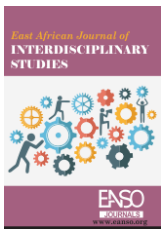

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Original Article

Spatial Interactions of a City-Region Using GIS and Survey-based Data

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Spatial Interaction, City-Region, Network of Settlements, Sustainable Regional Development, Sub-Saharan Africa, Global South.

ABSTRACT

The concept of spatial interaction deduced from Newton's first law of motion, which has been extended from interactions between two points of elements e.g., two cities to interactions between other points of other elements in a system, e.g., more than two cities, can be applied to elucidate settlements spatial interaction at the regional scale, particularly a city-region as a system. Elucidating the levels of spatial interactions in city-regions is crucial to support decision-making processes in regional development planning and policies, which in turn contributes to sustainable regional developments if implemented fully. The current study, therefore, combined Geographic Information Systems and survey-based data to evaluate the level of spatial interactions of a city-region as a system to support sustainable regional development planning and policies using the defined Abuja city-region as a case study. Data were collected through a questionnaire survey of residents, land cover maps that were produced using Remote Sensing processes of satellite image classification, and urban and regional land use plans. An integrated analysis was deployed, including descriptive statistics and spatial analysis through extraction, digitization, overlay, clipping, and geometrical calculation processes. Key findings showed that the work location for most residents in satellite settlements is Abuja city. Also, the study showed that while Lugbe, Kubwa, and Old Karu settlements have the highest level of spatial interaction with Abuja city, Kuje and Gwagwalada settlements have the lowest level of spatial interaction. The findings and their associated implications of the current study are useful to support decision-makers in planning and policies for the spatial distribution of urban infrastructures across settlements that make up defined city-regions in Sub-Saharan Africa in particular and in the Global South in general.

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INTRODUCTION

The concept of spatial interaction built on Newton's first law of motion assumes that the size and distance between two entities determine the spatial interaction between them (Koomen & Stillwell, 2007). The concept has been extended from interactions between two points of elements e.g., two cities to interactions between other points of other elements e.g., more than two cities, and states that the total interaction in a system is assumed to be equal to the sum of interactions between all elements in the system (Koomen & Stillwell, 2007). The assumption of the second idea can be applied to a city-region, which can be referred to as networks of settlements in the context of environmental, cultural, economic, and social activities, where one of the settlements, particularly a city serves as the Central Business District (CBD) to other surrounding settlements (Harding et al., 2006; Enoguanbhor E. C., 2021). Thus, the spatial interaction in a city-region is dependent on the size and distances between settlements such as cities, towns, and villages that make up the city-region and the total (volume) spatial interaction in a city-region is assumed to be equal to the sum of interactions between these settlements of the city-region. Considering the cultural, social, economic, and environmental networks of settlements are the function of movements of people from one settlement to another, the current study focuses on movements of people, especially between the CBD of a city-region and the surrounding settlements, where the sizes and distances between the settlements are used to determine the level of spatial interactions.

Determining the levels of spatial interactions in city-regions is crucial to support decision-making processes for regional development planning and policies, which in turn contributes to sustainable regional developments. In this context, sustainable regional development can be regarded as a condition that allows environmental, economic, social, and cultural developments without compromising any aspects of the development in any of the settlements found in a city-region for current and future generations (Enoguanbhor et al., 2024). From this point of view, it can be argued that settlements found in city-regions, especially the CBDs may not be able to actualize to the fullest the environmental, economic, social, and cultural objectives of their urban or master plans if settlements with high-level spatial interactions are neglected at the level of regional planning, which provides guidelines for local or urban planning (Wahab et al., 2014; Wang et al., 2014; Mohamed et al., 2020). Thus, the environmental, economic, social, and cultural problems of a particular settlement may affect other settlements due to the networks of such

