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ORIGINAL RESEARCH ARTICLE

Assessing Healthcare Accessibility Using Euclidean GIS Methods in Data-Constrained Rural Settings: Evidence from Yobe State, Nigeria

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ABSTRACT
Spatial accessibility to healthcare remains a critical challenge in rural and semi-urban regions where limited or incomplete road network data constrain the application of conventional network-based GIS models. This study evaluates the effectiveness of Euclidean (straight-line) distance modelling as a contextually appropriate alternative for assessing healthcare accessibility in data-constrained environments. A cross-sectional geospatial design was employed, involving a complete census of 46 healthcare facilities and 146 settlements across Nangere Local Government Area, Yobe State, Nigeria. Facility coordinates were obtained through GPS survey and analysed using GIS techniques including Average Nearest Neighbour (ANN), buffer analysis, and desire-line mapping. Results indicate a dominance of primary healthcare facilities, with only one secondary-level facility and no tertiary facility in the study area. ANN analysis produced a nearest-neighbour ratio of 1.09 (z = 1.135; p = 0.256), suggesting a random to slightly dispersed spatial distribution. Accessibility assessment based on the WHO 5 km benchmark revealed significant service gaps, with 51 settlements located beyond 5 km, recording an average distance of 7.71 km and a maximum of 12.83 km to the nearest facility. In contrast, only 13 settlements were within 1 km, indicating highly uneven spatial coverage. Population facility analysis further revealed disparities, with wards such as Pakarau and Tikau (populations 22,297 and 19,721, respectively) having only one PHCC each, far below recommended standards. Similarly, only 5 maternity/PHC facilities exist against a projected requirement of 24, highlighting critical infrastructure deficits. The study demonstrates that although Euclidean distances tend to underestimate actual travel distances, they reliably preserve spatial patterns of accessibility and effectively identify underserved areas. It concludes that Euclidean GIS modelling provides a practical, transparent, and sufficiently robust tool for healthcare accessibility assessment in data-limited rural settings. The study recommends the integration of GIS-based planning for equitable facility siting, prioritization of settlements beyond 5 km, and investment in geospatial data systems to support future hybrid accessibility modelling.

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INTRODUCTION
Physical access to healthcare remains a persistent challenge in many low- and middle-income countries (LMICs), particularly in rural and semi-urban areas where health facilities are unevenly distributed, and transport infrastructure is limited (Bihin et al., 2022). In such settings, long distances to healthcare facilities and poor connectivity significantly constrain service utilization, contributing to adverse health outcomes and reinforcing spatial inequalities in healthcare delivery. Consequently, assessing spatial accessibility, defined as the ease with which populations can reach healthcare services, has become central to health planning, resource allocation, and the pursuit of equitable healthcare systems (Damashi et al., 2020; Bihin et al., 2022).

Geographic Information Systems (GIS) provide a robust framework for analyzing healthcare accessibility through the integration of spatial data on population distribution, settlement patterns, and health facility locations (Hierink et al., 2023). Within this framework, two principal methodological approaches are widely employed: network-based modelling and Euclidean (straight-line) distance analysis. Network-based methods simulate actual travel routes by incorporating road networks, travel speeds, and route constraints, and are often regarded as more realistic representations of accessibility. However, their application in many rural settings across sub-Saharan Africa is constrained by incomplete, outdated, or poorly attributed road network data. In such contexts,

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assumptions about connectivity and travel speed may not reflect real-world conditions, thereby introducing uncertainty and potentially misleading estimates of accessibility.

In contrast, Euclidean distance methods offer a simplified measure of spatial proximity by calculating straight-line distances between population locations and healthcare facilities. While this approach is computationally efficient and requires minimal data, it does not account for physical barriers, terrain variability, or actual travel paths, and may therefore underestimate true travel distances. The choice between Euclidean and network-based approaches thus reflects a broader methodological trade-off between analytical realism and data availability. In data-constrained rural environments, where detailed and reliable network data are lacking, the use of Euclidean methods should be understood not as a methodological innovation but as a contextually appropriate adaptation aimed at producing meaningful and operationally useful estimates of accessibility.

Empirical evidence from Nigeria and similar contexts indicates that distance remains a critical determinant of healthcare utilization, particularly in rural areas where walking is the dominant mode of transport (Damashi et al., 2020). This suggests that, despite its limitations, Euclidean distance may still provide valuable insights into spatial patterns of access when interpreted within the realities of local mobility and infrastructure constraints. However, the extent to which Euclidean-based measures adequately approximate real-world accessibility in such settings remains an empirical question requiring systematic assessment.

