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Spatial Analysis for Determining Accessibility to Bus Stops in Kaduna Metropolis

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Abstract

Bus stop accessibility is a vital component of a successful transportation system. This study aimed at spatially analyzing bus stops to determine their physical accessibility considering the connecting roads surrounding the bus stops. This research used satellite imagery, Global Navigation Satellite System and Kaduna State Traffic and Environment Law Enforcement Authority documents. The spatial analysis covered bus stop accessibility and obtained data of transport routes, bus stop coordinates, bus stop spacing and physical characteristics of bus stops. GIS buffer, network and area analysis was used in measuring bus stop accessibility considering the road network surrounding it. The ratio of ideal access coverage to the actual access coverage of a stop was calculated. Paired sample statistics were used to compare ideal and actual access coverage; the finding revealed a significant difference between the ideal and actual access coverage. A range of 0 - 1.0 was used in the analysis where, a bus stop is less accessible the closer the value is to 0, and more accessible the closer the value is to 1.0. Linear regression statistics was used to determine if the level of accessibility of a bus stop is dependent on the length of roads within the buffer. This revealed that at R = 0.694, a strong degree of correlation exists between the level of accessibility and road length within the buffer. The study concluded that before siting bus stops, surrounding road networks need to be considered in order to make them accessible.

Keywords

Accessibility, Buffer, Network Analysis, Ideal Access Coverage, Actual Access Coverage

1. Introduction

Accessibility studies are vast in how they are carried out around the world. The method employed depends on what is aimed at achieving. The most common methods are socio-economic or socio-demographic which make use of questionnaires on commuter's perspectives, bus fare affordability, walking distances and waiting times. Other accessibility studies include bus stop spacing, physical accessibility, which employ various physical measurement methods. Most accessibility models assess accessibility in a GIS environment. Obtaining results that are accurate in a GIS-based analysis, the input data has to be detailed and of good quality [1]. An accessibility model requires information about land use and transportation systems. The types of activities that exist which are also known as land use data, where they are located, and transportation data must contain data such as road networks, transport routes, bus stops and their frequencies [2]. In their study based in Australia, [2] developed composite index measures in quantifying and measuring the accessibility of a place. They used a series of "value measures" so as to quantify accessibility. These values are basically travel distance and measures of time between two locations through the transportation route. The measures obtained are used within a GIS environment, which allows for the manipulation of large quantities of spatial data necessary for such an analysis.

Measuring the performance and effectiveness of public bus transportation is critical in assessing policy goals as well as planning for the future improvement [3]. Bus transport is one of the predominant means of transportation in Kaduna metropolis. The bus stops in Kaduna metropolis are currently not well organized as many are created due to convenience, as a result, the traffic situation reflects this reality. The location of the bus stops does not follow a planned sequence and so the bus spacing is not considered. Using the method of analysis this paper employed, it will help in getting the best and accessible location for bus stops within the metropolis. Bus stops within Kaduna metropolis are the major generators of congestion therefore, it was necessary to study the accessibility of these bus stops.

1.1. Literature Review

Accessibility analyses have been done in various ways; [4] in his study on Kaduna bus transportation based the analysis purely on the way respondents perceive accessibility; [5] assessed the quality of intra-urban passenger bus services in Kaduna metropolis with the view of determining its efficiency in terms of waiting time, convenience and safety of commuters. The study revealed that majority of commuters walk 1 - 500 mters to access bus stops. [6], attempted an assessment on the affordability levels of bus services among commuters and how their socio-economic characteristics affect this demand in Kaduna metropolis. The research confirmed that socio-economic characteristics of commuters have some influence on their transport demand and therefore underscored the importance of considering socio-economic characteristics of dwellers in a settlement while planning transportation systems of cities.

[7], in their research introduced the use of GIS to give the analysis a numeric basis. Variables such as capacity, frequency and coverage were covered to ascertain the index of coverage for public transit. The variables were also used to de-

termine ideal coverage, actual coverage and stop coverage ratio index to determine well-served and underserved areas connected to the bus stops. [8], used an analysis of walkways used by pedestrians round the bus stop that allows data collection about each link. This survey was centered on calculating cost function that depends on energy exerted, how long, footpaths, issues relating to maintenance, kerbs, gradients, traffic signals for pedestrians, and GIS was used to determine the least cost path for the pedestrian network. In another research by [9], distance of access to stops and spacing of these stops were the variables used to determine the inefficiencies seen in the number of bus stops examined. The model for this research was the Distance Constrained P-Median Problem model. [10], calculated accessibility using GIS to calculate the actual stop coverage, and this helped determine how accessible bus stops are and how each bus stop can be compared to know the most and least accessible ones. [10]'s research is similar to this research; it formed the basis of the methodology employed for this research.

Others such as [11] and [12] based their analysis on one variable they consider most significant in understanding accessibility to transit stops. What differentiates their research is, for [11], the mode of the public transport trip is the most important determinant of accessibility in walking distance. They reflected the different supplies and spacing of each mode in which they reflected there are many more bus stops than train stations, while [12] restricted their analysis to bus stops alone.

