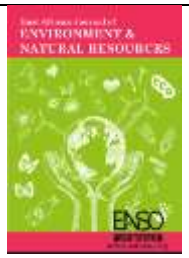

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Original Article

The City-Region Formation Patterns and Urban Spatial Density Using GIS-based Data

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CBD, Network of Settlements, Concentric Zone Model, Regional Development Planning, Sustainable Regional Development, Abuja City-Region.

ABSTRACT

Elucidating the formation of city-regions, which is associated with networks of settlements and their spatial densities is crucial for the spatial distribution or arrangments of regional elements for regional sustainability. The current study, therefore, deployed GIS-based data to evaluate urban spatial density patterns of city-regions' formation to support sustainable regional development planning and policies. Using the Abuja City-Region of Nigeria, the study deployed land cover maps of different temporal boundaries covering the city-region and adopted the concentric zone model of urban spatial patterns to calculate the spatial densities at the regional scale. Key findings showed that the urban spatial density of the city-region declined from Zone 1 to other Zones towards peri-urban of each settlement, except for Zone 5, which increased to Zone 6 from 1987 to 2002. Also, the urban density changes of the concentric zones between different temporal boundaries showed a decline from Zone 1 to Zone 9, except for the increase in change detection between Zone 8 and 9 from 2002 to 2017. The information derived from the current study is of importance to decision-makers in regional development planning and policies on the spatial distribution of regional elements and to reduce or eliminate future urban leapfrogging, especially in land demarcated for environmentally sensitive areas, including forest reserves, productive forestry, and intensive agriculture.

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INTRODUCTION

Urban spatial density, which is the spatial distribution of people or development with regard to the degree of compactness or concentration in a city (Hess, 2014; Krehl et al., 2016; Karimi et al., 2020), may contribute to the formation and spatial patterns of a city-region. A city-region can be seen as the cultural, social, economic, and environmental networks of settlements, where a city serves as the Central Business District (CBD) to the surrounding settlements (Harding et al., 2006; Enoguanbhor et al. 2024a). Investigating the urban spatial density of a city-region to elucidate its formation patterns is crucial to support regional development planning and policies, which in turn contributes to sustainable regional development. In this context, sustainable regional development can be regarded as a condition that allows a systematic distribution of regional elements, including networks of settlements with environmentally friendly, economically viable, and socio-culturally acceptable for current and future generations and within a defined city-region.

The formation and spatial pattern of a city-region can be linked to the formation and spatial pattern of settlements found in the city-region. To analyse and explain the spatial patterns of urban formation, various urban models, including the concentric zone model postulated by Burgess in 1925 have been used. According to the concentric zone model, the use to which urban land is put is organized around the CBD in the form of concentric zones, where each zone has different uses of land with different urban densities that decrease from zone 1 (the CBD) to other zones towards the peri-urban (Xu et al., 2019a). At the regional scale, the concentric zone model can be adopted to investigate and view holistically the spatio-temporal patterns and densities of various settlements to elucidate the formation and pattern of a city-region in relation to the network of settlements that make up the city-region. This enables the identification of a city-region formation process known as urban leapfrogging, which is a situation where vacant lands, suitable for urban development are skipped to develop farther lands from the city centre, often in environmentally sensitive areas demarcated e.g. for forest reserves, productive forestry (Xu et al., 2020; Agyemang & Silva, 2019; Chen et al., 2017; Enoguanbhor et al., 2024b).

In Sub-Saharan African city-regions (e.g., the Abuja City-Region, Nigeria, the Dodoma City-Region, Tanzania, and the Accra City-Region, Ghana), rapid urban expansion led to urban leapfrogging and haphazard spatial patterns (Mohamed et al., 2020; Mohamed & Worku, 2020; Enoguanbhor et al., 2019; Agyemang & Silva, 2019; EO4SD, 2018; Tope-Ajayi et al., 2016). Thus, the low and high urban spatial densities of some networks of settlements in a city-region may have emerged through the city-region formation process of urban leapfrogging characterized by haphazard spatial patterns as urban development tends to expand towards networks of settlements with low urban densities (Yang, 2010). Such a problem associated with a city-region formation can be addressed using regional development planning and policies for

