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Geospatial Mapping and Analytical Evaluation of Street Networks in Nnewi North LGA, Anambra State, Nigeria Using GIS Techniques

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Abstract *- This study presents a geospatial assessment of the street network in Nnewi North Local Government Area (LGA) of Anambra State, Nigeria, with an emphasis on hierarchical classification, spatial distribution, and infrastructural condition. The analysis categorizes the road system into three hierarchical classes: major roads, minor roads, and local streets. Major roads, which facilitate regional connectivity and economic activities, span 13.51 kilometers and are characterized by relatively good surface conditions but exhibit signs of physical degradation, including surface cracks and faded markings. Minor roads, covering a total length of 36.03 kilometers, serve as critical links between neighborhoods and essential services but show moderate surface deterioration, such as potholes and depressions, which compromise mobility during adverse weather conditions. The local street network comprises 2,111 streets totaling 505.71 kilometers, of which only 166 are tarred. The remaining untarred streets, representing over 92% of the network, are in poor condition, frequently impassable during the rainy season due to erosion and waterlogging, compounded by inadequate drainage infrastructure.*

A spatial statistical analysis using the Average Nearest Neighbor (ANN) tool revealed a significant clustering pattern of key road network features, with an ANN ratio of 0.854, a z-score of -4.956, and a p-value of 0.000001. This clustering indicates the concentration of infrastructural features along major corridors and intersection zones. Field verification and quality control measures validated the positional and attribute accuracy of the digital map, confirming the reliability of the geospatial data used. The study underscores the urgent need for infrastructural intervention, particularly in the local street network, and provides a high-accuracy digital street map for urban planning, transportation infrastructure development, and service delivery optimization in Nnewi North LGA.

Keywords: *Road Network Assessment, Geospatial Analysis, Hierarchical Road Classification, Urban Infrastructure, Spatial Clustering.*

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I. Introduction

Nnewi North Local Government Area is an urban and industrial center known for its commercial activities and fast-growing population. With rapid urbanization, there has been an increasing demand for accurate, up-to-date geospatial data to support urban planning, transportation management, and infrastructure development. However, the lack of detailed and reliable street guide maps in parts of Nnewi North has posed significant challenges for urban planners, government agencies, and residents alike (Okoye, 2020).

Accurate street mapping plays a crucial role in urban management and development, as it provides essential information on road networks, land use patterns, and accessibility. Without such maps, navigating through urban areas, especially in rapidly expanding cities like Nnewi, becomes difficult for residents, visitors, and emergency responders (Onyeka *et al*., 2018). Inadequate street mapping also hinders effective planning for transportation networks, traffic management, and the provision of public services (Ifeoma & Chinedu, 2019). Additionally, businesses that rely on transportation and logistics are often affected by the lack of well-defined street maps, leading to inefficiencies in service delivery (Nduka *et al*., 2016).

Existing efforts to map street networks in Nnewi North LGA have been limited in scope and accuracy, often relying on outdated methods or incomplete data (Ogu *et al*., 2021). Traditional methods of street mapping, which largely depend on ground surveys, can be labor-intensive and time-consuming, leading to delays in

generating updated maps (Ifeoma & Chinedu, 2019). Moreover, with the increasing complexity of road networks due to urban sprawl, manual methods may fail to capture the full extent of road infrastructure, especially in areas that have undergone recent development (Okoye, 2020).

Geospatial technologies, particularly Geographic Information Systems (GIS) and remote sensing, offer a more efficient and accurate approach to street mapping. Recent advancements in high-resolution satellite imagery and GIS tools have made it possible to create detailed and up-to-date street maps, which are critical for supporting urban planning and decision-making (Onyeka *et al*., 2018). These technologies can significantly enhance the accuracy and comprehensiveness of street guide mapping by providing continuous, real-time data that is less prone to errors associated with manual surveys (Adefemi *et al*., 2017).

Street guide mapping using geospatial techniques not only ensures that urban areas are properly mapped but also enables integration with various datasets, such as land use, population distribution, and transportation systems, for a more holistic approach to urban management (Obianuju & Nwankwo, 2021). In Nnewi North LGA, where rapid urbanization continues to challenge traditional methods of urban governance, leveraging modern mapping tools has become increasingly important for sustainable development.