[13] stated some underlying assumptions for buffer analysis; in a lot of scenarios, the buffer is limited by boundaries, regions which could be physical and social. The buffer and overlay approach are the methods often used for geographical locations to analyze their accessibility. This approach, however, is limited in that it overlooks road networks and barriers which occur naturally or manmade, with the assumption that within a buffer zone, competing established services and capacity level of services are ignored [13]. [13] shows that buffer analysis of a point or an area assumes spatial homogeneity. However, [10] stated that much previous research related coverage around stops use simple circular buffers delineating the access threshold around each stop with a certain measure of the radius, this however, brings about an overestimation of the access coverage of the stop. This means by implication that passengers can reach the bus stop from any location within the circular buffer (ideal case). This however, does not take serious note of the existing geography of the surrounding pedestrian routes around the bus stop [10].

[14] offered the following definitions which were used in this study; the Ideal Stop-Accessibility Index (ISAI) evaluates the accessibility of bus stops through the surrounding street network and can be used to assess and compare different stop locations from a spatial perspective. The Actual Stop-Accessibility Index (ASAI) gives a more accurate measurement of the street network density around a bus stop based on Network Analyst. The Stop Coverage Ratio Index (SCRI) evaluates the percentage of actual access coverage of a bus stop with respect to its ideal access coverage.

This study aimed at spatially analyzing bus stops to determine their physical accessibility considering the connecting roads surrounding the bus stops. This was achieved through identifying the surrounding roads, measuring the roads, calculating the area coverages of these roads around the bus stops and using a simple regression statistical test to determine the accessibility of the bus stops. This study differentiates itself where all the researches within Kaduna metropolis have been limited to use of questionnaires and none have calculated accessibility based on the access roads around the bus stop.

1.2. Study Area

Kaduna metropolis is the capital city of Kaduna State in Nigeria which covers about 118 km^2. The metropolis comprises Kaduna North, Kaduna South, parts of Chikun and Igabi Local Government areas [14]. It is located between Latitudes 10˚25'15"N and 10˚36'08"N as well as Longitudes 7˚23'31"E and 7˚29'33"E [15]. The state shares boundaries with the Federal Capital Territory and Niger state at the south-west, Katsina and Zamfara at the north-west, Kano and Bauchi at the north-east and Plateau and Nasarawa at the south-east as seen in **Figure 1** [16].

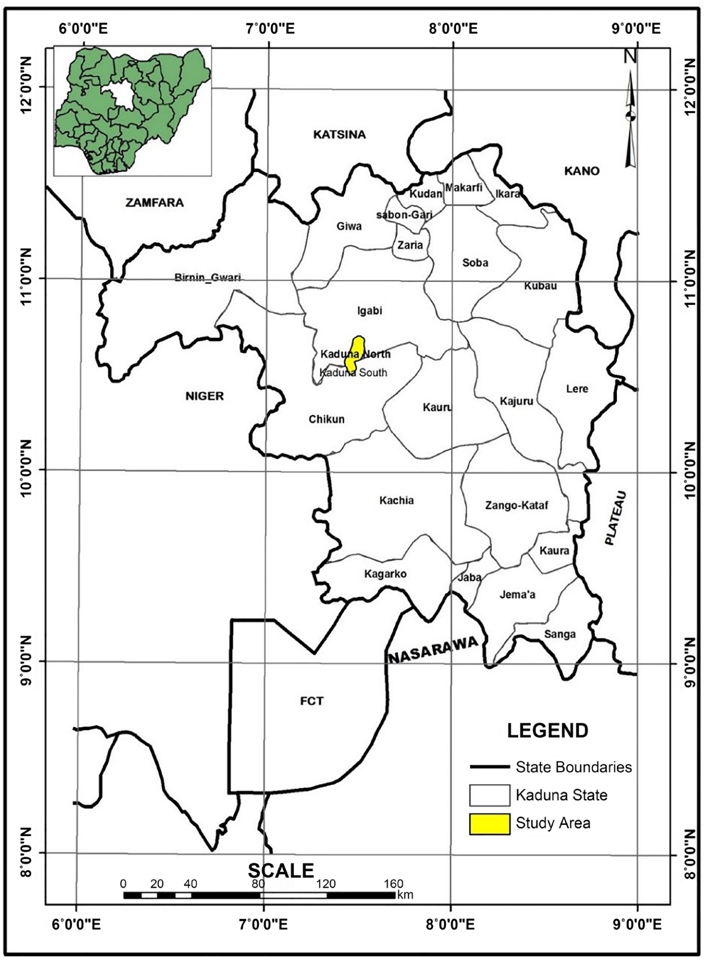

Figure 1. Kaduna state showing study area. Source: adapted from Administrative Map Kaduna State (2006).

Kaduna is a nodal town with roads, railway and an airport that connects it to other parts of the country. It has been a significant rail junction and passenger exchange point for trains from Kano, Port Harcourt, and Lagos since 1927 and recently, a rail line linking it to Abuja. The road transport system has many routes with express roads (Kaduna to Abuja and Kaduna to Kano, among others) linking the city with other States. Within the metropolis, the major roads within the Kaduna metropolis include; Nnamdi Azikiwe way, Ali Akilu Road, Ahmadu Bello way, Junction Road, Sabo expressway and Kachia road to which all other roads connect. Figure 2 shows the road network within the Kaduna metropolis. The major transport routes within the metropolis are about 20, having more than 87 bus stops along the routes (Kaduna State Ministry of Works and Transport, 2012).