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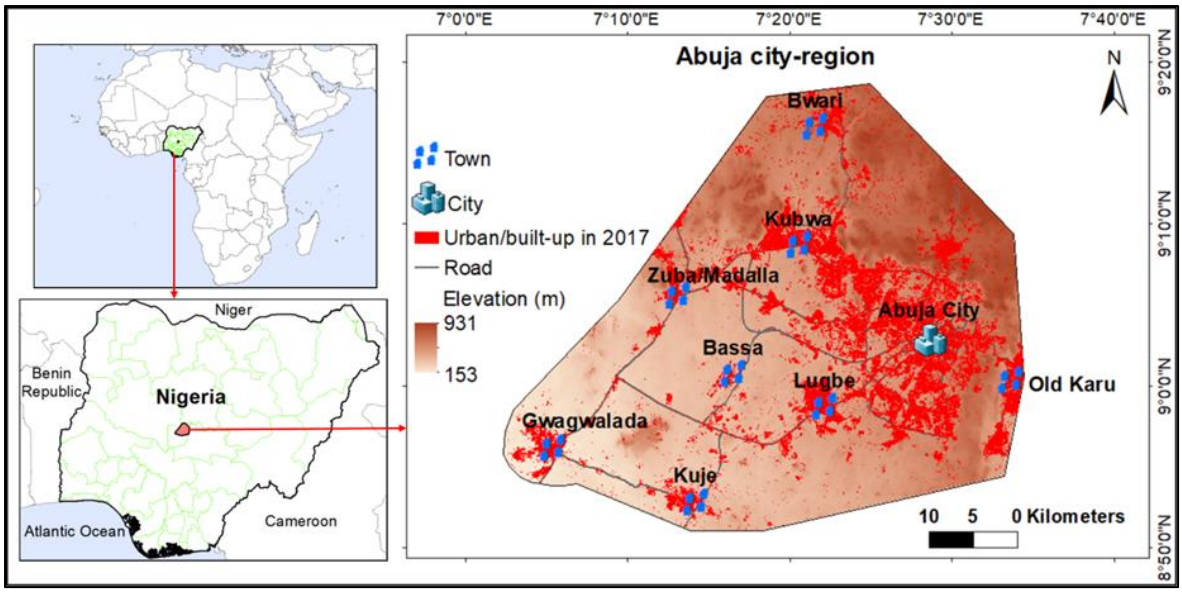
settlements through high-level spatial interactions of a city-region as a system.

As a system, every city-region, including the Abuja city-region has degrees of networks and interactions within the system. The Abuja city-region, including the Federal Capital City (FCC), Kubwa, Lugbe, Old-Karu, Gwagwalada, Bwari, Bassa, and Kuje settlements is chosen due to the observed movements of people from those other settlements to the FCC that serves as the CBD of the city-region. Additionally, due to the current implementation of the regional plan of the Federal Capital Territory (FCT) and the urban plan of the FCC (Gumel et al., 2020; Enoguanbhor et al., 2023). The urban and regional plans were prepared in 1979 (Abubakar, 2014; FMITI, 2015; Fola Consult Ltd., 2011; AS&P & Elsworth, 2008) and the implementation started in the early 1980s before the capital city was relocated from Lagos to FCC, Abuja in 1991 (Idoko & Bisong, 2010; Adama, 2020; Ejaro & Abubakar, 2013; Abubakar, 2014). The implementation of the land use plans has contributed directly and indirectly to the development of the city-region with networks of settlements within a system. As a system, in the Abuja city-region, Nigeria and most other city-regions in Sub-Saharan Africa, studies have not been able to integrate Geographic Information Systems (GIS) and survey-based data to evaluate the level of spatial interaction based on a network of settlements and its implications for urban and regional planning and policies, especially in the context of city-regional sustainability.

The current study, therefore, aims to use GIS and survey-based data to evaluate the level of spatial interactions of a city-region as a system to support sustainable regional development planning and policies. The specific objectives include:

- Using residents' experiences about their relative distance to work locations to identify the level of movement of people between the CBD of the city-region and the surrounding settlements, and;
- Evaluating the level of spatial interactions between the CBD of the city-region and the surrounding settlements.

Figure 1: Map showing the location of the defined Abuja city-region in Nigeria.



Source: Enoguanbhor et al. (2021).