Therefore, the project seeks to perform street guide mapping for of Nnewi North LGA using GIS to produce accurate, up-to-date maps.

II. Materials and Methods

1.1. Study Area

Nnewi North Local Government Area (LGA) is situated in the southeastern region of Nigeria, within Anambra State. Geographically, the area extends between latitudes 5°58'N and 6°02'N, and longitudes 6°52'E and 6°57'E. It occupies a position within the tropical rainforest zone of the country. The LGA shares boundaries with Nnewi South to the south, Ekwusigo to the west, and Ihiala to the southeast. The administrative center of the LGA is the city of Nnewi, which is a prominent urban district within the area. Nnewi North is widely recognized as a major industrial and commercial center, often referred to as the "Japan of Africa" due to its highly developed auto parts manufacturing industry and its importance in regional commerce.

According to the 2006 national census, Nnewi North had a recorded population of approximately 185,295 residents. However, more recent estimates place the current population at nearly 500,000 individuals, reflecting the rapid rate of urbanization and migration into the area. The LGA hosts a diverse demographic composition, predominantly comprising traders, industrial workers, and artisans. Its reputation as a commercial and industrial nucleus attracts inhabitants from various parts of Nigeria and beyond, thereby contributing to its status as one of the most rapidly urbanizing regions in southeastern Nigeria (Okoye, 2020).

The climate of Nnewi North is characteristic of the tropical rainforest ecosystem, with a distinct alternation between wet and dry seasons. The rainy season generally occurs from April to October, delivering annual precipitation between 1,500 mm and 2,000 mm. Conversely, the dry season extends from November to March and is influenced by the Harmattan, a seasonal wind that carries dry, dusty air from the Sahara Desert. Throughout the year, temperatures remain elevated, averaging between 26°C and 32°C, and high humidity levels are particularly prevalent during the wet months, which sustain the area's rich vegetation (Ifeoma & Chinedu, 2019).

Vegetation in Nnewi North is predominantly composed of tropical rainforest species. The landscape supports dense hardwood trees, shrubs, and grasses, thriving on the region's fertile soils. These conditions have historically facilitated robust agricultural practices, including the cultivation of staple crops such as yam, cassava, maize, and various vegetables. However, extensive urban and industrial development has led to considerable alterations in land cover, with significant portions of natural vegetation being replaced by built-up areas. Nevertheless, remnants of the original rainforest vegetation persist in less developed zones, contributing ecological benefits and sustaining local biodiversity (Nduka et al., 2016).

1.2. Methodology

The methodology adopted for this study integrates a sequence of geospatial data acquisition, processing, analysis, and presentation techniques geared towards revising and updating the base map of Nnewi North Local Government Area. The datasets utilized for the research include the existing base map of Nnewi North LGA, high-resolution imagery extracted from Google Earth, and ground control coordinates collected through GPS field surveys.

Primary datasets were acquired through direct field observations. Specifically, twenty ground control points were captured using a Garmin 76 handheld GPS device, which were later used for positional accuracy assessment. Additionally, non-spatial attribute data, describing features observable on the ground, were recorded during field visits to support feature annotation. Secondary datasets were obtained from institutional archives and online platforms. Administrative maps of Anambra State and Nnewi North LGA were sourced from the

Department of Surveying and Geoinformatics at Nnamdi Azikiwe University, while Google Earth imagery was downloaded from Google Earth Pro.

The research also required specific hardware and software configurations. The hardware included the Garmin GPS receiver for spatial data collection, a personal laptop system for data processing and analysis, and a printer for producing final cartographic outputs. The software components consisted of ArcGIS version 10.7, which was employed for spatial data management, processing, and map production, and Microsoft Excel and Word, which facilitated statistical analysis and textual report preparation.