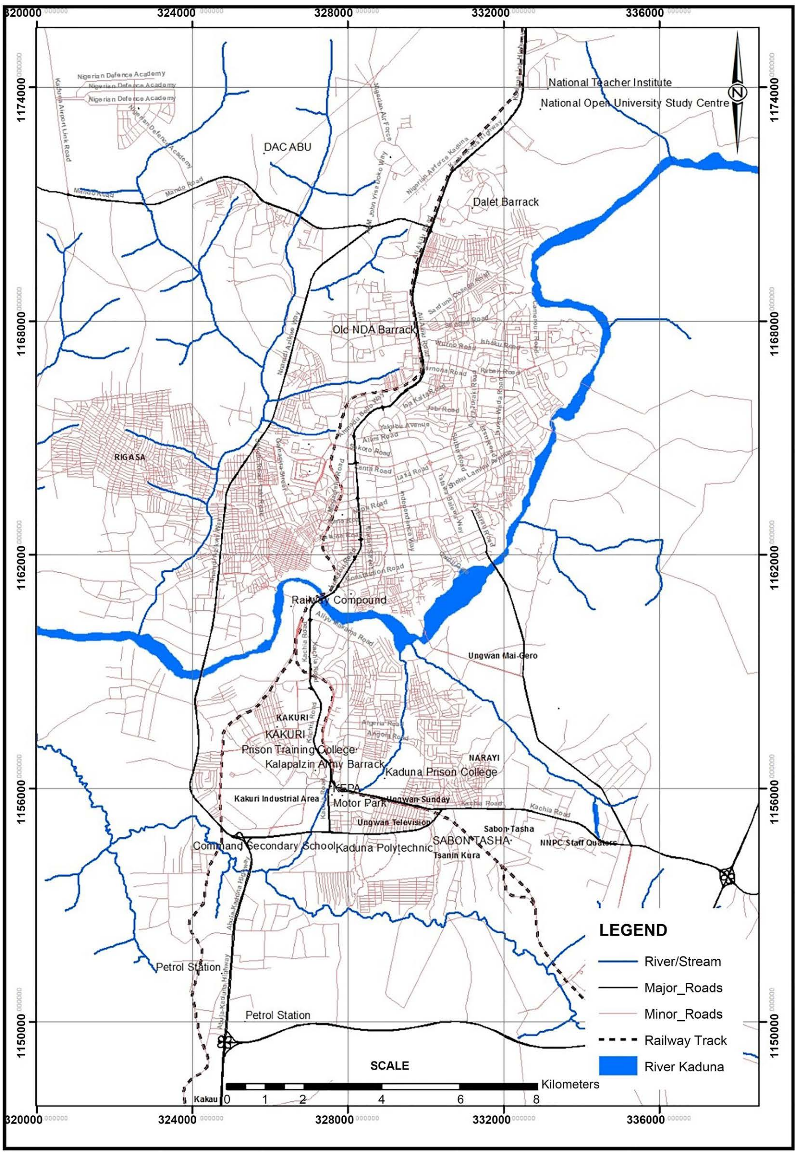

Figure 2. Road network in Kaduna metropolis. Source: adapted from Kaduna Metropolis Street Map (2013).

2. Methodology

The buffer analysis is used to estimate access coverage of bus stops on the basis of the actual road network surrounding the bus stop. All the road network connected to the stop within the delineated 400 m walking distance of the access threshold around each bus stop are considered. The ends of the access roads within the circular buffer, also called "ideal access coverage", touching the circle were joined, creating a polygonal area called the "actual access coverage" for the bus stop. The area of the created polygon is considered more representative of accessibility than the 0.4 km circular buffer when determining the measure of the bus stop access coverage. The step by step processes in achieving this research are as follows in **Figure 3**.

