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Geospatial Mapping for Effective Public Infrastructure: A Scenario of Bus Stops in Akure, South Ondo State, Nigeria

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Abstract

The bus stop is a designated place where buses stop for passengers to board and alight from. This study aims to map bus stops for effective public infrastructure using Geographic Information Systems (GIS). A total of 73 bus stops were identified within the study area. Data for the bus stops were collected using a hand-held GPS Map 76 CSX, while attribute data was sourced from the Ministry of Transportation and the base map from Google Earth. The study employed ArcGIS 10.3 software, where a database was created and different queries were performed based on attribute data. Two spatial distribution methods were used: the Quadrat method and the Nearest Neighbour method. The Quadrat method yielded a mean of 0.081111, a variance of 2.78145, and a variance/mean ratio of 3.432507, while the Nearest Neighbour method produced a z-score of −9.84310 and a p-value of 0.00000. Buffer analysis at 300 m and density analysis were also performed. Results from both methods indicated that the bus stops were clustered. The study concludes that mapping and analyzing bus stop spatial distribution is essential for optimizing public infrastructure.

Keywords Geospatial Mapping · Infrastructure · Bus Stops

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Geospatial Mapping for Effective Public Infrastructure: A Scenario of Bus Stops in Akure, South Ondo State, Nigeria

A bus stop is a designated place where buses stop for passengers to board or alight from and is a vital component of a successful transportation system (Fatunmibi, 2018, Daudu et al., 2022). Bus stops play an important role as they serve as transit service points of contact between the passenger and the bus (Olowosegun and Okoko, 2012). These are normally positioned on the highway and are distinct from off-highway facilities such as bus stations. The construction of bus stops tends to reflect the level of usage. Stops at busy locations may have shelters, seating, and possibly electronic passenger information systems; less busy stops may use a simple pole and flag to mark the location (Fatunmibi, 2018). Bus stop design and location are recognized as crucial elements in the drive to improve the quality of bus services and public transport in general and also to meet the required convenience and comfort of bus stops, just as the Bus Priority Team (2006) stressed their high level of importance. Any urban area must have an effective and well-planned public infrastructure to operate efficiently. An efficient public infrastructure system is essential for ensuring commuters' accessibility, connectivity, and comfort in the context of transportation. An effective tool for improving public infrastructure, such as bus stops, is provided by geospatial mapping in conjunction with data analysis.

The process of geospatial mapping entails the gathering of pertinent information on current bus stops, the examination of spatial patterns and variables affecting their placement, and the visualization of this data on maps to aid in comprehension and decision-making. Key information on the distribution of bus stops, their proximity to population centres, the demand for transportation, and accessibility to significant facilities like schools, hospitals, and commercial districts can be obtained by geospatial analysis. The management of traffic and congestion depends heavily on bus stops, which are an essential part of the transportation infrastructure (Allison, 2002). The design and placement of bus stops are acknowledged as key components in the effort to enhance the quality of bus services and public transportation in general. The term "Total Journey Quality" refers to the idea that all parts of the journey must be taken into account, including the fact that bus passengers are also pedestrians at both ends of the bus trip. It is important to consider the comfort and convenience of bus stops (Bus Priority Team, 2006). However, the difficulties that make bus use in Nigeria ineffective include illegal parking, abandoned vehicles, and cramped bus stops (Rodrigo and Tyler, 2004), as well as the un-spacious nature of bus stops in Nigeria, which impedes traffic flow along them. These challenges are more prevalent within the city of Lagos (Olaogbebikan et al., 2013).

In Nigeria and the world over, there is no denying the fact that transportation is essential to the fabric of urban life, as it enhances the quality of life of the citizens and delivers dividends to the entire populace. The basis of this assertion is not farfetched, as the study conducted in this context by O'Sullivan (2000) affirms that the quality of life of its citizens is heavily dependent on the efficiency and effectiveness of its transportation system. As good as the system is, there are also some identified threats to it. As such, public transportation is an essential system that helps curb the menace of transportation. The latter is diversified, and each of its components is highly pertinent to the delivery of a sustainable transport system. Among the components or factors that need to be considered for the proper implementation of the public transportation system are bus stops and bus stations.

A further study by Matisziw (2006) stated that to increase urban mobility, bus stops and articulated bus services must be placed in the best possible locations. By doing so, both those who use public transportation and those who own private vehicles will be encouraged to do so. As a result, there may be fewer private vehicles on the road, which would ease traffic and delays. In addition, research done in this area by Oyedepo (2014) showed that the demise of established public transportation networks has sparked a rapid rise in non-traditional modes of transportation, originally provided by minibuses, shared taxis, and vans, and more recently by commercial motorcyclists.