MATERIALS AND METHODS

Research Approach

An integrated research approach (Ohl et al., 2010), where GIS is combined with questionnaire surveys to provide detailed insights into the subject matter (Enoguanbhor, 2021) was deployed to evaluate the level of spatial interactions of a city-region as a system to support sustainable regional development planning and policies. The

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questionnaire surveys were used to collect data from urban residents as respondents and descriptive statistics were deployed to analyze and present the data to elucidate the likelihood of high-level spatial interactions between the CBD and other satellite settlements in the city-region. GIS was used to evaluate the level of spatial interactions between the CBD of the city region and the surrounding satellite settlements.

Data Collection

Surveys of urban residents as respondents were conducted from 19 February to 27 March 2018 in the satellite settlements of the Abuja city-region, including Lugbe, Gwagwalada, Kubwa, Kuje, Old Karu, and Bassa. The questionnaire was designed as closed-ended questions to elucidate the frequent movements of people from their residence locations to other locations within the city-region. Thus, work location was a focus of the questionnaire design to identify whether respondents go to work within their satellite settlement, Abuja city, or other satellite settlements. Questionnaires were administered to respondents using probability sampling (Secor, 2010; Kothari, 2004; Blaxter, et al., 2001). The reason the probability sampling was adopted is to randomly select the respondents to represent the population. 330 and 303 questionnaires were distributed and retrieved, respectively, which is a response rate of 91.8% (*Table 1*).

Table 1: Sampling and retrieved questionnaires.

Sample locations/regions	Distributed questionnaires	Retrieved questionnaires	Response rates
Lugbe	80	75	93.8%
Gwagwalada	50	50	100.0%
Kubwa	50	50	100.0%
Kuje	50	50	100.0%
Old Karu	50	50	100.0%
Bassa	50	28	56.0%
	330	303	91.8%

Additionally, GIS data on regional (settlement) land cover maps for 2002 and 2017 of the Abuja city-region were collected from Enoguanbhor (2021). The maps were produced from remotely sensed images of the Landsat 7 satellite (Enhanced Thematic Mapper Plus) in 2002 and Landsat 8 satellite (Operational Land Image) in 2017 (USGS, 2019) using the supervised classification and maximum likelihood algorithm (Campbell & Wynne, 2011; Lu et al., 2011; Vijayalakshmi et al., 2021; Tso & Mather, 2009; Enoguanbhor et al., 2019; Enoguanbhor et al., 2022a; Enoguanbhor, et al., 2022b). The user and producer accuracies of the maps were estimated at 88% and 87.8%, respectively for 2002, and 96% and 85.3%, respectively for 2017. The essence of this data was to determine the sizes of various settlements and to evaluate the level of spatial interactions of a city-region. Furthermore, the Abuja FCC land use plan Phases I-III (Fola Consult Ltd, 2011) and the FCT regional land use plan were collected from the Department of Urban and Regional Planning (DURP) of the Federal Capital Development Authority (FCDA), Abuja. The reason for collecting this data was to digitize various settlements based on county boundaries where they are located.

Data Analysis

Regarding the questionnaire survey data, descriptive statistics were deployed to summarize the data set characteristics for calculating the sampled frequencies (Visser & Jones III, 2010). The calculation can be expressed as:

$$X / Y * 100/1$$

Where X is the number of respondents identified with a particular variable and Y is the total number of respondents of a sampled population. Descriptive statistics were used to summarise and present the ontological perceptions/opinions of

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urban residents about their work locations from their residence.

