Geospatial Assessment of Spatial Distribution and Accessibility of Primary Health Care Centres in Abuja Municipal Area Council, Federal Capital Territory, Nigeria

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Abstract:

- ***Background:***

Rapid urbanization and population growth create increasing demands for accessible and adequately distributed primary health-care (PHC) services. Geographic Information Systems (GIS), remote sensing and field-based geographic data provide a practical framework for assessing where health facilities are located, how they relate to transport networks, and where service gaps occur. This study assessed the spatial distribution, geographic accessibility and selected facility characteristics of PHC facilities in Abuja Municipal Area Council (AMAC), Federal Capital Territory, Nigeria.

- ***Methods:***

The study used coordinates collected during fieldwork for 47 health-care facilities, together with high-resolution satellite imagery, administrative and drainage data, a digital elevation model (DEM), and a road network derived from imagery. GIS processing was undertaken using ArcGIS. Facility distribution was examined using Average Nearest Neighbour, Mean Centre, Median Centre, Central Feature, Standard Distance and Directional Distribution. Network-based service-area analysis was used to examine accessibility, while field observations were used to assess facility attributes, including cold-chain storage.

- ***Results:***

The Average Nearest Neighbour analysis produced a nearest-neighbour ratio of 1.028008 and a z-score of 0.371226, indicating a pattern close to random rather than a strong clustered or dispersed pattern. Spatial mapping showed greater concentration of facilities in the northeastern and northwestern portions of AMAC, with 17 and 12 facilities respectively, compared with 9 facilities in each of the southwestern and southeastern portions. The study identified a serviceable area of approximately 368.67 km² within the 1,769.43 km² AMAC study area. Of the 47 facilities, 45 (95%) reportedly had cold-chain storage, but only 29 were functioning, while 18 were reported as non-functional.

- ***Conclusion:***

The findings indicate that counting facilities alone is insufficient for judging equitable PHC provision. Spatial distribution, road accessibility, travel time, facility functionality and population demand should be considered jointly. GIS provides a useful decision-support framework for identifying underserved areas and prioritizing infrastructure, equipment and maintenance investments.

Keywords: *Geographic Information System; Remote Sensing; Primary Health Care; Spatial Distribution; Accessibility; Network Analysis; Abuja Municipal Area Council; Nigeria.*

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I. INTRODUCTION

➢ *Background*

Geographic Information Systems (GIS) are essential for determining when and where to intervene, enhancing the quality of care and accessibility of health services, identifying the most economical modes of delivery, protecting patient privacy, and meeting the needs of the research community regarding data accessibility (GIS Mapping of Healthcare 2013). Tracking child vaccinations, researching health policy, and creating health care districts and areas are all examples of GIS applications in public health (WHO 2010). Clinical and administrative data can be visualized as a geographical decision support tool using GIS, which also makes it possible to transfer data from the project level to become an all-encompassing resource for a full organization. GIS serves as a common platform for the convergence of multi-disease surveillance activities (ESRI, 2011). As towns have grown larger as a result of urbanization and industrialization, the concentration of population has, in turn, led to complicated health issues, what facilities and the kinds of specialists are available. Such problems can be addressed effectively by mapping and creating relevant databases using Geographic Information Systems (GIS). The Federal Capital Territory (FCT) Abuja, Nigeria has experienced a lot of population explosion in recent years, leading to complicated health issues, inadequate and inaccessibility of health care facilities. The population as at 2006 is 1,430,00 in 2016 is 2,591,000 while in 2020 the population is 3,278,000 (Nigeria Macrotrends population data) the percentage growth between 2006 to 2020 is 146% which shows there have been a drastic growth over years A proper understanding of the pattern of the spatial distribution of healthcare facilities is essential and addressing these challenges and a must for rational planning and management.

Health care administrators in the Federal Capital Territory (FCT) do not have access to a functional, current database of healthcare facilities. The lack of comprehensive information about healthcare facilities in the FCT, Abuja, is a major concern and an objective of this study, which aims to demonstrate the appropriate location and accessibility of health care services, just as educational services, polling places, etc. are essential features of a well-developed political region. One of the biggest challenges to Nigeria's sustainable growth has been the uneven distribution of health services.

Over the past few years, Nigeria's health care system has been severely neglected. Nigeria has a vital position in Africa, however their performance in the health care sector is lacking. Research has indicated that healthcare infrastructure—including medical facilities, staff, and equipment—are insufficient, particularly in rural regions (WHO, 2008). The Nigerian government has proposed a number of reforms to address the numerous problems with the health care system, but the results have not yet been observed or experienced (Nnamuchi, 2010). The Nigerian National Health Conference's 2009 Communiqué states that the health care system is still inadequate due to a lack of coordination, fragmentation of services, The lack of coordination, fragmentation of services, scarcity of resources, such as medications and supplies, inadequate and deteriorating infrastructure, unequal distribution of resources, access to care, and extremely poor quality of care are all signs that the health care system is still weak.(Nigerian National Routine Immunization Strategic Plan, 2013–2015).The conference also acknowledged the necessity for precise maps as a vital tool for monitoring areas of infectious outbreaks, particularly in northern Nigeria, supporting the micro-planning process, and evaluating performance and coverage. Nigeria's National Primary Health Care Development Agency (NPHCDA) was established in December 2011. (NPHCDA) and its partners in the Global Polio Eradication Initiative (GPEI), created geographic information system (GIS)-based maps for eight northern states, which accounted for around 75% of infectious disease outbreaks in 2010–2012, as part of an ambitious initiative to address these pressing needs with funding from the Bill & Melinda Gates Foundation (Egwari, 2013).

GIS makes it easier to map, visualise, monitor, retrieve, analyse, and model georeferenced data with high precision (Palaniyandi, 2015). Mapping and tracking ongoing disease control initiatives are two uses for it. The public health sector in Nigeria has not yet fully incorporated the use of GIS. Additionally, as data is the foundation of any GIS analysis, researchers are prevented from thoroughly exploring the issues encountered in this area due to insufficient data. Making data visualisations in the form of maps is the most popular application of a GIS; the notion is that the visualisation conveys information that may not be apparent from the raw data alone. According to WHO (2007), the ability of a population to get a particular set of health care services is referred to as access to health care services and delivery centers. The creation and distribution of maps that show the locations of health services—also known as health services mapping—is the main use of public health mapping. Mapping health services involves identifying settlement patterns, the kinds of services related to human settlements, and the locations of primary, secondary, and tertiary healthcare facilities. The accessibility of health services is significantly impacted by variables including road infrastructure, available transportation options, and the distances between communities and health facilities (hospital, primary care center, and emergency station).