It is important to keep in mind that bus stops are geographically positioned in various places for various reasons; as a result, using spatial optimization to support strategic planning can help improve the current service. Given precise restrictions on the number of stops to be located, choosing new service stops will allow access to places that do not already have enough access to a facility for servicing vehicles The location of a bus stop is heavily influenced by the volume of traffic in a particular area. This study intends to use the proper tools to evaluate the spatial distribution and mapping of bus stops in the study region. The problem of the spatial distribution of bus stops necessitates the use of digital mapping and Geographic Information Systems (GIS). To evaluate policy objectives and make future improvement plans, it is essential to measure the performance and efficacy of public bus transportation (Murray et al., 1998).

A study conducted by Shatnawia *et al.,* (2020) optimized bus stop locations in Amman, Jordan, using Geographic Information Systems (GIS), Particle Swarm Optimization (PSO), and Genetic Algorithm (GA) to enhance travel time and serviceability. GIS reduced travel time by up to 23.25%, PSO achieved a 39% reduction, and GA yielded a 47.96% reduction in Zahran Street. While increasing the number of bus stops on Al-Quds Street increased the travel time from 12.25 to 50.71 minutes, it improved accessibility by reducing the walking distance from over 2000 m to approximately 400 m. The models demonstrated reliability when applied to other roads, proving useful for urban planning and promoting sustainable, efficient public transportation systems.

This study evaluated public transportation accessibility in Hyderabad, Pakistan, using ArcGIS-10.8 network analysis and a questionnaire survey of 400 participants (Mir et al., 2024). Findings revealed that 53.5% of stops are highly accessible (5-min walk), while 29.3% are moderately accessible (10 min), 11.03% are poorly accessible (15 min), and 6.17% are inaccessible (20+ min). Inner-city areas show better accessibility, with distances ranging from 500 to 800 m, whereas stops 1600 m away require over 20 minutes of walking. Combining GIS analysis with commuter feedback highlights critical accessibility challenges, offering insights for reconfiguring transit systems and supporting sustainable urban development (SDG-11) in Hyderabad and similar urban centres.

Yaiza et al., (2024) combined geography, urban transit planning, and statistical learning to predict bus demand at the top level using a Generalized Additive Model. Incorporating non-linear relationships and spatial dependence, the model achieves a pseudo R-squared of 0.79. GIS processing identifies key factors such as land use, socioeconomic characteristics, and transit supply, with positive impacts from nearby universities, hospitals, and lodging areas. The methodology highlights the spatial dependencies for stops within 1.15 km and provides transferable insights for transit planners. Applications include route design, stop optimization, and urban planning impact assessment, promoting sustainable mobility with environmental and social benefits.

A study conducted by (Lach,2021) presents an evaluative framework to assess neighbourhood safety and transit convenience using indicators like elevation, service areas, crash statistics, and bus stop infrastructure. A case study of the Vine Neighborhood in Kalamazoo, MI, analyzed data with ArcGIS Pro, revealing that high elevations and crash rates compromise transit convenience. Improvements, such as pedestrian amenities or additional stops, were suggested. While further research is needed for practical implementation, this framework offers a foundation for creating safer, user-oriented transit systems that enhance residents' quality of life.

Hakan and Kocaman (2018) conducted a study on GIS Bus Stop Optimization for the Sakarya Public Transportation System. This study addresses the growing demand for urban transportation by analyzing Sakarya Metropolitan Municipality's (SBB) bus routes and stops using GIS. The research evaluates service levels in relation to regional populations and proposes an optimized bus stop model. The alternative model improves the current stop locations, aiming to enhance service efficiency and reduce traffic intensity.