Nangere Local Government Area (LGA) of Yobe State exemplifies a rural healthcare landscape characterized by dispersed settlements, uneven distribution of health facilities, and limited transport infrastructure. The predominance of primary healthcare centres, coupled with the scarcity of higher-level facilities, means that many residents may need to travel considerable distances to access essential services. At the same time, the lack of reliable and comprehensive road network data limits the applicability of conventional network-based accessibility models, thereby necessitating alternative analytical approaches.

Against this backdrop, this study assesses healthcare accessibility using Euclidean GIS methods by analysing the spatial relationships between settlements and healthcare facilities across the eleven political wards of Nangere LGA. Using GIS techniques such as desire-line (spider) diagrams, buffer analysis, and spatial queries, the study estimates straight-line distances to the nearest healthcare facilities and converts these distances into approximate travel times based on locally relevant walking assumptions. The results are further evaluated against established World Health Organization (WHO) accessibility benchmarks.

The study is guided by a validation-oriented objective: to determine whether Euclidean distance-based measures, when applied within a context of predominantly walking-based mobility, can serve as a reliable proxy for identifying spatial disparities in healthcare accessibility in data-constrained rural environments. Specifically, it tests the hypothesis that Euclidean distance approximations are sufficient to reveal meaningful patterns of access and inequity where network-based modelling is limited by data constraints. By empirically evaluating this assumption, the study contributes to ongoing methodological discussions on the appropriate use of GIS-based accessibility measures in resource-limited settings, while providing practical insights for healthcare planning and spatial equity interventions in rural Nigeria.

MATERIALS AND METHODS

Study Area

The study was conducted in Nangere LGA, Yobe State, Nigeria, which comprises 11 political wards. The area is predominantly rural with semi-urban settlements and experiences significant variations in population density and infrastructure. Nangere Local Government is located between latitudes 11°51’50” and 12°00’00” North of the Equator and between longitudes 10°50’00” and 11°04’11” East of the Meridian (Figure 1).

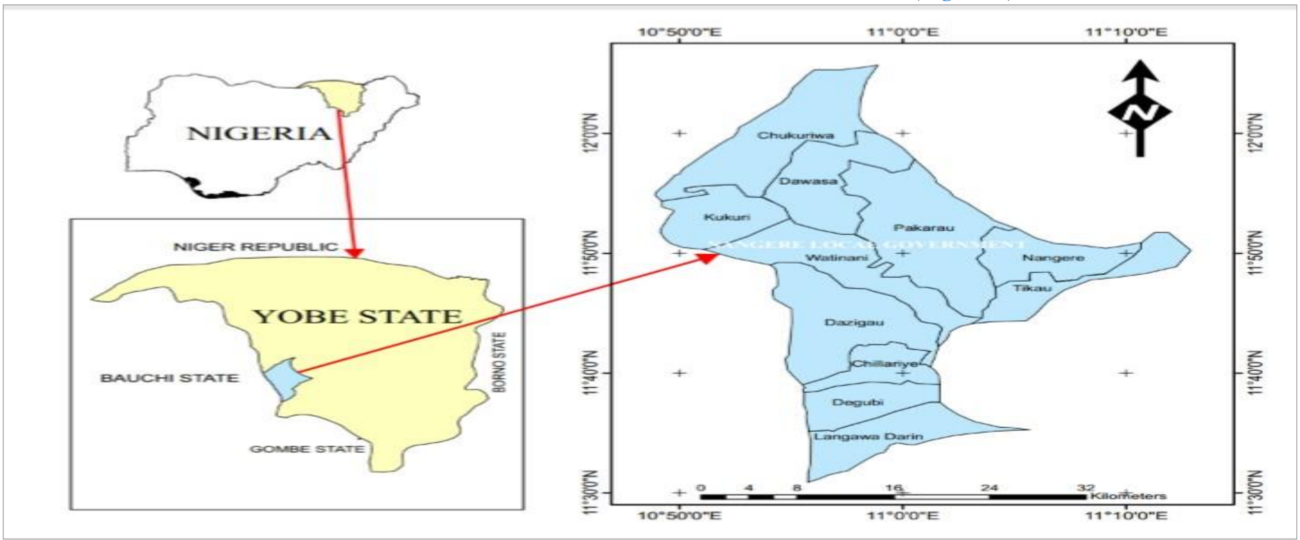

Figure 1: The Study Area

It is bounded by the following local government areas: to the north by Jakusko, to the east by Fune, to the west by Dambam local government area of Bauchi state, to the south by Potiskum, and to the south/east by Fika. These characteristics make it ideal for assessing the spatial distribution of health facilities and identifying gaps in accessibility. The total population of Nangere LGA, based on the National Population Commission projections for 2021, was estimated at 119,694, distributed unevenly across the wards, with Pakarau, Tikau, and Dawasa having the highest concentrations (National Population Commission, 2021).