The use of GIS mapping as a public health tool was examined by Musa et al. (2013), who pointed out that while typical GIS applications in public health are static and lack real-time components, adding a space-time animation to these tools will be crucial as data and technology continue to advance.

According to Murad (2008), GIS offers a number of methods and features that can be applied to the design of health services. He concentrated on showcasing a GIS program designed to investigate the supply and demand for medical services in Jeddah, Saudi Arabia. He developed a geodatabase for health services that displays the locations and features of health supply and demand. Three main analytical problems are addressed by the developed application. Murad (2008) identified the location of health services and

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categorised them according to the current level of availability in Jeddah. The study also identified the features of health demand in the same city. Additionally, the study identified patient locations as well as the real health care catchment areas. The expansion and size of the health catchment area in Jeddah city will be determined by the established health care catchment regions. Using accessibility indicator ratings, the study also determined the degree of health service accessibility. The application's findings were helpful in assessing Jeddah City's supply and demand for health services. The developed application is regarded as a spatial decision support system for health planners in Jeddah city, according to the study's conclusion. The significance of health mapping in relation to health indicators, monitoring, and evaluation was emphasised in the WHO technical discussion paper from 2007. According to the research, health mapping is expanding quickly as an e-health application to aid in the development of health systems.

It was mentioned that WHO has been monitoring the state of global health using mapping techniques in conjunction with surveillance and presenting the results using contemporary, user-friendly technologies like geographic information systems. Geographic information systems technology is used in public health mapping to enhance data for public health planning and decision-making. Health mapping plays a variety of roles and has a wide range of effects on how well health systems function. It enhances the capacity to arrange and connect thematic and spatial datasets for decision-makers, planners, academics, researchers, and medical professionals. Without utilising the spatial dimension, it enables the creation of relationships between datasets that might otherwise appear unrelated. These resources aid in the creation and discovery of new health information that may be applied to policies or actions. Professionals can visually comprehend intricate spatial linkages through mapping, and as planning involves making educated predictions, mapping can be an effective tool for trend analysis and forecasting. In a technical paper published in the Regional Committee of the Eastern Mediterranean in 2007, WHO stated that health mapping is most useful when analysing demographic data and its geographic distribution; disease distribution; high-risk group distribution; site selection and health service location; hydrographical and water supply and sanitation systems; hydrologic modelling and water resources management and delivery; emergency preparedness and disaster management; identification of hazardous sites and disaster-prone locations (natural or man-made); health services centers and the distribution and classification of human resources.

➢ *Problem Statement*

The original assessment identified several challenges affecting PHC service provision in AMAC, including poor staffing, inadequate equipment, uneven distribution of health workers, poor infrastructure and shortages or uneven distribution of essential drugs. It also identified the lack of a functional and current geospatial database of health facilities as a major planning concern. These challenges make it difficult to determine whether the existing network of facilities adequately corresponds to population needs and whether residents can reach facilities within reasonable travel times.

A spatially explicit assessment is therefore necessary to establish the location and distribution of facilities, identify areas of relative service deficit and evaluate accessibility through the existing road network. The study also considers facility readiness through the assessment of cold-chain storage.

➢ *Aim*

The aim of the study was to apply geospatial techniques to map and assess primary health-care facilities in AMAC and provide spatial information to support health-care planning and decision-making.

➢ *Objectives:*

- Determine the spatial distribution of primary health-care facilities in AMAC.
- Evaluate the accessibility of primary health-care facilities in AMAC using network-based analysis.
- Assess selected aspects of PHC facility status against the standards or criteria adopted in the original study, including cold-chain availability and functionality.

➢ *Study Area*

The study area is Abuja Municipal Area Council (AMAC), Federal Capital Territory, Nigeria. The submitted study describes the FCT as approximately 8,000 km² and identifies AMAC as the largest and most urbanized area council, with an area of approximately 1,769.43 km². AMAC contains a mixture of established urban areas and rapidly developing settlements. This combination of urban expansion, population growth and varying road accessibility makes it appropriate for a geospatial assessment of PHC distribution.

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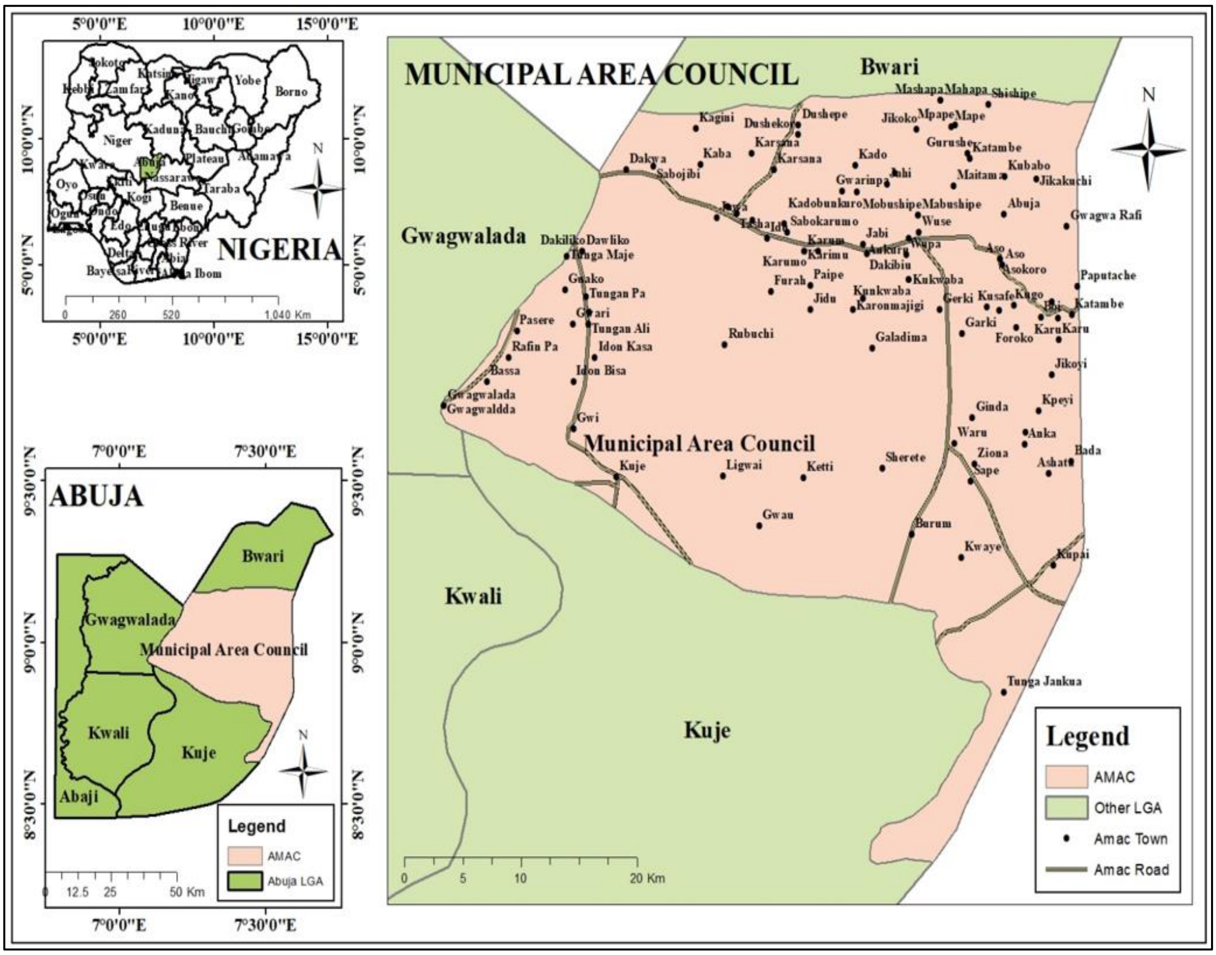