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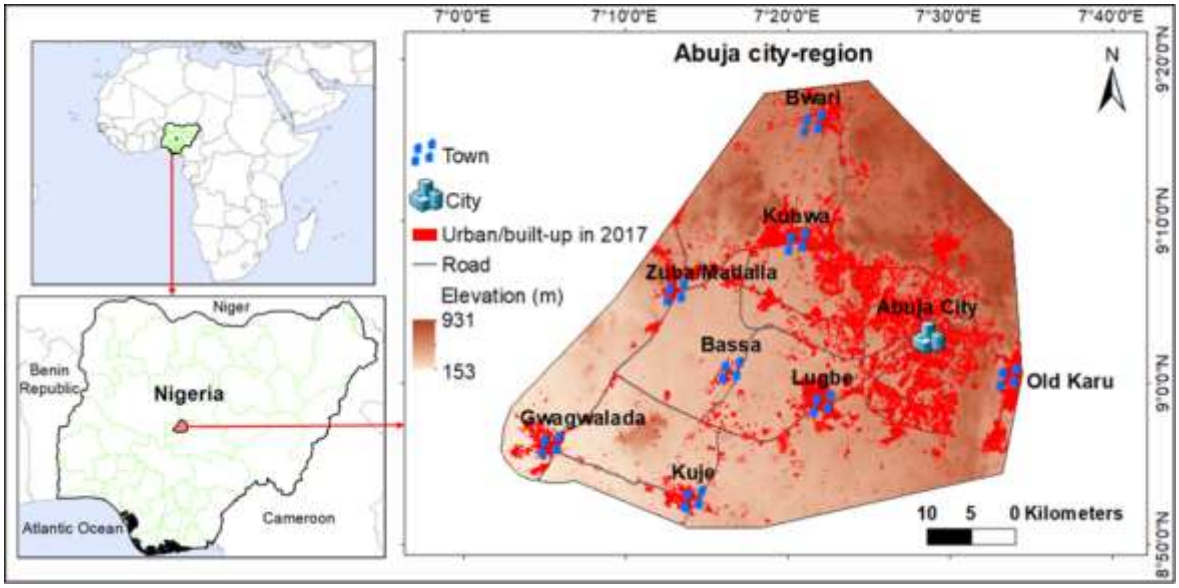
sustainable regional development, especially in Sub-Saharan Africa, including the Abuja City-Region in Nigeria.

The defined Abuja City-Region in Nigeria is made up of the Federal Capital City (FCC), which serves as the CBD of the city-region and the surrounding settlements, including Lugbe, Kubwa, Old-Karu, Bwari, Kuje, Gwagwalada, and Bassa (*Figure 1*). The city-region emerged over time after the declaration of the Federal Capital Territory (FCT) in 1976 (Abubakar, 2014), followed by the development of urban and regional plans in 1979 (Enoguanbhor et al., 2023; Abubakar, 2014; FMITI, 2015; Fola Consult Ltd., 2011; AS&P & Elsworth, 2008), and their implementation that started in the early 1980s before the government seat of power was relocated from Lagos to Abuja in 1991 (Gumel, et al., 2020; Idoko & Bisong, 2010; Adama, 2020; Ejaro & Abubakar, 2013; Sufiyan et al., 2015; Abubakar, 2014). Despite the implementation of the plans at both urban and regional scales, urban leapfrogging occurred e.g., at Lugbe with haphazard development and one of the settlements that formed the city-region (Enoguanbhor et al., 2019). In the Abuja City-Region or other Sub-Saharan African City-Regions, no previous study was conducted on spatial and temporal urban density patterns to elucidate the formation of city regions.

The current study, therefore, aims to use GIS-based data to evaluate urban spatial density patterns of city-region formation to support sustainable regional development planning and policies. The specific objectives include:

- To use the concentric zone model of urban formation to analyze the urban spatial density of the city-region, and;
- To analyze the change in urban spatial density of the concentric zones between different temporal boundaries.

Figure 1: Map showing the location of the Abuja City-Region in Nigeria



Source: Enoguanbhor et al. (2021).