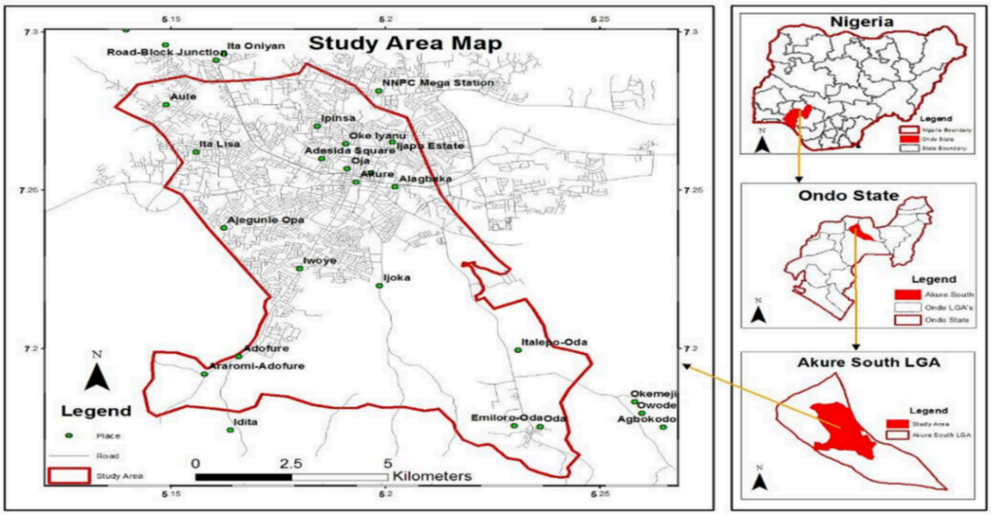
Alamri *et al.,* (2023) evaluated the adequacy and accessibility of public transportation in Melbourne's residential areas using a newly developed measurement model. By analyzing blank spots, transport options, and population density across local government areas (LGAs), the findings reveal that lower-density areas face reduced accessibility, while higher-density areas lack enhanced services like night-time and weekend options. This research highlights gaps in Melbourne's public transportation system, aiming to guide improvements by addressing geographical and demographic disparities, ensuring equitable access and supporting the city's growth.

Study Area

The study area selected for this research is Akure Environs in Ondo State, in the South-Western part of Nigeria. The geographic location is approximately between Latitudes 07°15′N to 07°30′N and Longitude 05°15′E to 05°25′E. The topography of the Basement Complex terrain of Akure is generally undulating with a virtually rugged terrain consisting of hills and valleys, with field recorded elevation varying between 330m above mean sea level in the south-western border (Nigeria Army barracks) and 399 m in the north-eastern border (Shagari Estate) (Michael and Franklin 2017 as cited by Tata and Ono (2018)).

Figure 1

Study Area Map of the Akure Environment
Source: (Tata and Ono, 2018)



Methodology

The attribute data (names and locations of the existing bus stops) were obtained from the Ondo State Ministry of Transportation. The Google Earth Imagery of the study area was clipped out of Google Earth to derive the base map through the digitizing process. The geographic coordinates of the existing bus stops were picked primarily from the field, geocoded, and integrated into the base map using ArcGIS 10.3 software. A GIS database was created, and the spatial and attribute data were encoded and queried (selection by

Location and Attributes). Quadrat and Nearest Neighbor using Microsoft Excel 2010 and ArcGIS 10.3 software, respectively, were used to determine the spatial distribution of the bus stops.

Quadrat analysis was used to estimate how the intensity of a point pattern varies over an area. It is a method suited for investigating first-order effects. The region was partitioned into sub-regions using AutoCAD software of equal area, or quadrats of 1000m 1000m, and superimposed on the bus stops in ArcGIS. The number of events in each quadrat was used to summarize the spatial pattern.

λ = N/A

where λ = intensity

N = number of bus stops

A = area

To describe the degree of spatial clustering of the point distribution, the nearest neighbour distance method uses the average distance from every point to its nearest neighbour point. Nearest neighbour distances provide an estimate of the presence of spatial dependence among events.

Results And Discussion

The variance-to-mean ratio of the event counts in the quadrats was used as a static test for randomness based on the chi-square frequency distribution. We had 90 quadrats. The test statistic is given by: (sum of squared differences)/Mean.

$$\frac{\sum_{i=1}^{n}(X_i - X^-)^2}{X^-} = \frac{\sum_{i=1}^{n} X_i^2 - \left[\frac{(\sum X_i)^2}{N}\right]}{X^-}$$

The values of the test statistics in our cases would be: $\frac{307-59.21111111}{0.8111111} = 319.2820914$

For degrees of freedom: N 1 = 90 1 = 89

Confidence interval 95% = 0.95 = 1 0.95 = 0.05

The value of the chi-square at the 0.95 level is 79.08.

If the variance-mean ratio is above 1, it is a clustered distribution; therefore, we conclude that the bus stops are clustered.