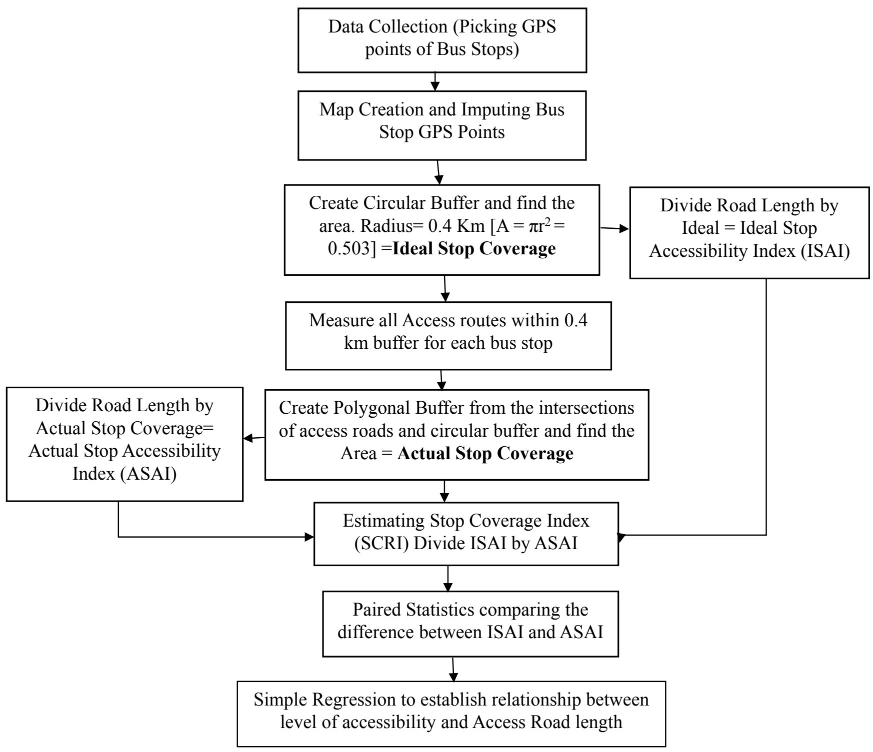

Figure 3. Data processing flowchart.

The simple regression can mathematically be expressed as:

$$Y = a + bX$$

where Y the dependent variable is: Level of accessibility;

X is the independent variable: Road Length within the buffer;

a is the intercept (Constant);

b is the slope.

3. Results and Discussion

Buffer and network analysis were used to achieve the objectives of this research as well as statistical tools that were appropriate to interpret the results.

3.1. Physical Accessibility: Buffer and Network Analysis for Bus Stops

The buffer threshold used was 0.4 km around the bus stops, the bus stops being the center of the circle. This forms the basis for further network analysis for determining how accessible the bus stops are.

3.2. Estimating Ideal Bus Stop Access Coverage

A buffer was created around each of the 63 bus stops along the selected route. Each bus stop has an area coverage of 0.503 km. Within this circular buffer, all the access roads were measured. Although the area of this circular buffer was uniform across all bus stops, this does not give an accurate representation of the accessibility of the bus stops. Across the entire bus stop, 30.68 km is accessible using the ideal bus stop access coverage. The total road length for the routes considered was 59.2 km. The percentage of the ideal bus stop access coverage for the considered route was 51.8%. This is slightly above average, using the ideal bus stop coverage of the area. The bus stops with the circular buffers can be seen in **Figure 4**.

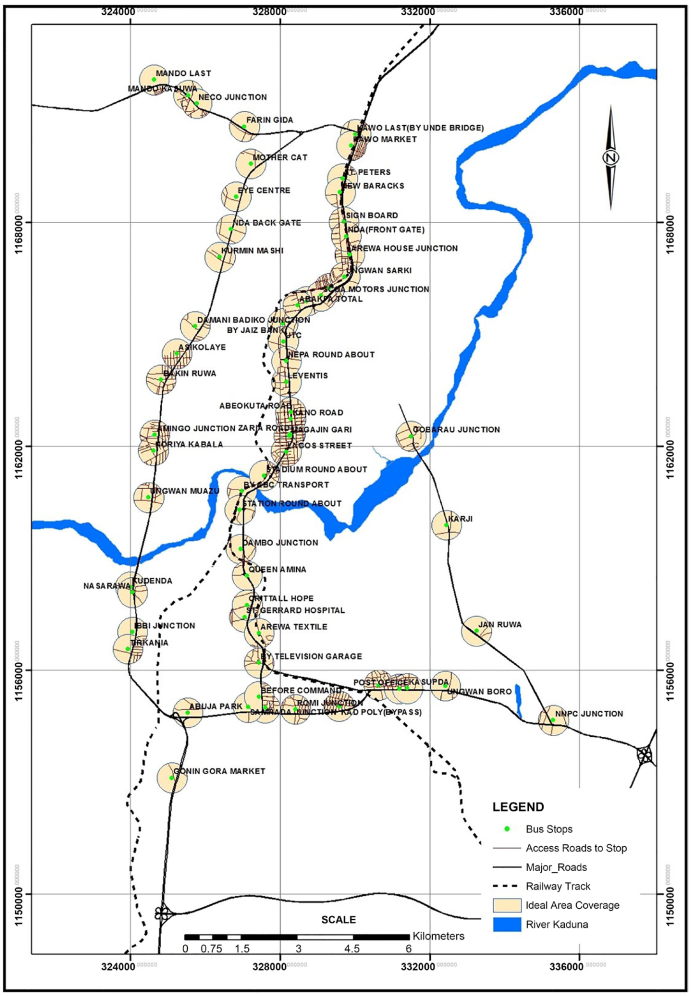

Figure 4. Kaduna metropolis showing ideal bus stops access coverage. Source: Author's Fieldwork (2018).

3.3. Actual Bus Stop Access Coverage Estimation

After creating the circular buffer, it was observed that the access coverage was overestimated using this method alone as revealed by the difference in the paired T-Test statistics in Table 2. To estimate the actual bus stop access coverage, a polygon across all 63 bus stops was created. The areas of these polygons are the actual bus stop coverage. No comparison can be made based on the actual bus stop coverage alone for all the bus stops within the study area because there is no uniform number of access roads across the bus stops. The polygons created have varying values in area, as seen in Figure 5, the actual bus stop with the highest coverage is Zaria Road with 0.489 km^2 area while Mother Cat bus stop has the lowest with 0.108 km^2 area coverage.