MATERIALS AND METHODS

We collected GIS data on regional land cover types for 1987, 2002, and 2017 of the Abuja City-Region from Enoguanbhor (2021). The maps were produced from remotely sensed images of the Landsat 4 satellite (Thematic Mapper) for 1987, the Landsat 7 satellite (Enhanced Thematic Mapper Plus) for 2002, and the Landsat 8 satellite (Operational Land Image) for 2017 (USGS, 2019). Supervised classification and maximum likelihood algorithm were deployed to produce the maps (Campbell & Wynne, 2011; Lu et al., 2011; Vijayalakshmi et al., 2021; Enoguanbhor et al., 2019; Tso & Mather, 2009; Enoguanbhor et

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al., 2022a) with user and producer accuracies estimated at 91% and 94.8%, respectively for 1987, 88% and 87.8%, respectively for 2002, and 96% and 85.3%, respectively for 2017.

To analyze urban density based on a concentric zone model of urban formation, we extracted urban land cover from the land cover maps for the three boundaries. Also, the CBDs of each settlement in the city-region were digitized as points. Additionally, we generated concentric rings of 1.5 kilometers into nine zones from all CBDs in the city-region. Furthermore, we overlayed the urban land cover maps and the generated concentric rings and calculated urban land in each concentric zone. The density of the urban land in each concentric zone was calculated using the formula:

$$UD = UIS/TA$$

where UD stands for urban density, UIS is the urban impervious surface, and TA is the total area. Lastly, we calculated the urban density change between 1987, 2002, and 2017 for the concentric zones using the formula:

$$UDC = UIS_2 - UIS_1$$

where UDC stands for urban density change, UIS_2 is the latter urban impervious surface, and UIS_1 is the initial urban impervious surface.

RESULTS AND DISCUSSION

The current study investigated and presented urban spatial density patterns of a city-region using the concentric zone model to offer insights into its formation over time and to provide useful information for sustainable regional development planning and policies.

Table 1 and *Figure 2* present the urban spatial density for 1987, 2002, and 2017 based on concentric zones of the Abuja City-Region. Zone 1, which is the CBDs of each settlement with the highest densities is estimated to be 0.155 km^2, 0.538 km^2, and 0.744 km^2 densities for 1987, 2002, and 2017, respectively. The results showed that urban density in the city-region declined from CBDs towards peri-urban of each settlement except for Zone 5, which increased to Zone 6 from 0.004 km^2 to 0.010 km^2 in 1987 and 0.057 km^2 to 0.065 km^2 in 2002. Thus, the lowest urban density is zone 9 with 0.005 km^2, 0.017 km^2, and 0.037 km^2 for 1987, 2002, and 2017, respectively. The findings that show a decline in the urban spatial density of the CBDs of different settlements that make up the city-region to other Zones towards peri-urban (*Table 1*) indicate that a city-region formation is highly similar to and dependent on urban formation patterns. The findings are similar to Xu et al. (2019b) who reported a decrease in urban spatial densities from the city centers towards peri-urban across African cities, including Kairo in Egypt, Lagos and Ibadan in Nigeria, Algers in Algeria, Addis Ababa in Ethiopia, Johannesburg in South Africa, Accra in Ghana, Arusha in Tanzania, and Bamako in Mali. However, from Zone 5 to 6, urban density increased from 0.004 km^2 to 0.010 km^2 in 1987 and 0.057 km^2 to 0.065 km^2 in 2002, indicating a different urban density pattern of the city-region.

Table 1: Urban density for 1987, 2002, and 2017 based on concentric zones.