Fig 1 Study Area Map

II. METHODS AND MATERIALS

➢ *Data Sources*

Primary data consisted of geographic coordinates of PHC facilities collected during fieldwork using GPS, together with facility attributes including information on cold-chain facilities and transportation. Secondary datasets included high-resolution GeoEye imagery, drainage data, a digital elevation model and road-network information. The original project states that the DEM was obtained from the USGS/Alaska Satellite Facility and that roads were digitized from satellite imagery.

➢ *Software and Processing Environment*

ArcGIS was used for spatial data processing, mapping and analysis. Microsoft Excel was used to organize coordinate and attribute data and to convert coordinates into a form suitable for GIS import. Microsoft Visio was used for workflow representation in the original project.

➢ *Remote-Sensing Interpretation and Road-Network Extraction*

High-resolution satellite imagery was interpreted visually and digitized on screen to delineate the road network. The original project classified roads into express, major, minor and footpath categories and assigned speeds to support network analysis. The DEM was used to characterize terrain and identify areas where elevation and relief could influence movement and accessibility.

➢ *Facility Geocoding and GIS Database Development*

GPS coordinates collected during fieldwork were compiled in a tabular database and converted to decimal degrees before import into ArcGIS. Facility points were displayed over the administrative and transportation layers. Attribute information collected during field visits was linked to the spatial facility records, producing a geospatial database for analysis.

➢ *Spatial Statistical Analysis*

The study applied several spatial-statistical techniques. Average Nearest Neighbour (ANN) was used to determine whether the facility pattern was clustered, random or dispersed. Mean Centre identified the geographic centre of the facility distribution, while Median Centre identified the location minimizing aggregate Euclidean distance. Central Feature identified the facility with the smallest accumulated distance to all other facilities. Standard Distance measured the degree of concentration or dispersion around the mean centre, while Directional Distribution was used to identify the predominant directional trend of the facility pattern.

➢ *Network Accessibility Analysis*

Network analysis was used to generate service areas around PHC facilities based on travel-time impedance. The original study used 3-, 5- and 7-minute service-area thresholds in its accessibility assessment. For publication, these thresholds should be explicitly documented as analytical assumptions and their attribution to a particular external standard should be verified against the exact guideline used by the authors.

WHO's current geospatial-accessibility guidance supports the use of GIS and travel-time modelling to measure physical accessibility, identify gaps and test alternative health-service configurations. WHO also provides AccessMod for geographic accessibility and coverage analysis.