Spatial analysis was performed using ArcGIS 10.8.2 version and Geo Pandas 0.14.0 version in Python 3.11.2 version. Urban land cover was extracted from the regional land cover types for 2002 and 2017. Also, the cadastral boundaries at the county level from urban and regional land use plans were digitized. Additionally, the urban land cover maps and the digitized cadastral boundaries of the county were overlayed and the urban land in each county of each settlement was calculated. Furthermore, the road network map was overlayed and the distances between the CBD and other surrounding settlements in the city-region were calculated. The level of spatial interaction is calculated using the formula:

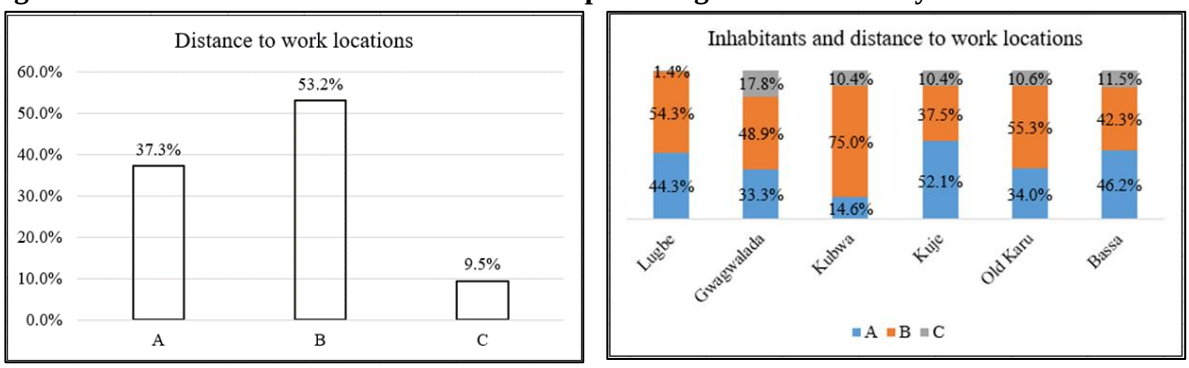
$SI = SS_1 + SS_2 / D$

Where SI connotes spatial interaction, SS_1 stands for the size of the first settlement e.g., one of the satellite settlements, SS_2 is the size of the second settlement e.g., the CBD of the city-region, and D connotes the distance between both settlements.

RESULTS AND DISCUSSION

Results in *Figure 2* show the relative distance to work locations based on surveys of residents. Figure 2A indicates that the work locations of most urban residents in satellite settlements are within Abuja City, followed by those working within a 20-minute' walk from where they live. Only a few residents in satellite settlements work in other satellite settlements in the Abuja city region. Based on the same surveys, most urban residents in satellite settlements that work in Abuja city are from Kubwa (75.0%), Old Karu (55.3%), Lugbe (54.3%), and Gwagwalada (48.9%). The residents that work within the satellite settlements of their residence are mostly from Kuje (52.1%) and Bassa (46.2%). The finding that shows Abuja city as the work location for most urban residents in satellite settlements indicates that the high level of spatial interaction in the city-region as a system is mostly between Abuja city and the surrounding settlements. This may be due to urban services, including administrative, commercial, and corporate office and informal job opportunities provided by Abuja city as the CBD of the city region (Abubakar, 2014). The findings on most residents in satellite settlements that work in Abuja city are from Kubwa, Old Karu, and Lugbe may be associated with the distance between Abuja city and those settlements, considering those settlements are closer to Abuja city when compared to other settlements within the defined city-region (see *Figure 3*).

Figure 2: Relative distance to work locations in percentage based on surveys of urban residents.



A: Within a 20-minute walk from where you live.
B: Within Abuja City.
C: Other parts of FCT Abuja

Table 1 and *Figure 3* present the results of spatial interactions and the network of settlements' spatial patterns between the CBD of the city region and the surrounding settlements for 2002 and 2017. In 2002, Old Karu had the highest level of spatial interaction followed by Kubwa and

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Lugbe. In 2017, the highest level of spatial interaction between Abuja city and the surrounding settlements was Lugbe, followed by Kubwa and Old Karu. Kuje had the lowest level of spatial interaction both in 2002 and 2017. While the change in spatial interaction from 2002 to 2017 indicated Lugbe as the highest change, followed by Kubwa and Old Karu, the lowest change showed Gwagwalada, followed by Kuje. The GIS finding that indicates Lugbe, Kubwa, and Old Karu with the highest level of spatial interaction between Abuja city and the surrounding settlements validates the survey findings that show the same settlements with most urban residents working in Abuja city. The findings are associated with the short distances between the settlements and Abuja city. The finding on Lugbe having the highest change detection of densities from 2002 to 2017 indicates that both Lugbe and Abuja city have been expanding over time, which may lead to the merging of both settlements in the future.