Table 1

Bus stops in each quadrat and the intensity

0	2	0	0	0	0	0	0	0
0	2	0	0	0	0	0	3	0
0	0	4	0	0	0	1	0	2
0	0	0	4	5	2	1	1	1
1	2	0	3	5	11	4	2	0
0	0	2	0	1	3	0	0	0
0	0	0	0	0	2	0	0	0
0	0	0	0	0	4	0	0	0
0	0	2	1	0	1	0	0	0
0	0	1	0	0	0	0	0	0
		intensity λ - number of events/Area						
0	0.000002	0	0	0	0	0	0	0
0	0.000002	0	0	0	0	0	0.000003	0

0	0	0.000004	0	0	0	0.000001	0	0.000002
0	0	0	0.000004	0.000005	0.000002	0.000001	0.000001	0.000001
0.000001	0.000002	0	0.000003	0.000005	0.000011	0.000004	0.000002	0
0	0	0.000002	0	0.000001	0.000003	0	0	0
0	0	0	0	0	0.000002	0	0	0
0	0	0	0	0	0.000004	0	0	0
0	0	0.000002	0.000001	0	0.000001	0	0	0
0	0	0.000001	0	0	0	0	0	0
	area - l^2	area - 1000000M^2						

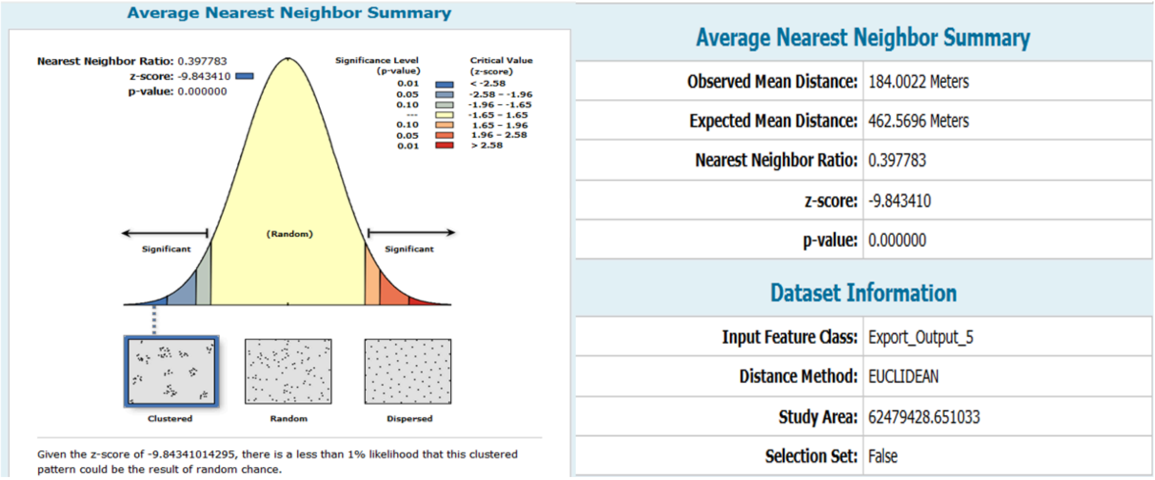
The quadrant method of analysis (Table 1) for bus stops was carried out to ensure equitable and efficient public transportation coverage. This method divides the area into manageable sections (quadrants), enabling a systematic evaluation of bus stop distribution, accessibility, and serviceability. It helps identify underserved areas, optimize stop locations, balance the spacing between stops, and ensure connectivity within neighbourhoods. Additionally, the quadrant method provided actionable insights for transit planning by highlighting high-demand zones, blank spots, and areas with overlapping services. Finally, this analysis boosts traveller accessibility, reduces walking distances, and promotes sustainable urban movement through better design of the transit network.

The ratio of nearest neighbours (Figure 2) serves to establish “how far the bus stops may be congregated or distributed”. A value <1 indicates clustering while >1 indicates dispersion. The Z-Score shows the statistical deviation of randomness from the observed pattern. A Z-Score with a high absolute value indicates either high levels of clustering or dispersion. The P-value complements the hypothesis, verifies the significance of the pattern, and informs if the chance occurred randomly. The spatial distribution of the bus stops, as revealed by the nearest neighbour analysis (Figure 2), indicates a clustered pattern. This is confirmed by a p-value below the significance level and a negative z-score, both of which signify significant clustering of the bus stops as affirmed by (Lach, 2021).

A higher clustering of bus stops can be observed in this data with a Nearest Neighbor Ratio of 0.4 z score of −8 and p value of 0.000 In this case, certain areas might be over-serviced while some have far fewer stops, which indicates that the placement of the stops requires reallocation or fine tuning. Reliable data is provided with this ANN analysis that aids transit planners in developing a better spatial distribution of bus stops and promotes the idea of a well-integrated and accessible public transportation system.

