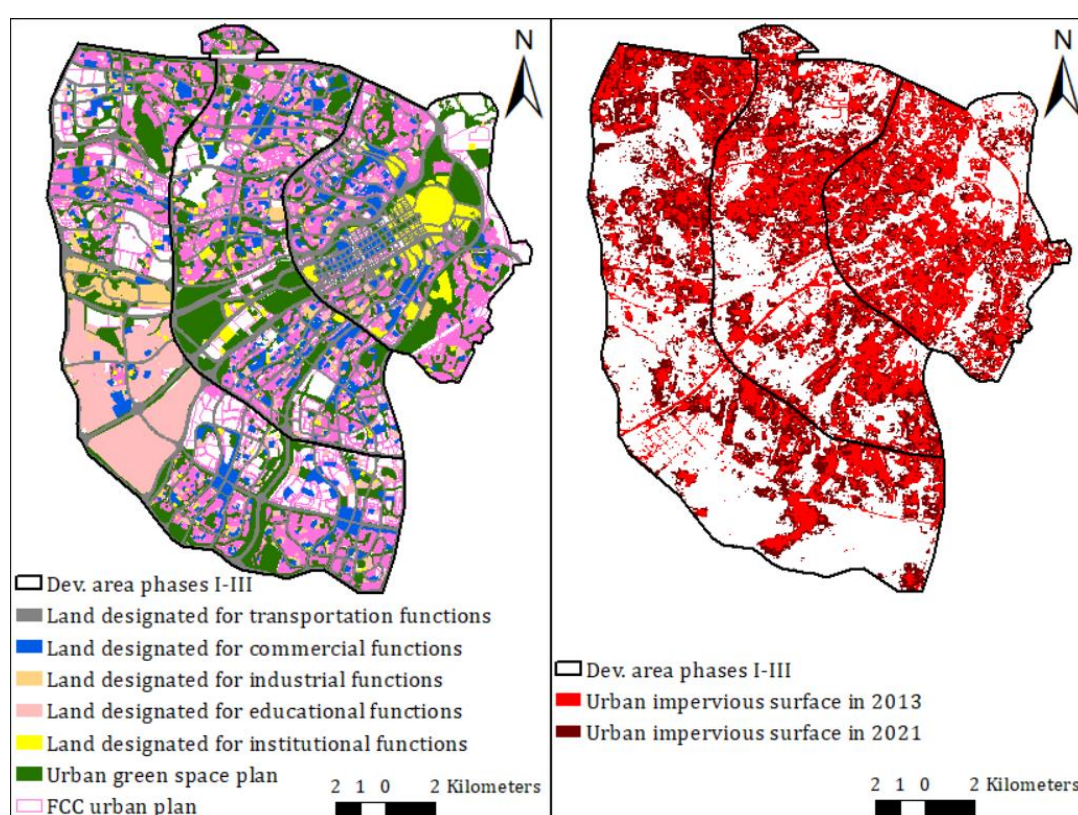

Figure 06. The digitized plan and the overlaid urban impervious surface for 2013 and 2021 for visual comparison.

IV. Discussion

Comparing the land use proposed for urban development and the observed urban impervious surface, the lands for urban development have not been fully developed (Figures 05 and 06). Out of about 80.7% of the land designated for urban development, about 29.3% and 48.8% were covered by the urban impervious surface in 2013 and 2021 respectively (Figure 05). This indicates spaces to guide urban spatial patterns corresponding to the city plan. At the scale of urban development phases, about 20.2%, 23.4%, and 37.0% of lands in phases I, II, and III, respectively, have not been developed. From 2013 to 2021, urban impervious surface increased from 10.4% to 14.1% in phase I, from 9.3% to 16.1% in phase II and from 9.6% to 18.6% in phase III. The results (Table 03 and Figure 03) on spatial patterns of urban land cover types show the increasing urban impervious surface to the detriment of urban green space. This finding is similar to those of Dinda et al. (2021); Koko et al. (2021); Enoguanbhor (2021); Abass et al. (2020); Gumel et al. (2020); Munyati and Drummond (2020); Mohamed and Worku (2020); Kabanda (2019); Akpu et al. (2017); Mahmoud et al. (2016); Tope-Ajayi