Image registration and rectification were conducted to ensure accurate spatial alignment. The Google Earth imagery used was pre-georeferenced to the WGS 1984 UTM Zone 32N coordinate system. An existing hardcopy base map of the study area was scanned using an AO scanner and saved in TIFF format. The scanned map was then imported into ArcGIS 10.7, where georeferencing was carried out using the image-to-image registration method. Prominent features such as road intersections were selected as control points. These were matched with field-collected GPS coordinates to validate spatial accuracy. The georeferencing process involved inputting known coordinates into ArcGIS and rectifying the image to produce a new, spatially referenced layer.

Subsequently, features from the scanned and georeferenced base map were digitized. On-screen digitization was performed using ArcGIS 10.7 to capture features such as expressways, major and minor roads, paths, and rivers. Feature classes were created within a geodatabase using ArcCatalog, and the digitizing process was conducted with proper snapping configurations to mitigate errors such as overshoots and undershoots. Layers were systematically created for each entity type and populated through heads-up digitizing.

Change detection was implemented by overlaying the digitized base map with the updated Google Earth imagery. This allowed for the identification of new roads and other infrastructural changes. Newly identified features were also digitized and integrated into the updated dataset. This analytical process culminated in the revision and updating of the existing base map.

The map revision stage also involved topological structuring. Spatial relationships among features were established using the topology tools in ArcGIS, ensuring connectivity among road networks and correcting geometrical anomalies such as dangling nodes. Additional editing was performed to refine feature shapes and correct attribute inconsistencies.

Database creation followed a structured GIS workflow. Conceptual design involved identifying key spatial entities and their attributes. Roads were modeled as linear features, landmarks and roundabouts as polygons, and bridges as lines. The logical design adopted a relational model, assigning entity types to attribute tables, while physical implementation was carried out within the ArcGIS environment. The database structure allowed for easy querying, updating, and visualization of the spatial entities.

Field validation was conducted at the final stage of the study. A draft of the revised map was taken to the field for verification. This phase involved updating the attribute data of mapped features, including road names, river labels, and facility locations. Positional accuracy was assessed by comparing coordinates from the revised map with those acquired via handheld GPS. Additional coordinates for features such as schools, markets, and churches were collected and plotted to enrich the final map. Field validation ensured consistency between the cartographic output and the real-world configuration of spatial features within Nnewi North LGA.

III. Results

2.1 Assessment of the Total Length of Road Network in Nnewi North LGA Across Three Hierarchical Levels

The road network in Nnewi North Local Government Area (LGA) is categorized into three distinct hierarchical levels: major roads, minor roads, and the local street network. Starting with the major roads, these serve as the primary transportation routes linking Nnewi North LGA to neighboring towns. These roads span a total distance of 13,510.28 meters (13.51 kilometers), with individual road lengths ranging from a minimum of 75.20 meters to a maximum of 3,344.55 meters. On average, each major road has a mean length of 1,125.86 meters. Some of the most notable major roads include the Nnewi–Okigwe Road, New Oba–Nnewi Road, and Nnewi–Nnobi Road. These major roads are vital for the Nnewi North's economic activities, as they facilitate the movement of people, goods, and services across both urban and rural areas within Nnewi North and beyond. They are typically wide, well-paved, and serve as key arteries connecting Nnewi to larger transportation hubs.

Moving on to the minor roads, which act as secondary links, connecting neighborhoods, local institutions, and business areas, the total length of these roads' amounts to 36,032.44 meters (36.03 kilometers). Minor roads in the LGA vary in length, with the shortest road measuring 173.60 meters and the longest reaching up to 2,932.59 meters. The average length of a minor road is 1,201.08 meters. Examples of important minor roads include Nwafor Orizu Way, Bank Road, Owerri Road, and Eme Court Road. These roads are important for local traffic and serve as connections between major roads and smaller streets, playing a significant role in ensuring accessibility to commercial centers, schools, hospitals, and other essential services. Although minor roads typically have narrower lanes than major roads, they remain essential for local mobility and supporting intra-city transportation.