Concentric Zones	1987 Density in km^2	2002 Density in km^2	2017 Density km^2
Zone 1	0.155	0.538	0.744
Zone 2	0.059	0.233	0.416
Zone 3	0.018	0.132	0.235
Zone 4	0.007	0.082	0.180
Zone 5	0.004	0.057	0.166
Zone 6	0.010	0.065	0.156
Zone 7	0.007	0.048	0.112
Zone 8	0.006	0.031	0.047
Zone 9	0.005	0.017	0.037

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Figure 2: Urban spatial density in km^2 for 1987, 2002, and 2017 based on concentric zones of the Abuja City-Region

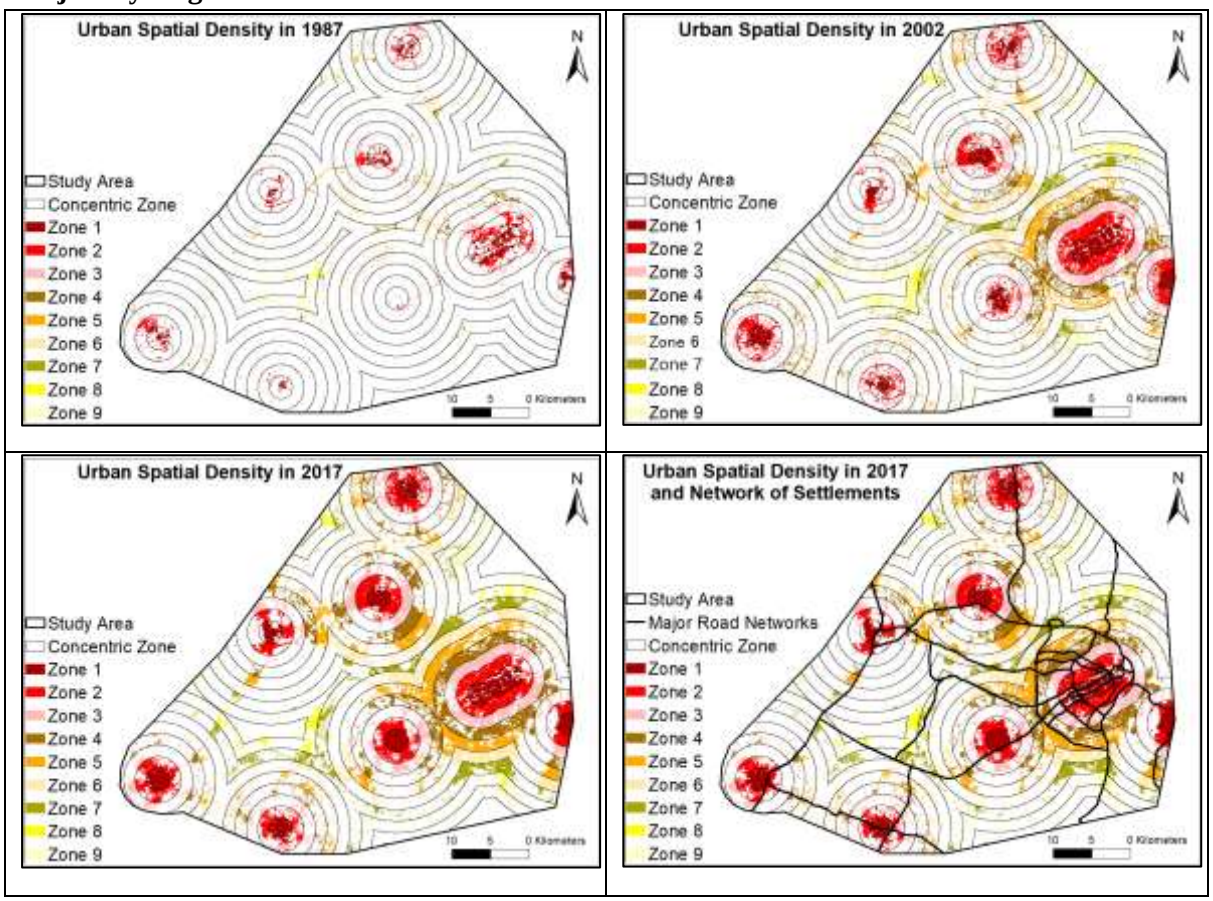

Table 2 presents the city-region density change detection from 1987 to 2002 and from 2002 to 2017. The highest change detection between 1987 and 2002 occurred in Zone 1, followed by between 2002 and 2017 in the same Zone 1. As expected, the change detection declined from Zone 1 to Zone 9, except for the change between Zone 8 to 9 from 2002 to 2017, which increased from 0.016 km^2 to 0.020 km^2. Other important observations are in Zones 1, 3, and 8, where the change detection between 2002 and 2017 is less than the change between 1987 to 2002, indicating a decreased rate of urban densities in those Zones between 2002 and 2017. This result may be associated with insufficient land availability to expand urban impervious surfaces, especially in Zones 1 and 3. Also, the finding may be due to urban spatial patterns based on urban and regional plans that demarcated sufficient lands for urban development with impervious surfaces that fell into other Zones.