Figure 2

Nearest Neighbor summary

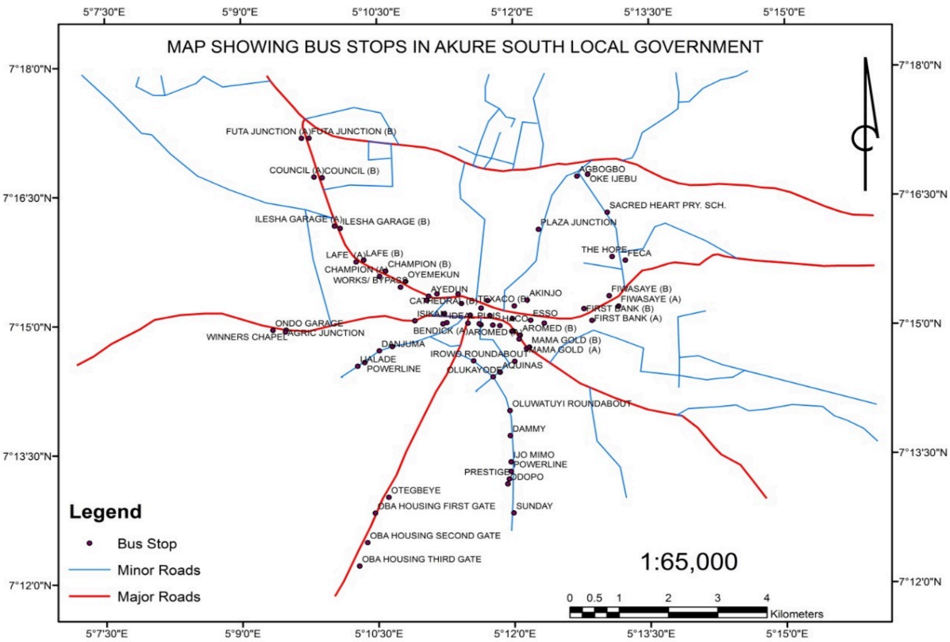


The clustering of bus stops (Figure 3) in urban areas highlights areas of high demand, such as central business districts, schools, or hospitals, enabling planners to enhance services in these zones. However, it may result in unequal coverage, leaving low-density or suburban areas underserved and contributing to traffic congestion and resource redundancy. Urban planning must address these challenges by optimizing stop (Figure 3) locations, balancing high-demand and underserved areas, and integrating bus networks with other transit systems. This ensures equitable accessibility, reduces car dependency, and promotes sustainable urban mobility, supporting goals like the Sustainable Development Goal (SDG-11) for sustainable cities and communities.

The Nearest Neighbor (ANN) analysis is highly suitable for analyzing bus stop distributions because it evaluates the spatial arrangement of points, helping to determine whether bus stops are clustered, randomly distributed, or dispersed across a given area. This is critical for assessing the efficiency, accessibility, and equity of public transportation systems.