Lastly, the street network is the most extensive in terms of both count and total length, reflecting the dense urban fabric of Nnewi North LGA. A total of 2,111 streets were identified, covering an impressive total length of 505,712.38 meters (505.71 kilometers). Individual streets range in length from 2.08 meters to 3,284.41 meters, with an average street length of 239.56 meters. These streets form the fine mesh of smaller roads that provide direct access to homes, businesses, and other localized services. The street network is typically composed of residential roads, alleyways, and service roads, which are critical for everyday mobility within smaller communities. While these streets are often narrow and less structured than major or minor roads, they are essential for ensuring last-mile connectivity for residents and play a key role in emergency response and service delivery.

2.2 Assessment of the Total Length of Road Network in Nnewi North LGA Across Three Hierarchical Levels

The assessment of the road network in Nnewi North LGA indicates variations in the condition of roads across the three hierarchical levels: major roads, minor roads, and the street network.

The major road network in Nnewi North LGA consists of 4 primary roads, all of which are tarred and generally in slightly good condition. While these roads are paved, it is important to note that their quality shows signs of wear and tear, with minor issues such as surface cracks, faded markings, and occasional potholes observed in certain sections. These conditions indicate a need for routine maintenance to preserve the usability and safety of the roads. Despite these minor flaws, the major roads still provide relatively smooth and uninterrupted flow for vehicular traffic, supporting the movement of goods and services, as well as serving as critical connectors between Nnewi North LGA and surrounding regions.

The 30 minor roads in Nnewi North LGA are also tarred, exhibiting similar characteristics to the major roads. These roads are in slightly good condition, with a functional but aging surface. Although they generally allow for efficient vehicular movement, several minor roads have visible surface deterioration, such as potholes, minor depressions, and uneven patches, which could pose challenges for daily commuters and increase the risk of accidents, particularly during the rainy season. The tarred nature of these roads ensures better durability compared to untarred roads, but ongoing maintenance efforts, such as patching and resurfacing, will be essential to improve the overall quality and extend the lifespan of these roads.

These minor roads play a vital role in connecting residential neighborhoods, institutions, and businesses within the LGA, their condition, although relatively stable, could be improved with strategic road upgrades and investment in maintenance.

The street network in Nnewi North LGA, which is the most extensive part of the road system, consists of 2,111 streets. However, the quality of these streets varies significantly compared to the major and minor roads. Out of the total street network, only 166 streets are tarred, while a substantial 1,945 streets remain untarred. The tarred streets are in relatively good condition, providing smoother and more reliable transportation for vehicles and pedestrians alike. These streets are mostly found in commercial and densely populated urban areas, where road infrastructure is more developed.

In contrast, the untarred streets, which make up the majority of the street network, are characterized by poor conditions, particularly in terms of surface quality. These roads are often uneven, dusty in dry seasons, and muddy or even impassable during the rainy season due to erosion and waterlogging. The lack of proper drainage systems further exacerbates the deterioration of these untarred roads, making them less reliable for consistent use, especially for motor vehicles. Pedestrians, motorcycles, and tricycles primarily use these untarred roads, though they face difficulties during inclement weather, contributing to delays and safety concerns.

2.3 Spatial distribution of features associated with the road network in Nnewi North LGA

The Average Nearest Neighbor (ANN) analysis assessed the spatial distribution of key features related to the road network in Nnewi North LGA, such as landmarks, intersections, and infrastructure, by comparing the observed mean distance between these features to an expected mean distance under a random distribution (figure 1).

The Nearest Neighbor Ratio is the ratio between the observed mean distance and the expected mean distance. A ratio of 1 indicates a random distribution, while values below 1 indicate clustering, and values above 1 suggest dispersion.

In this case, the ratio gotten is 0.854025, which is below 1. This indicates that the features (landmarks, intersections, and infrastructure) associated with the road network in Nnewi North LGA are spatially clustered rather than randomly distributed or dispersed. This clustering indicates that these features are concentrated near major road corridors and intersections, rather than being evenly spread out across the entire area.

The Observed Mean Distance between features is 199.88 meters, while the Expected Mean Distance, assuming random distribution, is 234.05 meters. This indicates that, on average, the distance between features is shorter than would be expected in a random scenario. The difference between the observed and expected distances further confirms the clustering pattern, as features are located closer to each other than they would be if they were randomly scattered across the road network.