Table 2: Level of spatial interaction between Abuja city and the surrounding settlements in km^2

Satellite settlements	2002	2017	Change (2002-2017)
Kubwa	42.0	180.1	138.1
Lugbe	38.4	335.3	296.9
Old Karu	59.6	167.6	108.0
Gwagwalada	13.7	48.1	34.4
Kuje	4.6	42.1	37.5
Dakwa/Madalla	12.9	81.6	68.7
Bwari	14.7	83.2	68.5

Figure 3: Network of settlements between the CBD and other satellite settlements in the Abuja City-Region for 2002.

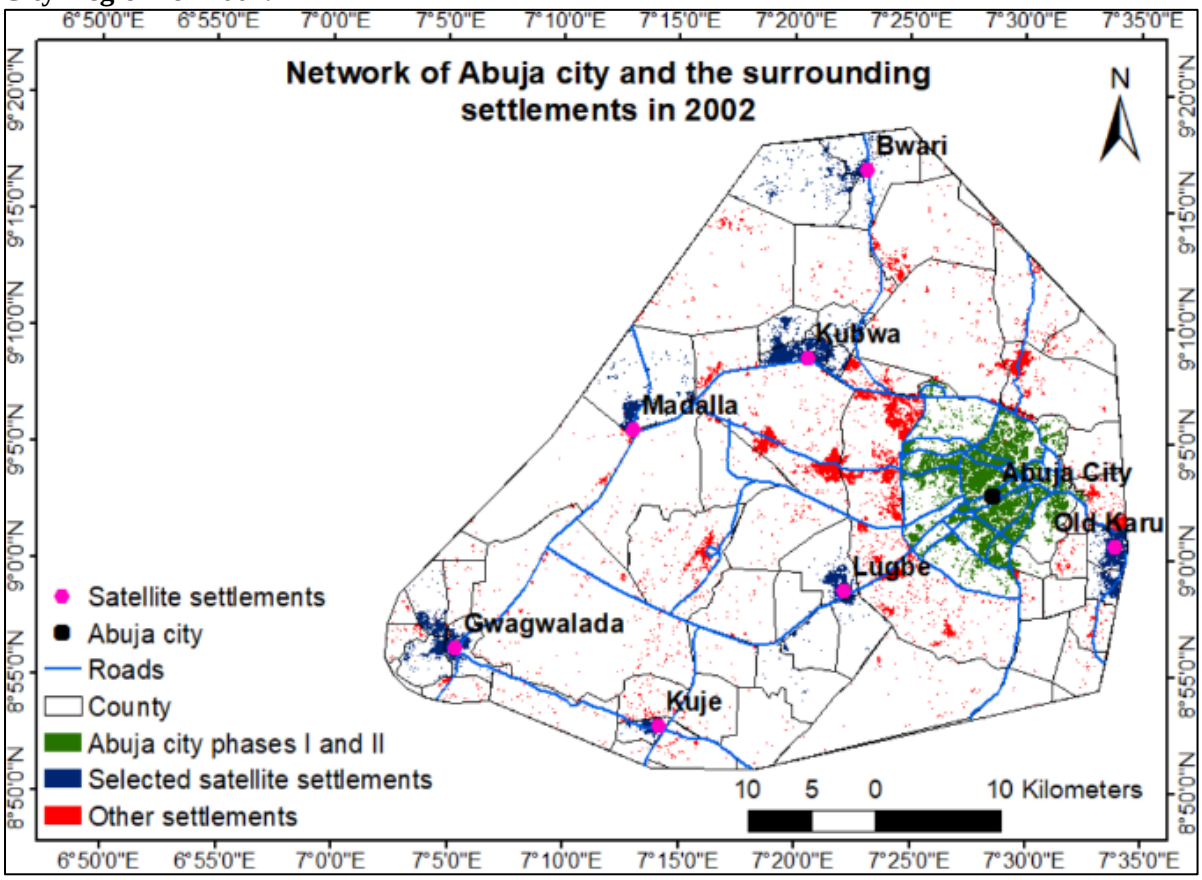

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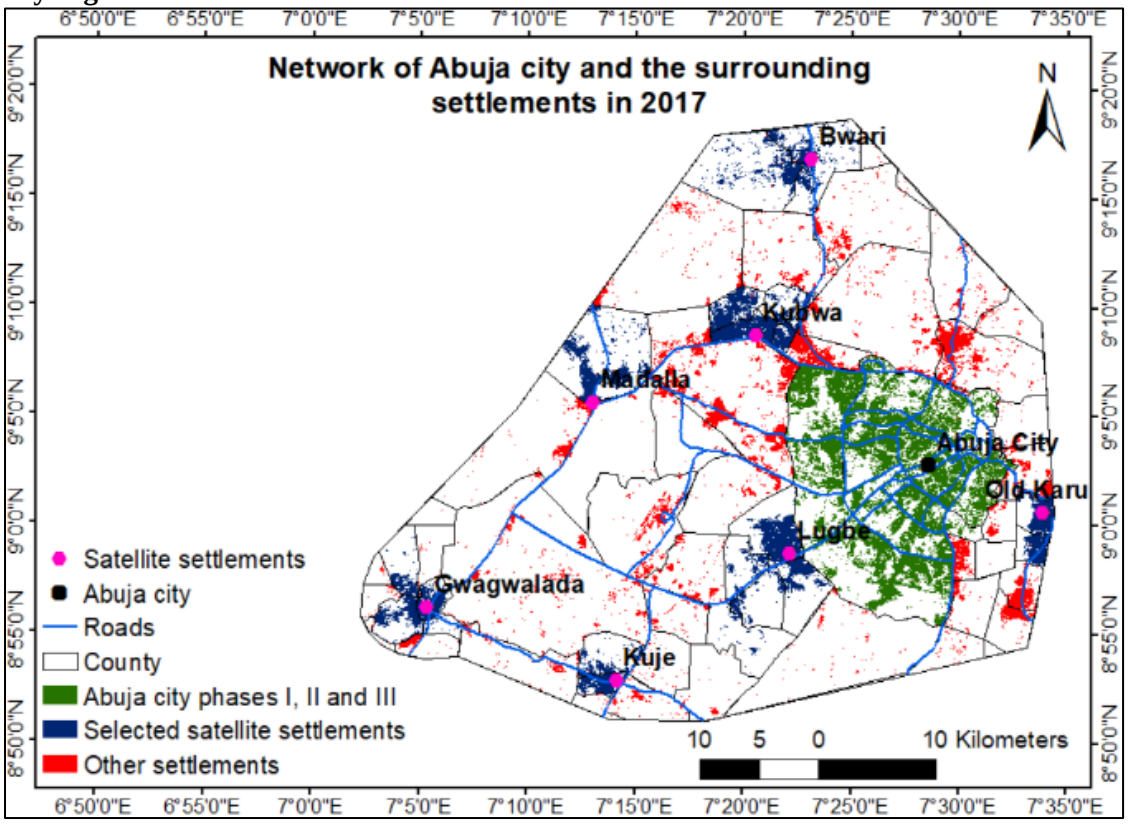
Figure 4: Network of settlements between the CBD and other satellite settlements in the Abuja city-region for 2017.



Implications of the Findings

The general implication of the current study can be deduced from the integrated methodological approach where both GIS and questionnaire surveys are combined to derive findings. While the questionnaire survey is used to guide GIS analysis on the settlements that are potentially associated with high-level spatial interactions based on the movement of people from one location to another, GIS is used to map and calculate the level of spatial interactions between those settlements and the CBD of the city-region. Such an approach that is deduced from social and spatial sciences increases the confidence or validation of the analysis and findings based on the choice of selected settlements from the ontological experiences of the city-region dwellers.