Figure 3

Map showing bus stops in the Akure South Local Government



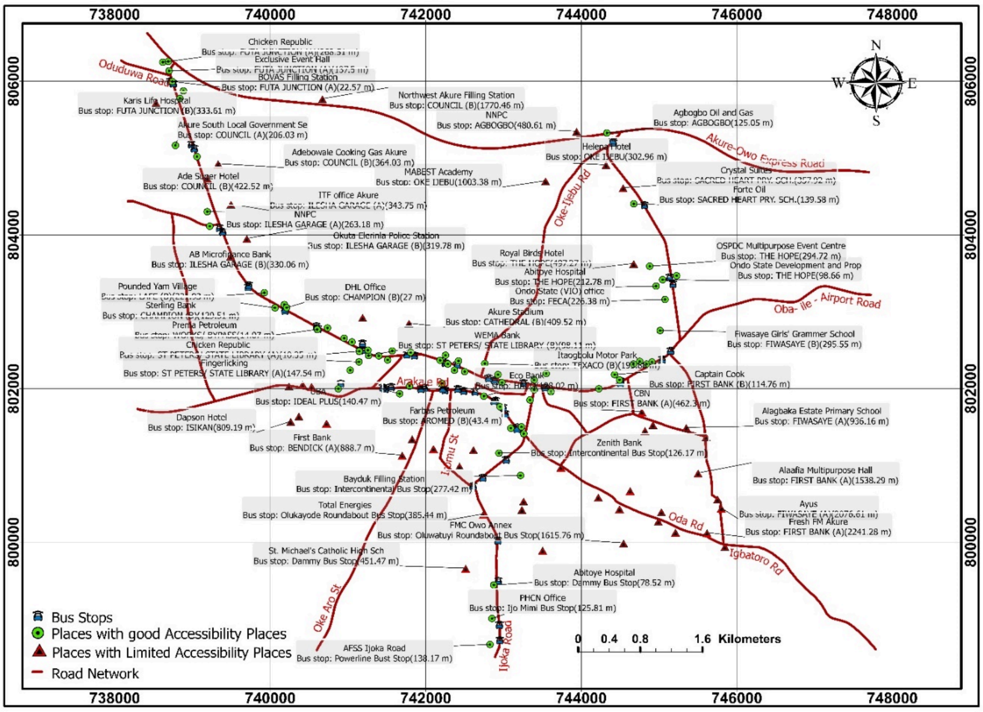
Proximity Analysis

The spatial join and the Near tool were used to allocate the closest bus stop to each chosen location (such as hospitals, churches, schools, hotels, etc.). Based on the spatial proximity, the nearest bus stop attributes to each location in the dataset were linked together using the spatial join. The Near tool was used to conduct a nearby neighbourhood analysis, which involved calculating the distance between each location and its closest bus stop. Equation 1 was used to calculate the travel and walking time (in minutes) between the two nearest bus stops as well as the proximity analysis between the bus stops (Table 1). In this study, 300 m was the maximum permitted walking or travelling distance. Additionally, the permitted walking speed is 4.5 km/h.

$$Walking\ Time\ (T) = \frac{Walking\ Distance\ (km)}{Walking\ Spead\ (km/hr)} * 60\ mins \tag{1}$$

Figure 4

Proximity Analysis Result



The outcome of the proximity analysis is shown in Figure 4. 72 locations were discovered to be just a few minutes walk from bus stations, indicating adequate accessibility to public transportation. Additionally, 48 locations are far from bus stations, which limits their access to public transportation. Considering this, a location for new bus stops was suggested.

Table 2

Walking time between bus stops

From	To	Walking Distance (km)	Walking Time (mins)
Sammy Store (B)	Sammy Store (A)	0.023	0.308
Champion (B)	Champion (A)	0.024	0.320
Mama Gold (B)	Mama Gold (A)	0.025	0.334
Lafe (B)	Lafe (A)	0.025	0.334
First Bank (B)	First Bank (A)	0.027	0.364

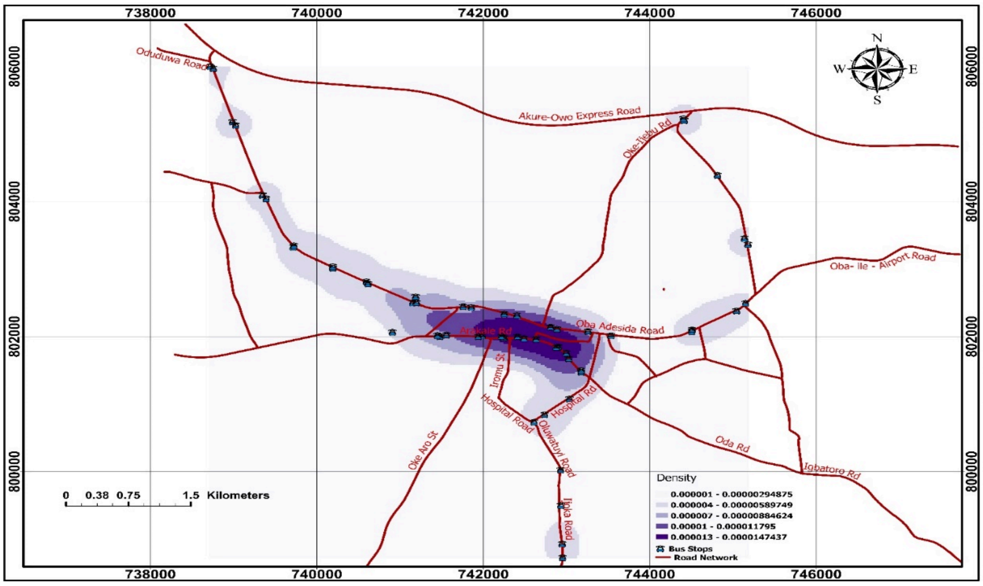
From	To	Walking Distance (km)	Walking Time (mins)
Agbogbo	Oke Ijebu	0.028	0.367
Bendick (B)	Bendick (A)	0.035	0.462
Health Center (B)	Health Center (A)	0.036	0.477
Works/Bypass	Oyemekun	0.038	0.503
Oyemekun	Futa Junction (A)	0.038	0.503
St Peters/State Library (B)	Futa Junction (B)	0.045	0.604
St Peters/State Library (A)	Council (A)	0.045	0.604
Futa Junction (B)	Futa Junction (A)	0.047	0.627
Council (B)	Council (A)	0.065	0.862
Ilesha Garage (B)	Ilesha Garage (A)	0.067	0.889
Ideal Plus	Bendick (A)	0.082	1.092
Texaco (B)	Lafe (B)	0.083	1.110
Texaco (A)	Champion (A)	0.083	1.110
Glober Plaza (A)	Glober Plaza (B)	0.083	1.113
Aromed (B)	Aromed (A)	0.088	1.176
Ayedun	Council (A)	0.088	1.179
Cathedral (B)	Council (B)	0.098	1.303
Cathedral (A)	Ilesha Garage (A)	0.098	1.303
The Hope	Feca	0.098	1.307
Haco	Glober Plaza (A)	0.144	1.925
Post Office (B)	Ilesha Garage (B)	0.154	2.048
Post Office (A)	Lafe (A)	0.154	2.048
Fiwasaye (B)	Fiwasaye (A)	0.156	2.075
Aquinas Bus Stop	Olukayode Round Bus Stop	0.167	2.230
Powerline Bust Stop	Ijo Mimi Bus Stop	0.202	2.694
Adegbemile	Champion (B)	0.284	3.785
Esso	Oyemekun	0.284	3.785
Intercontinental Bus Stop	Aquinas Bus Stop	0.380	5.062
Isikan	Futa Junction (B)	0.496	6.609
Oluwatuyi Bus Stop	Dammy Bus Stop	0.527	7.026
Sacred Heart Pry. Sch.	Oke Ijebu	0.906	12.081