92

et al. (2016); Owoeye and Ibitoye (2016); Ade and Afolabi (2013) and Fanan et al. (2011) who observed and opined that urban spatial patterns encroached into vegetation/urban green spaces in their respective study areas across the Global South. Also, the finding is similar to that of La Serena and Concepcion metropolitan cities of Chile (Barrera and Henríquez, 2017) and Rangpur, Rajshahi, Sylhet and Khulna cities of Bangladesh (Hassan, 2017). The results of the transition change detection between the urban impervious surface and other urban land cover types from 2013 to 2021 (Figure 04) showed the largest transition that occurred is urban green space, followed by urban bare land and water bodies. This confirms urban spatial patterns to the detriments of urban vegetation/green spaces. This result aligns with Enoguanbhor et al. (2019) and Mahmoud et al. (2016).

One implication of the current study shows that within implemented urban planned areas, urban spatial patterns have been guided to a large extent (but not effectively) when compared to reports from previous studies (Gumel et al., 2020; Enoguanbhor et al., 2019; Mahmoud et al., 2016; Ade and Afolabi, 2013) that incorporated peri-urban/satellite settlements into their investigations. This shows that when urban planning is implemented fully beyond Abuja city to peri-urban/satellite settlements, the unguided urban spatial patterns in those areas may be reduced to a large extent. Also, the awareness of lands proposed for urban development that have not been fully developed may challenge urban planners and other stakeholders, including developers, to utilize the undeveloped land to contribute to the need for balancing urban spatial growth and the protection of urban greeneries, especially those areas proposed by the city plan. A similar situation may be the case for other Sub-Saharan African cities in particular and other parts of the developing world in general, where city planning is implemented to achieve its central focus of urban sustainability.

The spatial information provided by the current study is crucial to support strategic action decision-making processes in urban development to monitor the city planning implementation towards improving the environmental sustainability of cities. By adopting the combined methods to obtain new findings on the percentage of area covered by the urban impervious surface against the undeveloped land, this paper provides new insights into urban spatial patterns within the implemented urban planned areas and contributes to urban planning as an approach for improving the environmental sustainability of cities.

One limitation of the current study is attributed to some urban impervious surfaces, e.g., buildings, car parks, and footpaths within the land use for urban green spaces, which are not indicated in the plan due to lack of details on the plan. This made distinguishing the legal and illegal urban impervious surface on land designated for urban green spaces was impossible. Also, the city plan (phase 1) was revised in 2008 (Abubakar, 2014) and reproduced (phases I-III) in 2011 (Fola Consult Ltd 2011), indicating some changes that might have occurred in the real world but are not updated on the plan. Such changes may have impacts on the findings. Additionally, the medium spatial resolution (30m) of the remotely sensed data used can be challenging to capture all urban elements, especially at the local scale, and can be associated with classification accuracy problems.

V. Conclusion

The results of the transition change detection indicated that the transition from urban green space is the highest transition between the urban impervious surface and other land cover types. The comparison between the urban impervious surface and land designated for urban development by the urban plan showed that land areas for urban development were not fully developed. The implications of the current study are deduced from urban spatial patterns that have been guided to a large extent but not effectively and the awareness of lands proposed for urban development that have not been fully developed. Creating this awareness is an important step towards balancing the need for outward city growth and protecting city green spaces in Sub-Saharan Africa and other parts of the developing world. By providing new insights into urban spatial patterns within the implemented urban planned areas, particularly the urban impervious surface against the undeveloped land, this study contributes to urban planning as an approach to improving the environmental sustainability of urban areas. The findings provided in this study are crucial to support decision-making processes in city planning for improving the environmental sustainability of cities across Sub-Saharan Africa and other parts of the developing world with similar urban spatial patterns. This is crucial because a well-designed urban

plan is not enough to provide the plan's cultural, social, economic, and environmental objectives if the implementation process is not in line with the plan. Future research should be conducted on assessing urban planning implementation on land use proposed for different urban functions using surveys of experts, the reviewed city plan, and high spatial resolution satellite images.

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