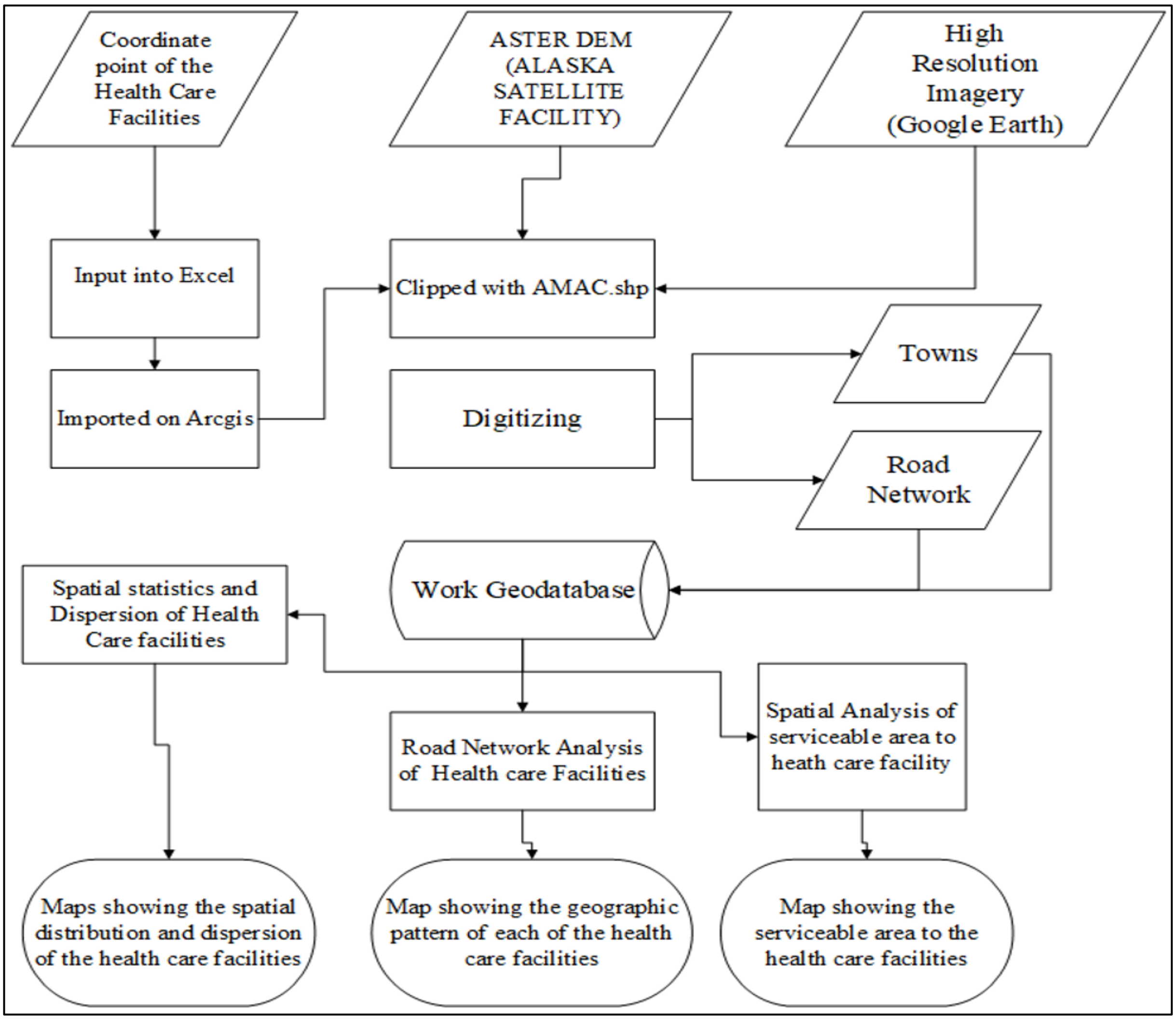

Fig 2 Workflow Methodology

➢ *Ground Truthing*

Field verification was undertaken to confirm the position and attributes of mapped features. The original study specifically emphasized verification of roads because the road network was used in service-area analysis. Ground truthing also supported the collection of facility-level information.

➢ *Facility Readiness: Cold-Chain Assessment*

Cold-chain information was assessed for the 47 facilities included in the analysis. Facilities were categorized according to whether cold-chain storage was present and whether the available system was functioning. This provided a basic indicator of operational readiness relevant to vaccine and temperature-sensitive medical supply management.

III. RESULTS

The results and discussion of the GIS and remote sensing analysis performed on the several thematic maps produced are presented in this chapter. The investigation's findings were used to create thematic maps that illustrate how various factors affect the spatial distribution of medical facilities in the research area.

➢ *Average Nearest Neigbourhood Analysis*

The results of the average nearest neighbourhood analysis for the Municipal Area Council's healthcare facilities show that the facilities in the study area are randomly distributed, indicating that they are neither dispersed nor clustered, which is typical for the distribution of healthcare facilities for better residential population service in the study area.

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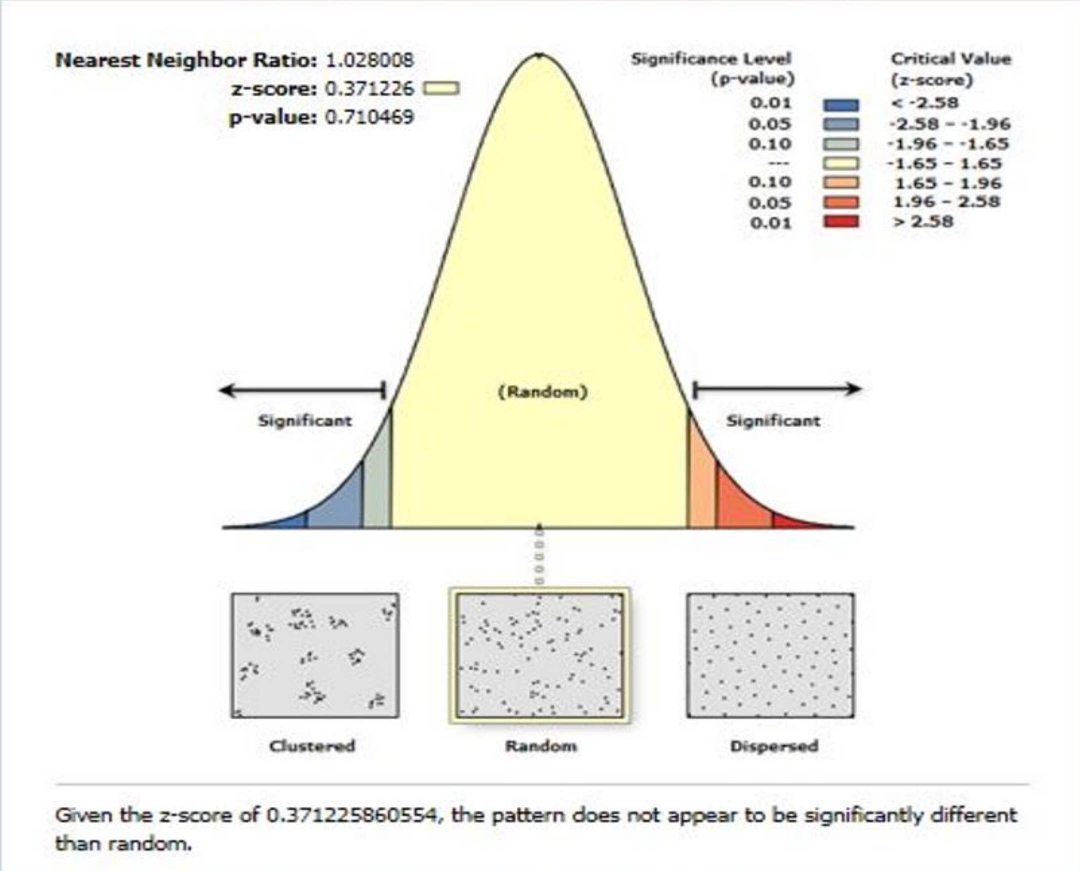
The nearest neighbourhood analysis, directional distribution, and standard distance were used to analyse the spatial distribution of the medical facilities. The distribution of health care facilities in the study area is random, according to statistics derived from the closest neighbourhood analysis (Figure 3). The Z-Score is 0.371226, the Nearest Neighbourhood Ratio is 1.028008, and the P value ranges from 1.96 to 2.58, suggesting that the healthcare facilities are mostly random. Considering the 0.371 z-score

In order to conduct this analysis, the local area council used a total of 47 healthcare facilities, all of which were dispersed at random throughout the area.

Average Nearest Neighbor Summary



Average Nearest Neighbor Summary

Observed Mean Distance:	3560.6684 Meters
Expected Mean Distance:	3463.6573 Meters
Nearest Neighbor Ratio:	1.028008
z-score:	0.371226
p-value:	0.710469

Dataset Information

Input Feature Class:	Mac_Hcfs
Distance Method:	EUCLIDEAN

Fig 3 Average Nearest Neighborhood of HCFs

➢ *Geospatial Location of Heathcare Facilitiies*

The health care facilities' geographic locations are respectfully indicated.According to their proper position on the ground, the health care facilities are more prevalent in the northeastern region of Abuja Municipal Area Council than in the western and southern regions of the study area (Fig. 4). Research indicates that there are seventeen healthcare facilities in the Northeastern region, twelve in the Northwestern region, nine in the Southwestern region, and nine in the Southeastern region.