Density Analysis

To visualize the spatial distribution and locate the concentrations of bus stops, Density Analysis was performed. To perform the Density Analysis on the bus stop dataset, which includes the X- and Y- coordinates of each bus stop, the “Kernel Density” tool on ArcGIS Pro software was used.

Figure 5

Density Analysis Result



In Figure 5, the density analysis revealed the concentration of the bus stops. The results show that bus stops are unevenly distributed across the study area. Notably, Mixed-use areas (banks, offices, restaurants, hotels, hospitals, petrol stations, etc.) emerged as prominent hotspots. These high-density cluster areas indicate that this area is well supported by public transportation and serves as an attractive destination for transit riders. However, the density analysis also reveals disparities in the bus stop distribution. Some routes exhibit lower densities of bus stops, while others exhibit no bus stops. The outcomes of the density analysis provide valuable insights for infrastructure decision-making and urban planning. High-density areas around bus stops demand targeted investment in transportation infrastructure and enhanced transit services. Moreover, the identification of low-density areas underscores the need to expand public transportation access and improve connectivity for residents. Addressing these planning considerations can lead to well-integrated urban development and more efficient transit systems.

Buffer Analysis

Buffer analysis involves creating a buffer zone around a point, line, or polygon feature. A buffer zone is a defined area around each feature within a specified distance. In this study, a buffer (which represents a walking distance) of 300 m was created around each bus stop (Figure 6). This is approximately 5 minutes at a walking speed of 4.5 km/h. This analysis was carried out to give a clearer overview of the places that fall within a 300-m walkable distance of each bus stop and to determine the area that is mostly in need of bus stops.

The buffer analysis successfully delineated the service areas around each bus stop, representing the areas within a reasonable walking distance from the stops, and the result is shown in Figure 6. The result reveals that most places along Oba-Adesida and Arakale, the hospital, Oluwatuyi, and Ijoka Road fall within the coverage of each bus stop. Conversely, the buffer analysis also revealed areas with limited service coverage around certain bus stops. It can be seen clearly from Figure 6 that places along the Oke-Aro, Oba-Ile-Airport, Oda, Oke-Ijebu, Igbatoro, and Akure-Owo express roads have limited coverage because there are inadequate or no bus stops along these roads. This reveals that more bus stops are needed in these areas with limited coverage (Underserved areas).