The z-score is a statistical measure that indicates how far the observed distribution deviates from a random distribution. A negative z-score (in this case, -4.956372) indicates clustering, with more negative values indicating stronger clustering.

The z-score of -4.956372 is highly significant, indicating that the clustering is far from what would be expected under a random distribution. A z-score this low indicated a strong degree of clustering, meaning the features are tightly grouped together.

The p-value of 0.000001 indicates that there is less than 0.01% chance that this clustering pattern could be the result of random chance. This statistically significant result confirms that the observed clustering is not random and likely reflects the underlying structure of the road network and the distribution of key features.

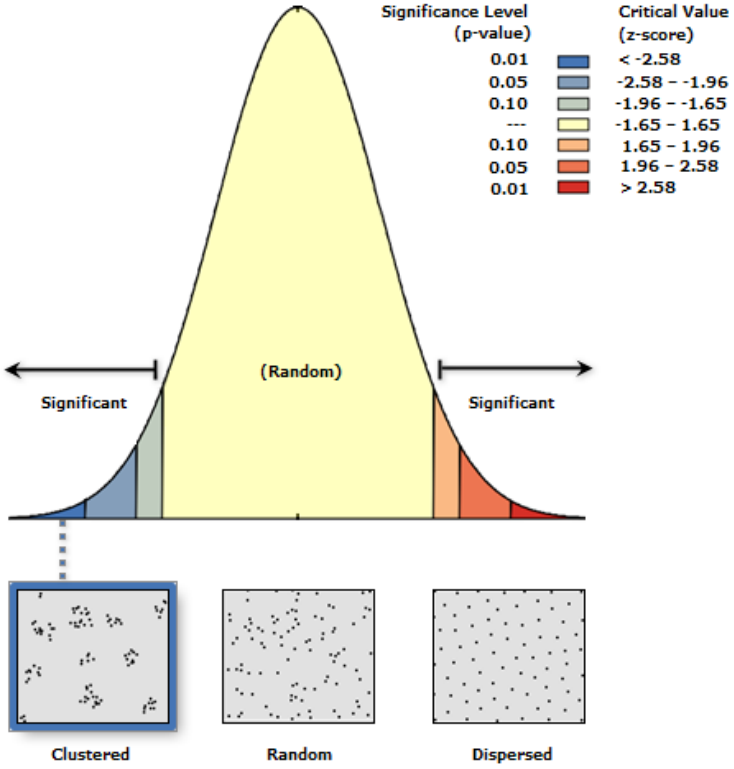

Figure 1: Spatial distribution of features along the road network of Nnewi North LGA

IV. Conclusion

The assessment of the road network in Nnewi North Local Government Area (LGA) examined the total length of roads across three hierarchical levels: major roads, minor roads, and the local street network.

The major roads, which serve as the primary transportation routes connecting Nnewi North to neighboring towns, span a total of 13,510.28 meters (13.51 kilometers). These roads, such as the Nnewi–Okigwe Road, New Oba–Nnewi Road, and Nnewi–Nnobi Road, play a vital role in facilitating economic activities by enabling the movement of goods and people. The lengths of the individual major roads vary, ranging from 75.20 meters to 3,344.55 meters, with an average length of 1,125.86 meters. These roads are wide, well-paved, and essential for connecting Nnewi North to larger transportation hubs.

The minor roads, acting as secondary links between neighborhoods, institutions, and businesses, cover a total length of 36,032.44 meters (36.03 kilometers). They range in length from 173.60 meters to 2,932.59 meters, with an average of 1,201.08 meters. Roads such as Nwafor Orizu Way, Bank Road, Owerri Road, and Eme Court Road are examples of important minor roads in the area. While they are generally narrower than major roads, these minor roads are crucial for ensuring access to commercial centers, schools, hospitals, and essential services.