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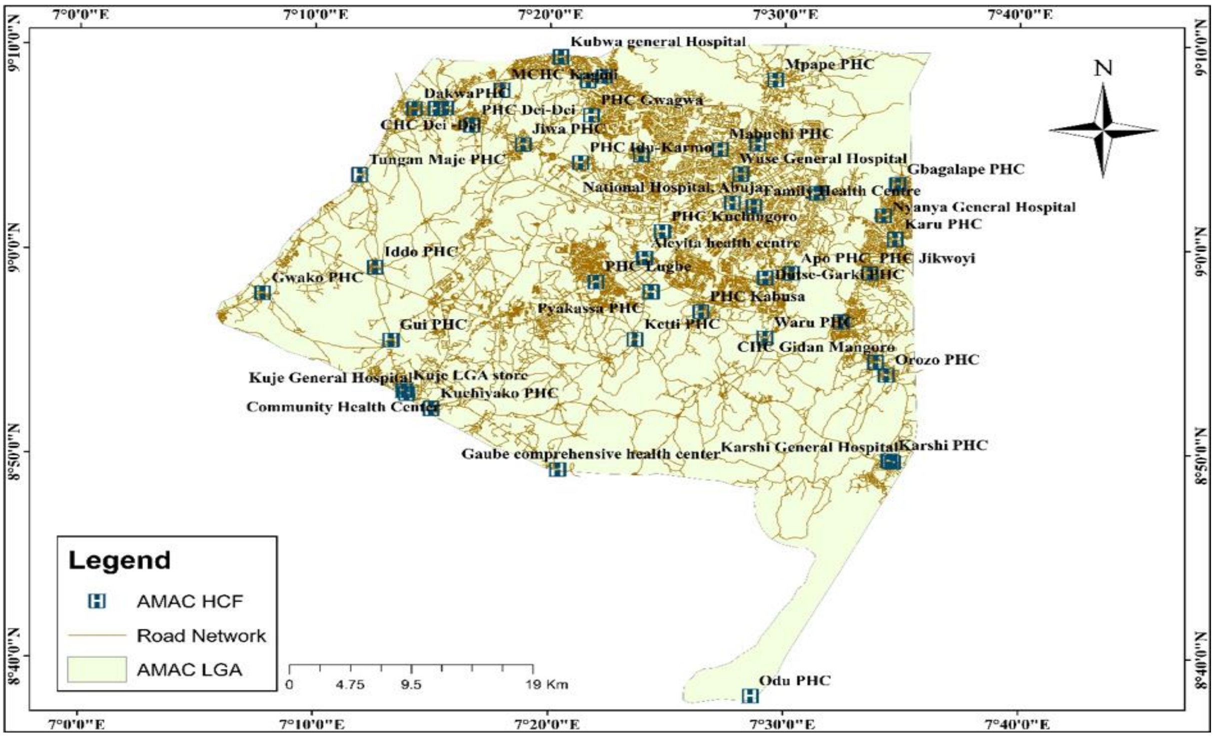

Fig 4 Geospatial Location of AMAC Health Care Facilities

➢ *Mean Center, Median Center and Central Feature*

The mean center determines the geographic center of the healthcare facility that, in relation to all other healthcare facilities in the research region for the provision of health equipment, can be the ideal site for a headquarters. It shows the geographic center of the healthcare facility within the study region. The mean center for the healthcare facility within the study area is extremely close to Aleyita, and it takes into account all other healthcare facilities. The most centrally located healthcare facility in the study area is identified by the central feature. This facility can also serve as the headquarters for all other healthcare facilities in the study area, but this is taking into account the characteristics of all existing healthcare facilities.

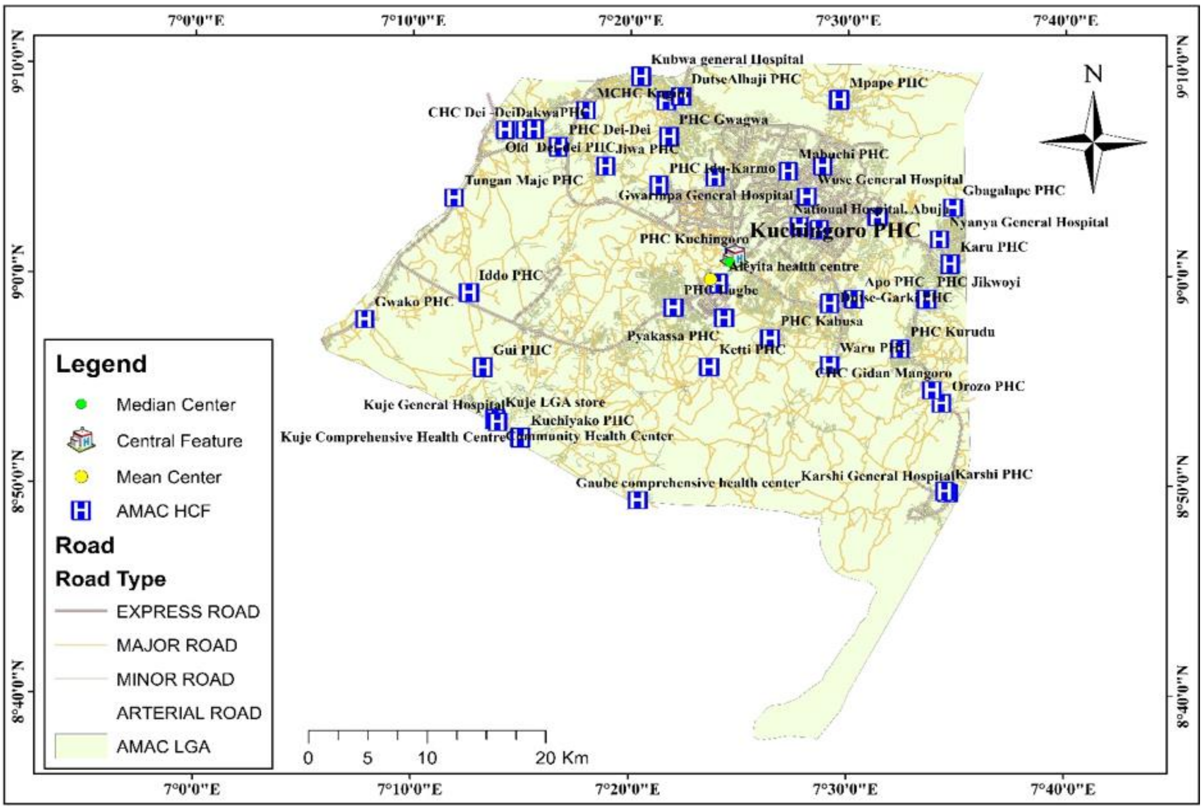

Fig 5 Map Showing the Mean Center, Median Center and Central Feature

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➢ *Directional Distribution and Standard Distance*

- Standard Distance: The Abuja Municipal Area Council's health care facilities' standard distance shows how concentrated or dispersed the characteristic is around the study area's geometric mean center.
- Directional Distribution: This method determines whether the distribution of medical facilities in the research area shows a directional tendency in a specific direction. Twenty healthcare facilities are within and concentrated around the geographic mean center of all healthcare facilities, according to the analysis's findings, while twenty-five healthcare facilities show a directional trend from the north toward the study area's northeastern region and a small portion of its southeast region.