Figure 6

Buffer Analysis Result

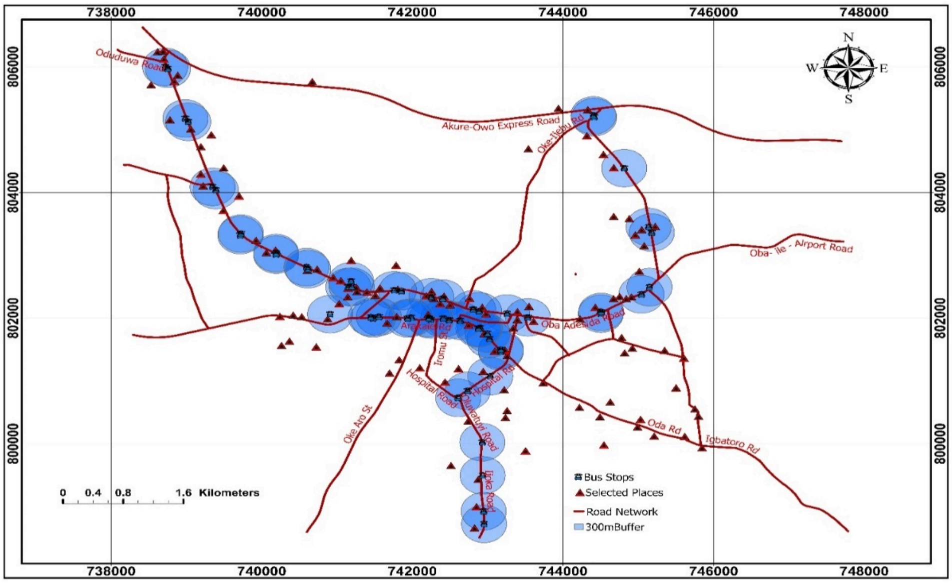
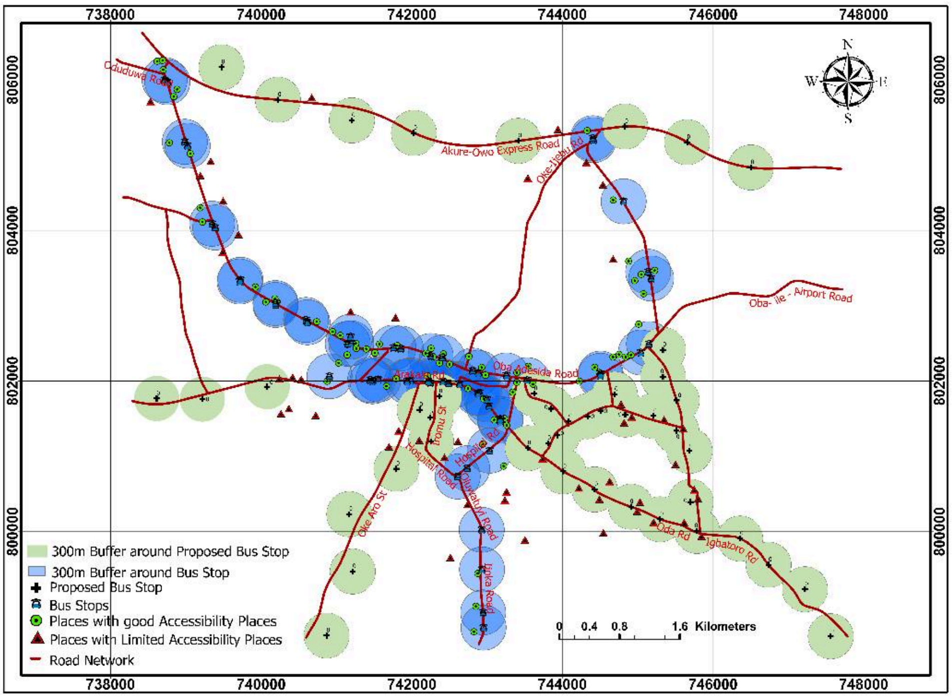


Figure 7 shows the spatial distribution of the bus stops and their accessibility within a 300 m buffer zone in relation to the proposed bus stops in the study area. Areas with good accessibility are shown in blue, while those with limited accessibility are highlighted in green. The results reveal significant gaps in coverage, particularly in marginal areas, where limited accessibility zones dominate. The Proposed bus intends to cover up areas not having access to bus stops, to enhance connectivity and service equity. Furthermore, this analysis reveals the need to optimize bus stop locations to ensure all-inclusive access, reduce walking distances, and improve public transportation service within these areas.

Figure 7

Shows the locations of the proposed bus stops



Conclusion

The study assesses the spatial distribution of Bus Stops in the Akure south local government area of Ondo state through the identification number of bus stops, mapping of the bus stops, generating the attribute data of bus stops, creation of a GIS database for bus stops and, analyzing the spatial distribution of bus stops in the study area. The Quadrat and the Nearest Neighbor analysis results show that the bus stops are Clustered. Furthermore, the proximity analysis between the bus stops at 300 m was the maximum permitted walking or travelling distance. The outcome of the proximity analysis shows that 72 locations were discovered to be just a few minutes walk from bus stations, indicating adequate accessibility to public transportation while 48 locations were far from bus stations, which limits their access to public transportation. The density analysis carried out revealed the concentration of bus stops. The results show that bus stops are unevenly distributed across the study area. Notably, Mixed-use areas (banks, offices, restaurants, hotels, hospitals, petrol stations, etc.) emerged as prominent hotspots. The successful implementation of this study can positively impact the lives of residents by providing a more reliable, convenient, and sustainable public transportation system.

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