As seen on Figure 6, the difference between the ideal and actual access area coverage represents the overestimated value when only the circular buffer, otherwise known as the ideal access area cover, is used to determine accessibility.

3.4. Ideal Stop-Accessibility Indices (ISAI)

The value in kilometres obtained from measuring the roads was divided by the area of the circular buffer. The resulting index value is the ideal road network density within the access threshold from a bus stop (Foda and Osman, 2010). Judging from the ISAI, the bus stop with the least index is Mother Cat with 1.83, which makes it have low accessibility in the ideal situation. Zaria Road has the highest with 17.849, which is the ideal situation has the highest accessibility. This is found to overestimate accessibility, therefore, does not fully present what is obtainable. The ISAI is seen in Table 1.

3.5. Actual Stop-Accessibility Indices (ASAI)

The roads maintain the same measurement; the value in kilometres obtained from measuring the roads was divided by the area of the created polygon within the buffer. The resulting index value represents the actual density of the road network within the bus stop access threshold. The index that shows the highest accessibility is KadPoly (by express) Bus stop with 19.165, which shows that judging from the ASAI alone, it is the most accessible bus stop while the bus stop with the lowest ASAI is Abuja Park with 5.118, indicating low accessibility. This alone cannot be used to determine the level of accessibility as there is no uniform length of roads and coverage area; therefore, a stop coverage ratio index is required. The ASAI is seen in Table 1.

3.6. Stop Coverage Ratio Index (SCRI)

The SCRI is calculated by dividing the ISAI by the ASAI, as seen in Table 1. The resulting value does not exceed 1 and not less than 0. The bus stop is less accessible the closer the value is to 0, and more accessible the closer the value is to 1.0. Evaluating the SCRI, showed that the IBBI Bus stop has the lowest SCRI value, this denotes that it has the lowest actual access coverage area. This, however is in