Table 1 Table Showing Directional Distribution of Primary Healthcare in AMAC

S/N	Names of Healthcare Centers in AMAC
1	PHC MPAPE
2	PHC APO
3	PHC JIKWOYI
4	PHC KPEGYI
5	PHC KARU
6	PHC KABUSA
7	PHC WARU
8	PHC GIDAN MAN GORO
9	PHC GBALAPE
10	PHC OROZO
11	PHC KARISHI
12	PHC LUGBE
13	PHC KUNCHINGORO
14	PHC GWAGWA
15	PHC JIWA
16	PHC KARUMO
17	PHC GARIKI
18	PHC KUTU
19	PHC PYAKASSA
20	PHC MABUSHI

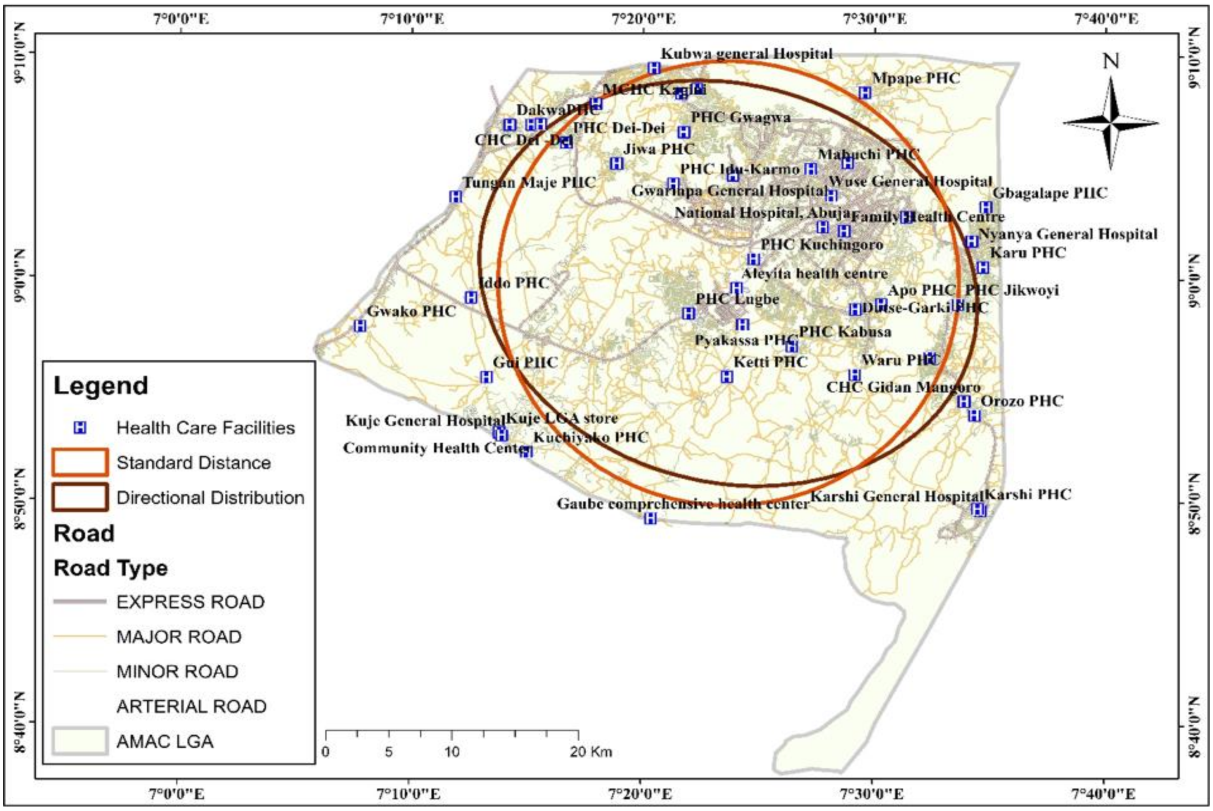

Fig 6 Map Showing the Directional Distribution and Standard Distance of Health Care Facilities

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➢ *Network Analysis*

- Service Area: This result, which is based on the standard of specified time impedance in accordance with the project carried out, assesses the area and territory that may reach a specific health care facility within a specified time impedance. It is claimed that WHO's criteria for getting to a medical institution, which is crucial for preserving human health and saving lives, In accordance with the World Health Organization's standard time of three, five, or seven minutes to reach a healthcare facility from a residential area (WHO 2016), a serviceable area using network analysis was conducted. This indicates the coverage area that can reach a healthcare facility in accordance with the standard set by the WHO in a specified time impedance.