Table 2: Urban density change from 1987 to 2002 and from 2002 to 2017 based on concentric zones.

Concentric zones	Density Change (1987 - 2002) in km^2	Density Change (2002 - 2017) in km^2
Zone 1	0.383	0.206
Zone 2	0.174	0.183
Zone 3	0.114	0.103
Zone 4	0.075	0.098
Zone 5	0.053	0.109
Zone 6	0.055	0.091
Zone 7	0.041	0.068
Zone 8	0.025	0.016
Zone 9	0.012	0.020

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The general implication of the study is that the formation of a city-region is similar to the formation of a single urban area with regard to its urban density decreasing from the CBD to the peri-urban areas. However, the urban density patterns that increased from Zone 5 to 6 between 1987 and 2002 (*Table 1*) and the density change detection that increased from Zone 8 to 9 (*Table 2*), indicate that decreasing urban densities from city centers to peri-urban is not always the same for all zones at every given time in all urban areas, especially when urban areas that form a city-region expand and merge with leapfrogged settlements with high densities. This underscores the necessity of proper investigation of urban spatial structure and city-region formation at any given time to reduce or eliminate the current and possible future uncontrolled urban leapfrogging and the associated haphazard urban spatial patterns for sustainable urban and regional development (Enoguanbhor et al., 2022b). By using a concentric zone model initially proposed for a single city development, particularly its spatial density to elucidate the formation of a city-region, this study contributes to urban and regional planning as academic and professional disciplines.

This study is limited by the methodological gap, considering the last temporal boundary is 2017, about seven-year gap from today. Within these seven years, the spatial pattern and density of the city region might have changed due to the dynamic nature of socio-economic activities as drivers of urban development. However, the study elucidetes wholistically the trends of the city-region formation, considering the temporal boundaries started in 1987 when the region can not be termed a city-region and in 2002 when the city-region already emerged with some leapfrogged settlements.

CONCLUSIONS

The current study used GIS-based data to evaluate urban spatial density patterns of a city-region formation to support sustainable regional development planning and policies. The concentric zone model of urban formation showed the urban spatial density of the city-region declined from Zone 1, which is the CBDs of different settlements that make up the city-region to other Zones towards peri-urban of each settlement, except for Zone 5, which increased to Zone 6 from 1987 to 2002. Also, the urban density changes of the concentric zones between different temporal boundaries showed a decline from Zone 1 to Zone 9, except for the increase in change detection between Zone 8 and 9 from 2002 to 2017.

The study demonstrated that even if the formation of city-regions is similar to the formation of a single urban area with regard to their urban densities that decrease from the CBDs to the peri-urban areas, it is not always the same for all zones at every given time in all urban areas and city-regions due to leapfrogged settlements with haphazard urban development and high urban densities. The information provided by the current study is crucial to support decision-making processes in urban and regional planning and policies on spatial arrangements of urban and regional elements to support sustainable regional development in the context of a defined city-region in the Global South, especially in Sub-Saharan Africa City-Regions.

Based on the limitations, findings, and possible implications of the current study, the following are recommended. First, the zones where densities increased, instead of the decreasing patterns should be monitored in relation to urban leapfrogging that is associated with high density and haphazard development. This should be controlled to reduce the environmental impacts, especially on land demarcated for environmentally sensitive areas. Second, future research should adopt a similar approach and incorporate a temporal boundary of the current or recent year to elucidate the city-region formation and investigate the possible future city-regions under different scenario alternatives.