Another important implication of the study can be attributed to the finding that shows Abuja city as the work location for most urban residents in satellite settlements, which may be due to urban services, including administrative, commercial, and corporate office jobs provided by Abuja city as the CBD of the city-region. This finding indicates that there are no sufficient urban services, especially job opportunities in other satellite settlements in the city-region. Spreading urban services across the city region would increase job opportunities and reduce the number of people travelling from the surrounding settlements to the CBD of the city-region.

An additional implication of the finding that indicates Lugbe, Kubwa, and Old Karu with the highest level of spatial interaction with the CBD of the city-region indicates that good transportation infrastructures, including road expansion and efficient public means of transportation, are required on those routes to reduce or eliminate traffic congestions and their impacts on urban dwellers or the routes' users.

A further implication of the study can be associated with four key issues, including cultural, social, economic, and environmental networks of the satellite settlements and the CBD of the city-region. These four key issues, which are the pillars

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of sustainability must be addressed holistically for sustainable regional development, considering the spatial diffusion of these issues from one settlement to another. For example, if the environmental problems (e.g., air and water pollution) associated with the satellite settlements are not addressed, the direct or indirect impacts of such problems can diffuse into Abuja city. Similarly, the impacts of socio-cultural and economic problems such as criminal activities can diffuse from satellite settlements to Abuja City. By integrating GIS and questionnaire surveys to evaluate the level of spatial interaction within a city region as a system, this study contributes to Urban and Regional Planning and Sustainable Development as academic and professional domains.

The current study is limited by the time gap the questionnaire survey was conducted (2018), the satellite image of the last boundary was captured (2019), and the publication. Considering the human activities as drivers of land, environment, and urban expansion change over time, there might have been a slight change in the levels of spatial interactions between the CBD of the city region and the surrounding settlements. However, the study has demonstrated the real-world situation, especially during the data collected, which can also be used to assume the current and recent situations.

CONCLUSIONS

The current study integrated GIS and survey-based data to evaluate the level of spatial interactions of a city region as a system to support sustainable regional development planning and policies using Abuja as a case study. The survey of residents showed Abuja city as the work location for most residents in satellite settlements. GIS findings showed that while Old Karu, Kubwa, and Lugbe had the highest spatial interaction level with Abuja city in 2002, Lugbe, Kubwa, and Old Karu, respectively had the highest level in 2017. The change in spatial interaction from 2002 to 2017 indicated Lugbe as the highest change, followed by Kubwa and Old Karu and the lowest change showed Gwagwalada, followed by Kuje.

The current study demonstrated the applicability of the first and second ideas of the concept of spatial interaction deduced from Newton's first law of motion, considering the sizes and distances between satellite settlements and the CBD of the city-region determine the levels of spatial interaction. For example, settlements like Lugbe, Kubwa, and Old Karu, which are closer to Abuja city have high-level spatial interactions with Abuja city when compared to other settlements such as Gwagwalada and Kuje, which are farther from Abuja city. The findings and their associated implications provided by the current study are crucial to support decision-making processes in urban and regional planning and policies on the spatial distribution of urban infrastructures across settlements that make up the defined city region to support sustainable regional development in city regions found in the Global South, especially in Sub-Saharan Africa.

From the findings and the limitations of the study, the following are recommended: urban and regional services, especially job opportunities should be provided and distributed across the settlements in the city-region to reduce the movement level of residents from satellite settlements to work in Abuja city. Also, transportation infrastructures such as road expansion and adequate public transportation systems should be provided and distributed between Abuja city and satellite settlements, especially Lugbe, Kubwa, and Old Karu with high-level spatial interaction. Additionally, to avert, reduce, or eliminate the diffusion of the negative impacts of socio-cultural, economic, and environmental problems that are associated with spatial interaction from one settlement to another, the satellite settlements should be developed along with Abuja city by implementing urban and regional plans of the city-region for sustainable urban and regional development. Furthermore, future research should incorporate the recent or current GIS data of land cover and surveys of residents and experts in urban and regional

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planning to investigate both current and future spatial interaction of the city-region as a system.

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