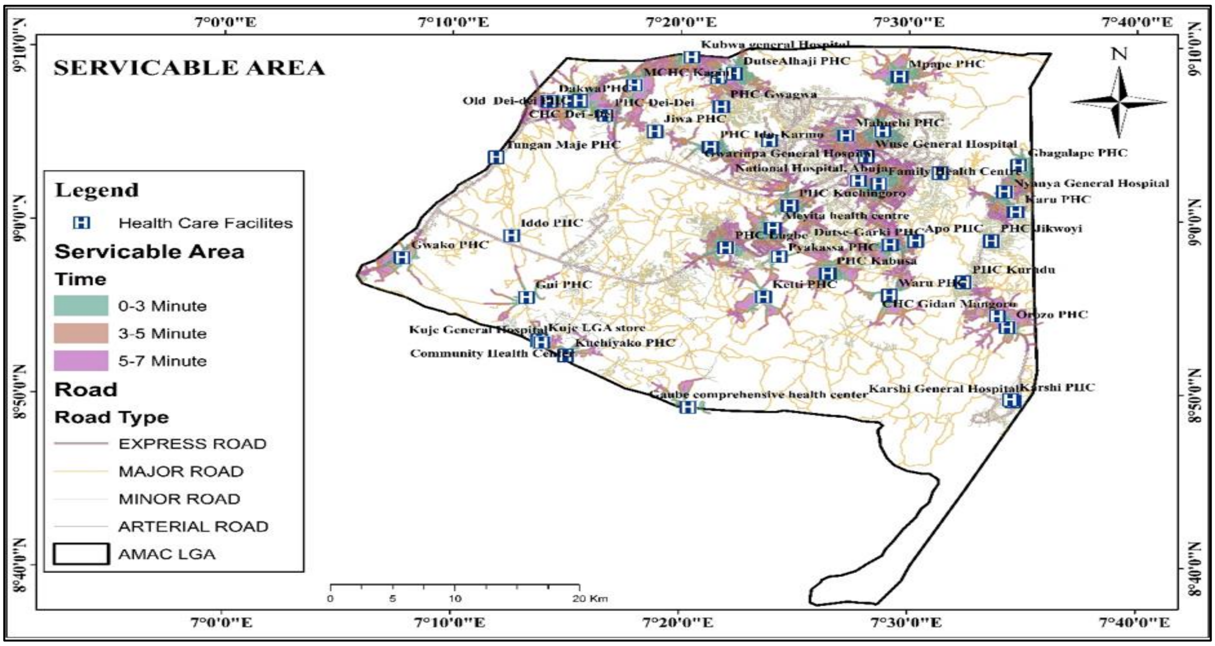

Fig 7 Serviceable Area to AMAC Heath Care Facility

➢ *Storage Facility*

A cold storage, which is a cold room where some medications and vaccines are kept for proper preservation, is one of the requirements for a health care facility to be referred to as a standard health care center. This analysis and result evaluates the health care facilities that serve as cold chain storage and which of the cold chain storage facilities are operating properly. It was found that 45 out of 47 health care facilities serve as cold chain storage, indicating that three do not currently have a cold chain storage, while twenty-nine do, but eighteen do not.

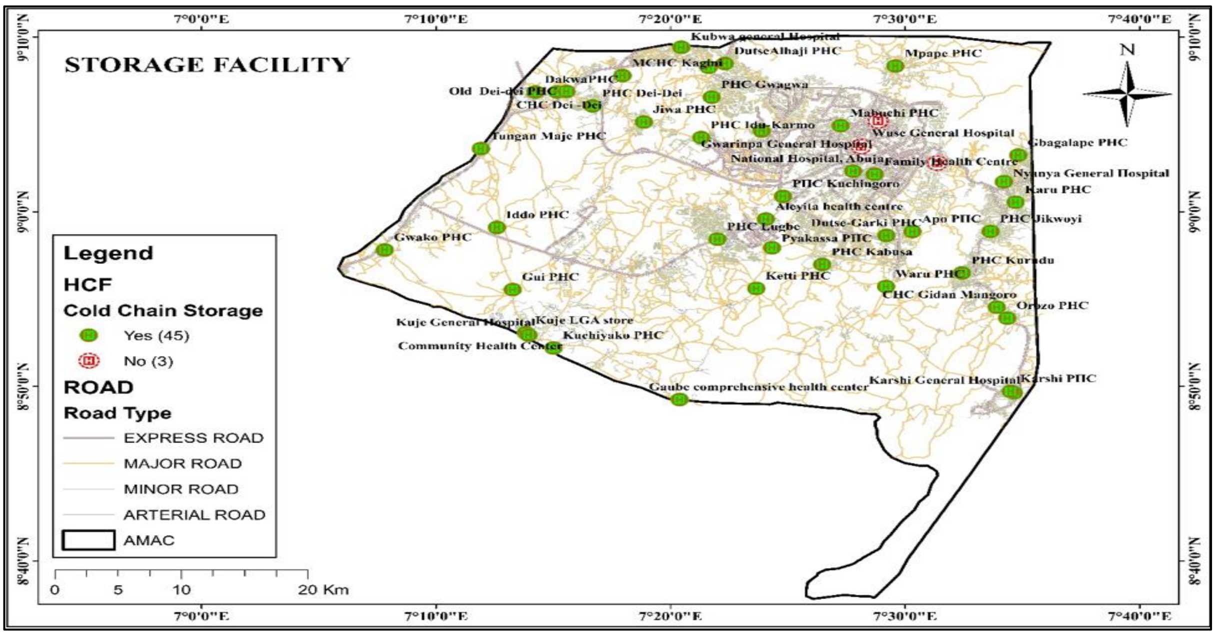

Fig 8 Health Care with Storage Facility in AMAC

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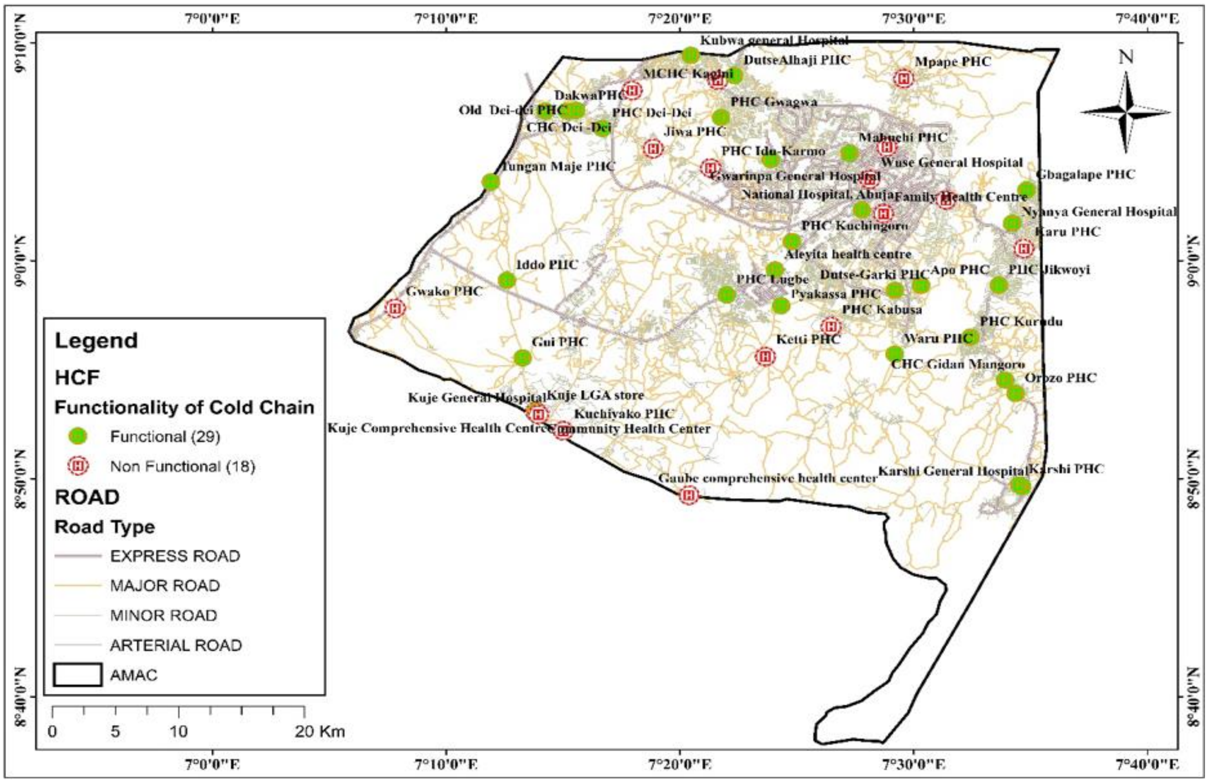