The most extensive part of the road system is the street network, consisting of 2,111 streets with a total length of 505,712.38 meters (505.71 kilometers). The lengths of these streets range from as short as 2.08 meters to 3,284.41 meters, with an average street length of 239.56 meters. These streets, typically narrow and less structured than major or minor roads, provide direct access to homes and businesses. They form a dense network of residential roads and alleyways, which are critical for local mobility and play an important role in emergency response and service delivery.

When examining the condition of the road network in Nnewi North, it was found that all four major roads were tarred and generally in slightly good condition. However, signs of wear and tear, such as surface cracks, faded markings, and occasional potholes, were noted, indicating the need for routine maintenance to preserve their usability and safety. Despite these minor issues, the major roads continue to provide relatively smooth traffic flow and support the movement of goods and services within and beyond the LGA.

Similarly, the 30 minor roads in Nnewi North were tarred and in slightly good condition, though many showed surface deterioration, including potholes, minor depressions, and uneven patches. While these roads still allow for efficient vehicular movement, their aging surfaces could pose challenges for daily commuters, especially during the rainy season. Continuous maintenance and upgrades are necessary to improve the quality and extend the lifespan of these roads, which are vital for connecting residential neighborhoods and local institutions.

In contrast, the street network showed significant variation in quality. Out of 2,111 streets, only 166 were tarred, with the remaining 1,945 streets untarred and in poor condition. The untarred streets were uneven, dusty in dry seasons, and often impassable during the rainy season due to erosion and waterlogging. The lack of proper drainage systems exacerbated the deterioration of these streets, making them less reliable for consistent use. Despite these challenges, the tarred streets, mostly located in commercial and densely populated urban areas, were in relatively good condition, providing smoother transportation for vehicles and pedestrians.

A spatial analysis of key road network features, such as landmarks, intersections, and infrastructure, revealed that these features were not randomly distributed but were clustered. The Average Nearest Neighbor (ANN) analysis showed a ratio of 0.854, indicating spatial clustering of road network features. The observed mean distance between these features was 199.88 meters, while the expected mean distance under random distribution was 234.05 meters. This shorter-than-expected distance confirmed the clustering pattern, which was statistically significant, with a z-score of -4.956 and a p-value of 0.000001. The clustering suggests that key features of the road network are concentrated near major road corridors and intersections.

Field verification and quality control were critical aspects of the project to ensure the accuracy of the digital map and geographic database. The quality control process assessed positional accuracy, attribute accuracy, completeness, and logical consistency. A comparison of field measurements with digital map values showed minimal discrepancies, indicating high relative accuracy. Absolute accuracy was confirmed by comparing the GPS coordinates of key landmarks, such as road intersections and major buildings, to their corresponding positions on the map. The attribute accuracy of the map was also verified, ensuring that the descriptive data associated with roads and buildings accurately reflected real-world conditions. The results of this accuracy testing demonstrated that the map produced was both reliable and precise, making it a valuable tool for decision-making and urban planning in Nnewi North LGA.

The street guide mapping of Nnewi North Local Government Area (LGA) in Anambra State, Nigeria, highlights the intricate structure and varying conditions of the area's road network. The study reveals a well-defined hierarchy of roads, including major roads, minor roads, and a dense network of streets, each serving distinct functions in facilitating transportation and access to essential services. The major roads, with a total length of 13.51 kilometers, are crucial for connecting Nnewi North to surrounding towns and supporting economic activities. Although these roads are generally in slightly good condition, the presence of wear and tear underscores the need for regular maintenance to ensure their continued usability and safety.

In contrast, the minor roads, covering 36.03 kilometers, provide important secondary links but show signs of surface deterioration that could hinder efficient vehicular movement, particularly during adverse weather conditions. The street network, which consists of 2,111 streets totaling 505.71 kilometers, presents a more complex scenario. While only a fraction of these streets is tarred and in relatively good condition, the majority remains untarred and in poor condition, posing significant challenges for local mobility and accessibility.

The spatial analysis indicates a clustering of key road network features, which is significant for urban planning and infrastructure development. The high level of accuracy achieved in the digital mapping and geographic database creation demonstrates the effectiveness of the methodologies employed, providing a reliable resource for future decision-making.

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