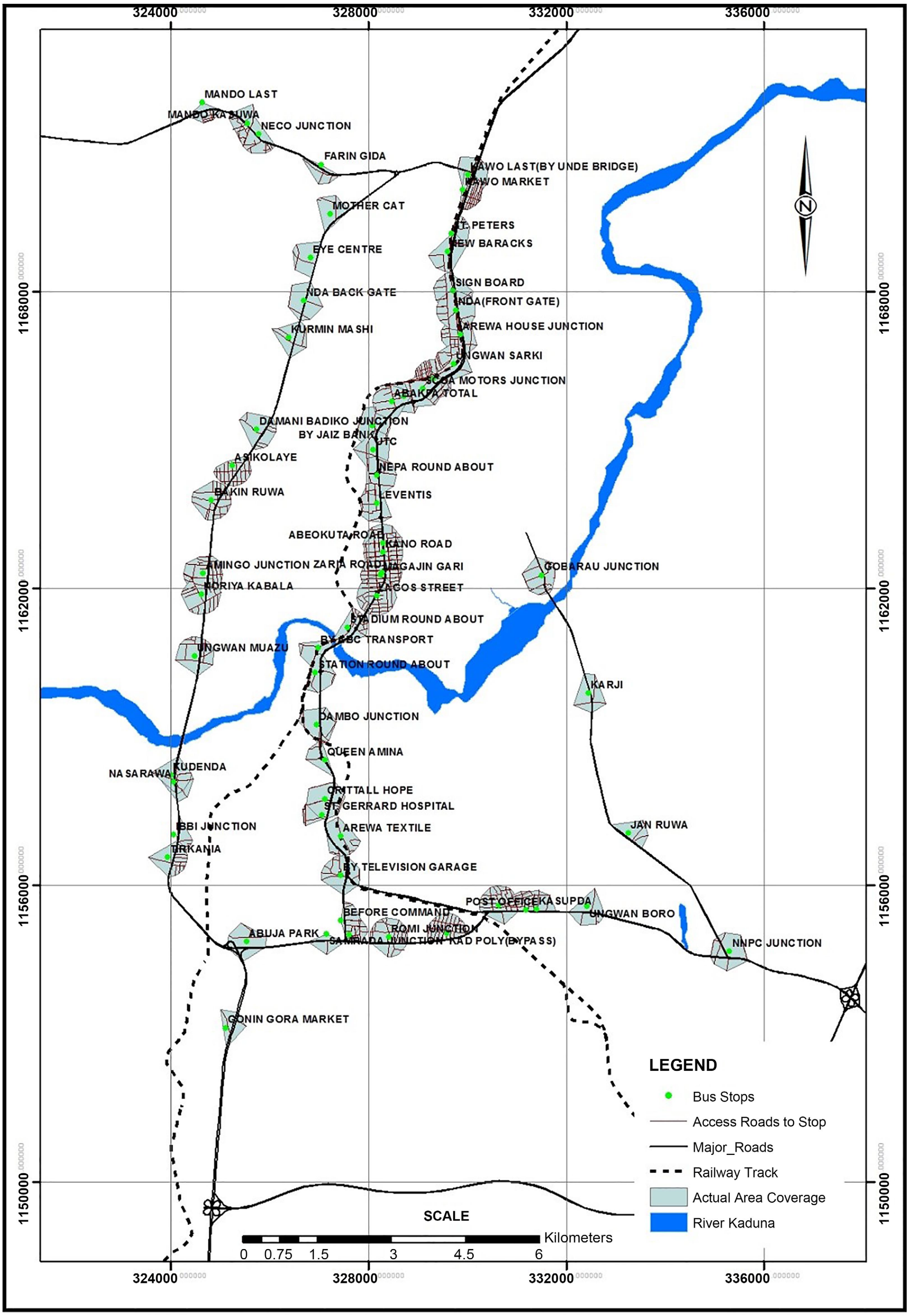

Figure 5. Kaduna metropolis showing actual bus stops access coverage. Source: Author's Fieldwork (2018).

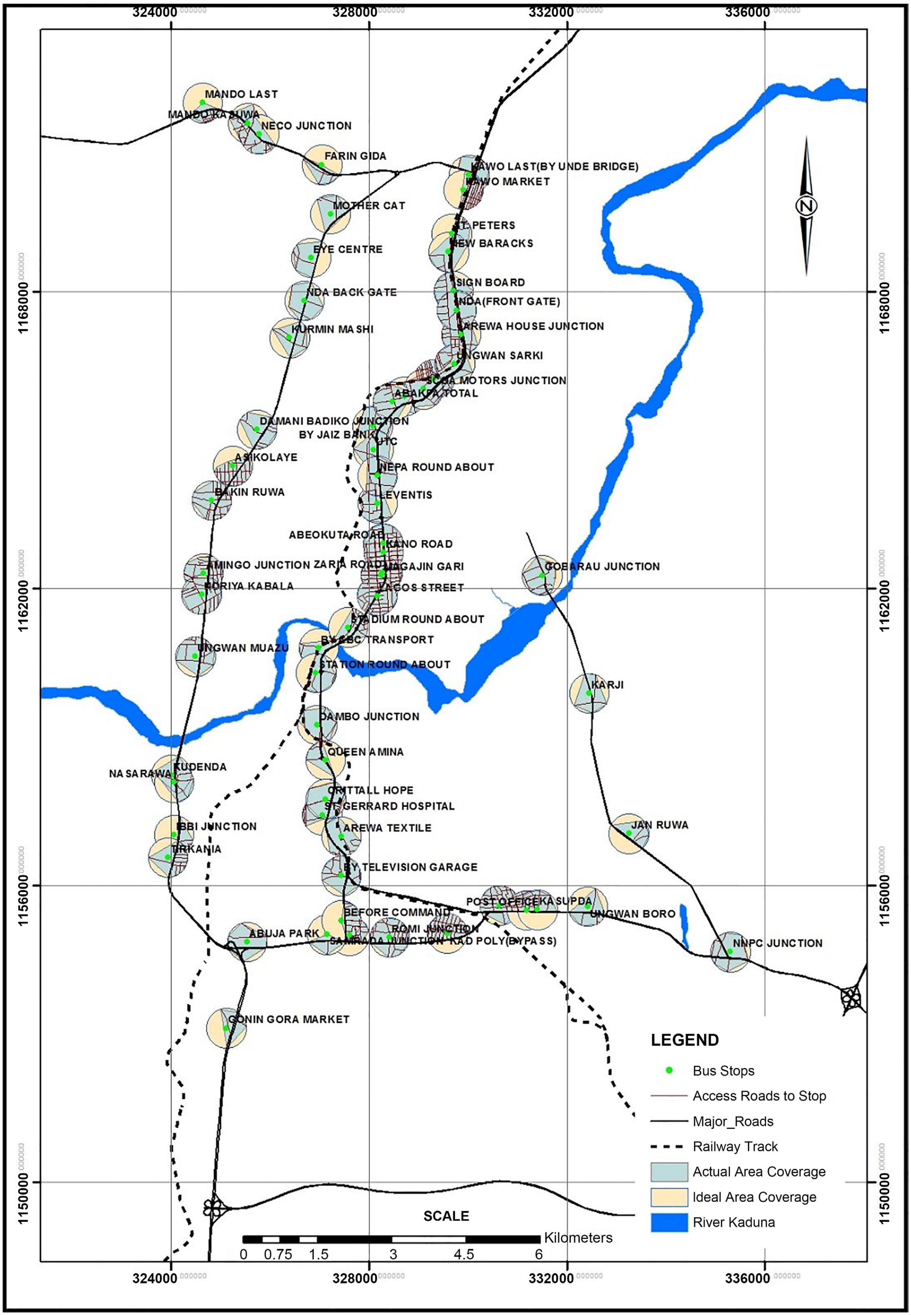

Figure 6. Kaduna metropolis showing actual and ideal bus stop access coverage. Source: Author's Fieldwork (2018).

Table 1. Bus stop access and road network coverage.