Fig 9 Functional and Non Functional Health Care Storage Facility in AMAC

IV. DISCUSSION

The study demonstrates the value of integrating facility coordinates, satellite imagery, road networks and terrain information in a single GIS environment. The near-random ANN result should be interpreted carefully. A random point pattern does not necessarily indicate that facilities are optimally located relative to population demand, socioeconomic vulnerability or travel barriers. Spatial accessibility is fundamentally a relationship between service locations and the population that needs those services.

The concentration of facilities toward the northeastern and northwestern parts of AMAC, together with the limited serviceable area reported by the network analysis, suggests that facility numbers alone may conceal important spatial gaps. Current WHO guidance similarly emphasizes geolocated facility data, physical accessibility and the use of geospatial modelling to identify underserved populations and support health-system planning.

The road network is particularly important because straight-line distance can overestimate accessibility where roads are discontinuous, poorly connected or affected by terrain. The original study therefore appropriately used network analysis rather than relying exclusively on Euclidean buffers. For a future update, accessibility analysis could be strengthened by incorporating current road speeds, walking access, public transport, seasonal road conditions and population-weighted travel times.

The cold-chain findings provide a second dimension of service readiness. Although most facilities reportedly had cold-chain storage, less than two-thirds of the 47 facilities had functioning storage based on the counts in the original study. This distinction is important for planning because the physical presence of a facility does not guarantee that it can deliver all expected PHC services effectively.

The results are consistent with the broader principle that health-facility master lists should be complete, georeferenced and routinely updated. WHO's Geolocated Health Facilities Data initiative emphasizes unique facility identification, accurate coordinates and continuous maintenance of facility information as a foundation for health planning.

The findings also have implications for health-resource allocation in Nigeria. The National Primary Health Care Development Agency identifies the Basic Health Care Provision Fund as a mechanism intended to improve access to primary health care and strengthen PHC-level service delivery. Spatial evidence on where facilities are located, which are functional and where accessibility gaps occur can complement such financing and planning mechanisms.

V. CONCLUSION

The following is the expected conclusion based on the spatial study of healthcare facilities in Abuja Municipal Area Council.

- It is observed that the health care facility appeared to be random but not equally distributed with respect to the study area based on the result generated from the average nearest neighborhood analysis carried out
- The geo-spatial location of the shows that there are much and larger part of the health care facilities located in the Northeastern and North Western part of the study area

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which is of about 75% of the health care facility in the study area

- The geographic central shows the health care facility that is central located with respect with all other health care facility which comes out to be Kunchingoro PHC
- The standard distance and directional distribution indicates twenty and twenty-four health care facility that falls within the geometric mean center and exhibit a directional trend from the north towards the northeastern part of the study area
- The total serviceable area to all the health care facility is368.67km² out of 1769.43km² which is the coverage of the study area absolutely is not all the area of study that will be covered by residential area but AMAC is covered by of about 900km² residential and workplace which they all need medical attentions
- It was also found that 95% (45) of the 47 healthcare facilities have a cold chain storage, while only 3 do not, which is still in a moderate situation. Additionally, it was found that only 29 of the 47 healthcare facilities have a well-functioning cold chain storage, while the remaining 18 do not. This conclusion includes the healthcare facilities that have no cold chain storage at all, which indicates that roughly 61.70%

This study demonstrates that GIS and remote sensing can support systematic assessment of primary health-care infrastructure in AMAC. Forty-seven facilities were mapped and analysed using spatial-statistical and network techniques. Although the overall facility pattern was close to random according to the Average Nearest Neighbour analysis, the facilities were not evenly represented across all parts of the study area. Greater concentration occurred in the northeastern and northwestern portions, while the network analysis identified a serviceable area substantially smaller than the total AMAC administrative area.

The assessment further shows that infrastructure presence should be distinguished from operational functionality. While 45 facilities were reported to have cold-chain storage, only 29 were reported as functional. These findings indicate that improving PHC access in AMAC requires a combination of spatial redistribution, improved transport accessibility, facility rehabilitation, equipment maintenance and stronger geospatial monitoring.

The study therefore concludes that an updated, georeferenced health-facility database should form part of routine PHC planning in AMAC and the FCT. Such a system can support evidence-based decisions on where to establish new facilities, where to upgrade existing ones, how to improve transport access and where operational resources are most urgently required.

RECOMMENDATIONS

- Establish or upgrade PHC facilities in spatially underserved areas identified through GIS and population-weighted accessibility analysis.
- Maintain a current georeferenced health-facility master list containing facility coordinates, services, staffing, equipment, infrastructure condition and operational status.
- Rehabilitate non-functional cold-chain systems and provide appropriate cold-chain infrastructure to facilities without adequate storage.
- Integrate population distribution, settlement growth and demographic characteristics into future facility location and accessibility analyses.
- Use road-network and travel-time analysis routinely when selecting locations for new facilities or upgrading existing facilities.
- Improve road and transport connectivity to PHC facilities that are geographically available but difficult to reach.
- Strengthen staffing, essential medicines, equipment and infrastructure in facilities where service readiness is inadequate.
- Conduct periodic GPS-based ground verification to update facility locations and attributes and to validate changes in road networks.
- Develop a GIS-based monitoring dashboard for routine reporting of facility functionality, accessibility and infrastructure status.
- Before publication or policy adoption, verify all external standards cited in the original project—particularly the travel-time thresholds attributed to WHO—and replace secondary or outdated references with the exact authoritative guideline used.

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