REFERENCES

Abubakar, I. R. (2014). Abuja city profile. *Cities, 41*, 81– 91. https://doi.org/10.1016/j.cities.2014.05.008

Article DOI: https://doi.org/10.37284/eajenr.7.1.2105

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

Agyemang, F. S., & Silva, E. (2019). Simulating the urban growth of a predominantly informal Ghanaian city-region with a cellular automata model: Implications for urban planning and policy. *Applied Geography, 105*, 15-24. https://doi.org/10.1016/j.apgeog.2019.02.011

AS&P (Albert Speer & Partner GmbH) & Elsworth, D. (2008). 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. Frankfurt am Main: AS&P.

Campbell, J. B., & Wynne, R. H. (2011). *Introduction to Remote Sensing* (Fifth ed.). New York: The Guilford Press.

Chen, Y., Irwin, E. G., Jayaprakash, C., & Irwin, N. B. (2017). Market thinness, income sorting and leapfrog development across the urban-rural gradient. *Regional Science and Urban Economics, 66*, 213– 223. https://doi.org/10. 1016/j.regsciurbeco.2017.07.001

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

Enoguanbhor, E. C. (2021). 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. https://doi.org/10.18452/23620

Enoguanbhor, E. A., Enoguanbhor, E. C., & Albrecht, E. (2022a). Spatial Determinants of Forest Landscape Degradation in the Kilimanjaro World Heritage Site, Tanzania. *Central European Journal of Geography and Sustainable Development, 4*(2), 5-23. https://doi.org/10.47246/CEJGSD.2022.4.2.1

Enoguanbhor, E. C., Gollnow, F., Nielsen, J. O., Lakes, T., & Walker, B. B. (2019). Land Cover Change in the Abuja City-Region, Nigeria: Integrating GIS and Remotely Sensed Data to Support Land Use Planning. *Sustainability, 11*(5), 1313. https://doi.org/10.3390/su11051313

Enoguanbhor, E. C., Gollnow, F., Walker, B. B., Nielsen, J. O., & Lakes, T. (2021). Key Challenges for Land Use Planning and its Environmental Assessments in the Abuja City-Region, Nigeria. *Land, 10*(5), 443. https://doi.org/10.3390/land10050443

Enoguanbhor, E. C., Chukwurah, G. O., Enoguanbhor, E. A., John-Nsa, C. A., Isimah, M. O., Edo, I., Achenui, R., Matemilola, S., Fotang, C., Ijioma, U. D. & Ibrahim, E. S. (2023). Evaluating urban land-use demarcation and implementation for various urban functions using GIS and survey-based data: The case of Abuja City, Nigeria. Town and Regional Planning, 83, 45-56. https://doi.org/10.38140/trp.v83i.7436

Enoguanbhor, E., Enoguanbhor, E., Chukwurah, G., Isimah, M., John-Nsa, C., Oloruntoba, E., Fotang, C., Ngwator, T., Yangni, G., Oladosu, O., & Agunbiade, M. (2024b). Assessment of conformity to demarcated environmentally sensitive areas in land use plans: The case of Abuja, Nigeria. Town and Regional Planning, 84, 58- 71. https://doi.org/10.38140/trp.v84i. 7985

Enoguanbhor, E., Enoguanbhor, E., Chukwurah, G., Oloruntoba, E., Edo, I., John-Nsa, C., Fotang, C., Yangni, G., Oladosu, O., Agunbiade, M., Njunda, F., Achenui, R. (2024a). Spatial Interactions of a City-Region Using GIS and Survey-based Data. East African Journal of Interdisciplinary Studies, 7(1), 176- 185. https://doi.org/10.37284/eajis .7.1.2015

Article DOI: https://doi.org/10.37284/eajenr.7.1.2105

Enoguanbhor, E., Gollnow, F., Walker, B., Nielsen, J., & Lakes, T. (2022b). Simulating Urban Land Expansion in the Context of Land Use Planning in the Abuja City-Region, Nigeria. *GeoJournal, 87*, 1479–1497. https://doi.org/10.1007/s10708-020-10317-x

EO4SD (Earth Observation for Sustainable Development). (2018). Earth Observation for Sustainable Development Urban Project: Dodoma City Report. Dodoma: EO4SD.