S/No.	Bus Stop Name	Ideal Access Coverage (Km^2)	Actual Access Coverage (Km^2)	Road Network Within 400 m (Km)	ISAI (Km^2/Km)	ASAI (Km^2/Km)	SCRI (Km^2/Km)
1	Mando Last	0.503	0.15	1.744	3.467	11.627	0.298
2	Mando Kasuwa	0.503	0.285	2.271	4.515	7.968	0.567
3	Neco Junction	0.503	0.318	2.815	5.596	8.852	0.632
4	Farin Gida	0.503	0.165	1.897	3.771	11.497	0.328
5	Mother Cat	0.503	0.284	0.921	1.831	8.528	0.215
6	Eye Centre	0.503	0.289	1.093	2.173	8.473	0.256
7	Nda Back Gate	0.503	0.375	2.121	4.217	5.656	0.746
8	Kurmin Mashi	0.503	0.315	2.34	3.857	11.548	0.334
9	Damani Badiko Junction	0.503	0.378	2.375	4.722	7.027	0.672
10	Asikolaye	0.503	0.314	5.425	10.785	17.277	0.624
11	Bakin Ruwa	0.503	0.452	5.422	10.779	11.996	0.899
12	Amingo Junction	0.503	0.463	5.302	10.541	11.451	0.920
13	Noriya Kabala	0.503	0.451	5.209	10.356	11.550	0.897
14	Ungwan Muazu	0.503	0.429	2.875	5.716	8.846	0.646
15	Kudenda	0.503	0.327	2.389	4.750	7.306	0.650
16	Ibbi Junction	0.503	0.156	1.623	3.227	19.793	0.163
17	Nasarawa	0.503	0.338	2.543	5.056	7.524	0.672
18	Tirkania	0.503	0.351	1.891	3.759	5.387	0.698
19	Gonin Gora Market	0.503	0.227	1.538	3.058	6.775	0.451
20	Abuja Park	0.503	0.389	1.991	3.958	5.118	0.773
21	Samrada Junction	0.503	0.149	1.01	2.008	6.779	0.296
22	Command Junction	0.503	0.184	3.026	6.016	16.446	0.366
23	Romi Junction	0.503	0.458	5.22	10.378	11.397	0.911
24	Kad Poly (By Express)	0.503	0.346	6.631	13.183	19.165	0.688
25	Angwan Gimbiya	0.503	0.446	6.568	13.058	14.726	0.887
26	Ungwan Boro	0.503	0.313	1.765	3.509	5.639	0.622
27	Nnpc Junction	0.503	0.415	3.137	6.237	7.559	0.825
28	Jan Ruwa	0.503	0.225	1.633	3.247	7.258	0.447
29	Karji	0.503	0.324	2.009	3.994	6.201	0.644
30	Gobarau Junction	0.503	0.371	3.643	7.243	9.819	0.738
31	Scoa Motors Junction	0.503	0.394	2.511	4.992	6.373	0.783
32	Ungwan Shanu	0.503	0.451	6.39	12.704	14.169	0.897
33	Ungwan Sarki	0.503	0.397	3.829	7.612	9.645	0.789
34	Arewa House Junction	0.503	0.428	4.806	9.555	11.229	0.851
35	Nda (Front Gate)	0.503	0.477	4.18	8.310	8.763	0.948

Continued

36	Sign Board	0.503	0.424	3.116	6.195	7.349	0.843
37	New Baracks	0.503	0.348	1.9	3.777	5.460	0.692
38	St. Peters	0.503	0.205	1.664	3.308	8.117	0.408
39	Kawo Market	0.503	0.264	4.614	9.173	17.477	0.525
40	Kawo Last (By Unde Bridge)	0.503	0.363	2.839	5.644	7.821	0.722
41	Abakpa Nepa	0.503	0.406	3.453	6.865	8.505	0.807
42	Abakpa Total	0.503	0.385	3.443	6.845	8.943	0.765
43	By Jaiz Bank	0.503	0.413	2.532	5.034	6.131	0.821
44	Utc	0.503	0.393	2.994	5.952	7.618	0.781
45	Leventis	0.503	0.353	3.608	7.173	10.221	0.702
46	Zaria Road	0.503	0.489	8.978	17.849	18.360	0.972
47	Magajin Gari	0.503	0.485	7.614	15.137	15.699	0.964
48	Stadium Round About	0.503	0.292	3.095	6.153	10.599	0.581
49	By Abc Transport	0.503	0.213	1.425	2.833	6.690	0.423
50	Station Round About	0.503	0.297	2.558	5.085	8.613	0.590
51	Dambo Junction	0.503	0.373	3.208	6.378	8.601	0.742
52	Queen Amina	0.503	0.195	1.739	3.457	8.918	0.388
53	Crittall Hope	0.503	0.421	2.615	5.199	6.211	0.837
54	St. Gerrard Hospital	0.503	0.239	3.141	6.245	13.142	0.475
55	Arewa Textile	0.503	0.36	2.422	4.815	6.728	0.716
56	By Television Garage	0.503	0.436	3.825	7.604	8.773	0.867
57	Before Command	0.503	0.211	2.782	5.531	13.185	0.419
58	Kano Road	0.503	0.483	8.121	16.145	16.814	0.960
59	Abeokuta Street	0.503	0.483	7.067	14.050	14.631	0.960
60	Post Office	0.503	0.255	3.763	7.481	14.757	0.507
61	Kasupda	0.503	0.26	3.889	7.732	14.958	0.517
62	Nepa Round About	0.503	0.39	3.562	7.082	9.133	0.775
63	Lagos Street	0.503	0.485	6.719	13.358	13.854	0.964
	Total	**31.689**	**21.054**	**216.429**	**430.276**	**646.673**	**41.856**

Source: Author's Fieldwork (2018).

comparison to the bus stops under study, using the surrounding road networks. Inversely, the Zaria Road bus stop is found to have the highest SCRI value, which means that it has the highest actual access coverage area among the stops.