FMITI (Federal Ministry of Industry, Trade and Investment). (2015). *Resettlement and social audit: Abuja technology village project.* Abuja: FMITI.

Fola Consult Ltd. (2011). Federal Capital City: revised land use plan - 2011 phases I, II & III. Abuja: Federal Capital Development Authority.

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

Harding, A., Marvin, S., & Robson, B. (2006). *A Framework for City-Regions.* London: ODPM Publications.

Hess, P. (2014). Density, Urban. In A. C. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 1554–1557). Dordrecht: Springer. https://doi.org/10.1007/978-94-007-0753-5_698

Idoko, M. A., & Bisong, F. E. (2010). Application of Geo-Information for Evaluation of Land Use Change: A Case Study of Federal Capital Territory-Abuja. *Environmental Research Journal, 4*(1), 140- 144. http://dx.doi.org/10.3923/erj.2010.140.144

Karimi, A., Delavar, M. R., Mohammadi, M., & Ghadirian, P. (2020). Spatial urban density modelling using the concept of carrying capacity: a case study of Isfahan, Iran. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, 13(4), 489– 512. https://doi.org/10.1080/17549175.2020.1753225

Krehl, A., Siedentop, S., Taubenböck, H., & Wurm, M. (2016). A Comprehensive View on Urban Spatial Structure: Urban Density Patterns of German City Regions. *International Journal of Geo-Information*, 5(6), 76. https://doi.org/10.3390/ijgi5060076

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

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

Mohamed, A., Worku, H., & Lika, T. (2020). Urban and regional planning approaches for sustainable governance: the case of Addis Ababa and the surrounding area changing landscape. *City and Environment Interactions*, 100050. https://doi.org/10.1016/j.cacint.2020.100050

Sufiyan, I., Buhari, A. M., Abubakar, U. S., & Ubangari, A. Y. (2015). 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, 9*, 17-24. doi:10.9790/2402-091121724

Tope-Ajayi, O. O., Adedeji, O. H., Adeofun, C. O., & Awokola, S. O. (2016). 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, 7*(1), 51- 63. https://doi.org/10.19188/06JSSP012016

Article DOI: https://doi.org/10.37284/eajenr.7.1.2105

Tso, B., & Mather, P. M. (2009). *Classification methods for remotely sensed data.* (Second, Ed.) Boca Raton: CRC Press.

USGS (United States Geological Survey). (2019). *USGS science for a changing world*. Retrieved 04 02, 2019, from https://earthexplorer.usgs.gov/

Vijayalakshmi, S., Kumar, M., & Arun, M. (2021). Astudy of various classification techniques used for very high-resolution remote sensing [VHRRS] images. *Materials Today: Proceedings, 37*, 2947–2951. https://doi.org/10.1016/j.matpr.2020.08.703

Xu, C., Jiang, W., Huang, Q., & Wang, Y. (2020). Ecosystem services response to rural-urban transitions in coastal and island cities: A comparison between Shenzhen and Hong Kong, China. *Journal of Cleaner Production, 260*, 121033. https://doi.org/10.1016/j.jclepro.2020.121033

Xu, G., Dong, T., Cobbinah, P. B., Jiao, L., Sumari, N. S., Chai, B., & Liu, Y. (2019b). Urban expansion and form changes across African cities with a global outlook: Spatiotemporal analysis of urban land densities. *Journal of Cleaner Production, 224*, 802- 810. https://doi.org/10.1016/j.jclepro.2019.03.276

Xu, G., Jiao, L., Yuan, M., Dong, T., Zhang, B., & Du, C. (2019a). How does urban population density decline over time? An exponential model for Chinese cities with international comparisons. *Landscape and Urban Planning*, *183*, 59- 67. https://doi.org/10.1016/j.landurbplan.2018.11.005

Yang, X. (2010). Integration of Remote Sensing with GIS for Urban Growth Characterization. In B. Jiang, & X. Yao (Eds.), *Geospatial Analysis and Modelling of Urban Structure and Dynamics* (pp. 223-250). New York: Springer Science+Business Media B.V.