3.7. Paired t-Tests for Ideal and Actual Distance Coverage

The paired samples t-test was conducted to compare ideal access coverage and actual access coverage in Table 2.

From Table 3, t(62) = 12.937, $p < 0.0005$. Due to the means of the two distance

Table 2. Paired statistics for ideal and actual distance coverage.

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Ideal Access Coverage (Km^2)	0.50300	63	0.000000	0.000000
	Actual Access Coverage (Km^2)	0.34532	63	0.096740	0.012188

Source: Author's Fieldwork (2018).

Table 3. Paired samples test.

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Ideal Access Coverage (Km^2) - Actual Access Coverage (Km^2)	0.157683	0.096740	0.012188	0.133319	0.182046	12.937	62	0.000

Source: Author's Fieldwork (2018).

coverage and the direction of the t-value, it can be concluded that there was a significant difference between the ideal and actual access coverage. It can be further deduced that the actual access coverage is a more reliable indicator of accessibility than the ideal access coverage of the bus stops.

3.8. Regression Analysis for Level of Accessibility (SCRI) and Road Length

The regression model summary in Table 4 revealed that at R = 0.694, there is a strong degree of correlation between the level of accessibility and road length within the buffer. And the $R^2 = 0.482$ indicates that 48.2% of the level of accessibility (SCRI) can be explained by the density of the road network, this also shows that there may be other factors outside the study that may have effect on the level of accessibility apart from the density of road network. However, the relationship between the level of accessibility (SCRI) and density of road network is statistically significant at p-value (0.000). The regression model significantly predicts the outcome variable, which means the model fits the data in appendix v and vi.

3.9. Regression Coefficients

This section analyses the level of accessibility commuters have to bus stops within the Kaduna metropolis using linear regression. The linear regression models have been widely used in literature to estimate the degree of fitness and also forecast and determine relationships between dependent and independent variables that are continuous, have a linear relationship, have no significant outliers,

Table 4. Regression model summary.

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.694[a]	0.482	0.474	0.155960

[a]Predictors: (Constant), road network within 400M. Source: Author's Fieldwork (2018).

Table 5. Regression coefficients.

Coefficients[a]								
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	0.388	0.042		9.303	0.000	0.304	0.471
	ROAD NETWORK WITHIN 400M	0.080	0.011	0.694	7.538	0.000	0.059	0.102

[a]Dependent variable: accessibility level SCRI. Source: Author's Fieldwork (2018).

have independence of observation, show homoscedasticity and are normally distributed.

It can therefore be conceptualized that variable X can be used to explain the level of accessibility of commuters to bus stops from adjoining land areas in Kaduna metropolis.

Table 5 shows that road length has a strong positive correlation with the level of accessibility. However, this model indicates that for every unit increase in road length within the buffer, the level of accessibility increases by 0.080. Therefore, the regression model for the level of accessibility is described thus:

Level of accessibility (SCRI) = 0.388+ 0.080 (Road Network)

4. Conclusions

This research used the ArcGIS 10.8.1 software for buffer and network analysis, where three indices to assist in assessing a bus stop location were developed, based on the interaction between the bus stop location and the actual road network surrounding it. To evaluate the accessibility of bus stops through the surrounding road network, the Ideal Stop-Accessibility Index (ISAI) was employed, also to assess and compare different stop locations from a spatial perspective. For a more accurate measurement of the road network density around a bus stop, the Actual Stop-Accessibility Index (ASAI) was employed. The percentage of actual access coverage of a bus stop with respect to its ideal access coverage was evaluated using the Stop Coverage Ratio Index (SCRI). The accessibility of a bus stop is higher when the road network surrounding it is denser and has a higher ISAI value. The ratio known as the SCRI which is; actual access coverage to the ideal access coverage of the bus stop. The ASAI value showed the estimated actual road network density within the access threshold from the bus stops, it did not offer a suitable base to compare the accessibility of different bus stop locations. The SCRI, however offered a basis to compare the bus stops within the Kaduna metropolis.

The rationale of this research is to move a step further away from the conventional research that relies heavily on questionnaires. Previous researches, especially within the study area which focused on accessibility have not gone into much detail considering pedestrian access roads. This research is recommended as a method for transit planners and highway engineers in getting the best way of locating bus stops. Further studies could focus on studying the accessibility of bus stops to various land uses and compliance to bus spacing standards within Kaduna metropolis.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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