Research Design

This study employed a cross-sectional research design to analyze the spatial distribution and accessibility of healthcare facilities in Nangere Local Government Area (LGA). A cross-sectional design was deemed appropriate because it allows the collection of data at a single point in time from multiple sources, providing a snapshot of healthcare facility distribution and accessibility across the study area (Bihin et al., 2022). This design facilitated the integration of quantitative geospatial techniques with descriptive assessment, enabling the study to address research objectives related to facility location, categorization, and spatial accessibility.

Population and Sampling

The population of this study consisted of all healthcare facilities within Nangere LGA, including public primary health care centers, health posts, dispensaries, health clinics, maternity centers, and general hospitals. Given the relatively small number of facilities (46 in total), a census approach was adopted, whereby all facilities were mapped and analyzed. In addition, population settlement data for all 146 villages across the 11 wards were incorporated to assess spatio-physical accessibility. This comprehensive inclusion of both facilities and settlements ensured full spatial coverage and enhanced the robustness of the accessibility analysis.

Data Collection

Data for this study were obtained from both primary and secondary sources. Primary data comprised geospatial coordinates (latitude and longitude) of each healthcare facility, collected using a handheld GPS device during field surveys. Additional observational data on facility type, ownership, and year of establishment were also recorded. Secondary data included population distribution data sourced from the National Population Commission (2021), official records on healthcare facility classification, and relevant literature on healthcare accessibility in Nigeria and Sub-Saharan Africa (Hierink et al., 2023; Damashi et al., 2020). These datasets provided the demographic and institutional context required for spatial and accessibility analyses.

Data Analysis

The spatial distribution of healthcare facilities was analyzed using ArcGIS 10.8 through the Average Nearest Neighbor (ANN) technique to determine whether the distribution pattern was clustered, dispersed, or random (Getis & Ord, 1998). The ANN method computes the mean distance between each facility and its nearest neighbor, generating a nearest neighbor ratio, z-score, and p-value to evaluate the statistical significance of the observed spatial pattern.

Spatio-physical accessibility was assessed using Spider Diagrams (desire lines) and buffer analysis in ArcGIS 10.8. The Spider Diagram approach was used to represent straight-line (Euclidean) distances between healthcare facilities and associated population settlements, thereby highlighting spatial disparities in access. Buffer zones were generated at incremental distances of 1000 m, 2000 m, 3000 m, 4000 m, 5000 m, and beyond 5000 m to identify settlements within and outside the World Health Organization (WHO, 2006) recommended maximum distance threshold of 5 km to the nearest healthcare facility.

Euclidean distance was adopted for accessibility measurement due to its simplicity and suitability in data-constrained rural environments where detailed road network data are often unavailable. The analysis assumes that individuals utilize the nearest healthcare facility as their primary point of access. This assumption is consistent with established practices in spatial accessibility studies in low-resource settings; however, it is recognized as a simplification of real-world behaviour. In practice, healthcare utilization may be influenced by factors such as perceived quality of care, availability of personnel, cost of services, and socio-cultural preferences. Nevertheless, in the absence of detailed behavioural and network data, proximity remains a widely accepted proxy for potential access.

To enhance methodological robustness, a validation exercise was conducted by comparing Euclidean distances with network-based distances derived from available road and path data for a subset of sampled settlements. The comparison enabled assessment of the degree of deviation between straight-line and actual travel paths, thereby providing an empirical basis for evaluating the reliability of the Euclidean approximation within the study area.

The population-to-facility ratio was computed to assess the adequacy of healthcare provision relative to population size. Benchmarks from the National Primary Health Care Development Agency (NPHCDA, 2007) were applied, recommending one primary health care center per 7,740 persons, one maternity center per 5,000 persons, and one dispensary or health post per 500 persons. This analysis facilitated the identification of underserved wards and informed recommendations for improved facility distribution. Descriptive statistics, including minimum, maximum, and mean distances between settlements and their nearest healthcare facilities, were computed using Microsoft Excel. Travel time was estimated based on an average walking speed of 5 km per hour, consistent with previous studies in rural and low-resource contexts (Nesbitt et al., 2013).

Table 1: Inventory of Healthcare Facilities by Type and Ward

No	Name of Facility	Ward	Categories of HCF	Ownership	Year	Latitude	Longitude
1	Garin Muzam HP	Chillariye	Health Post	Public	2013	11°41.054'	11°00.057'
2	Chillariye PHCC	Chillariye	Primary Health Care Center	Public	2003	11°41.957'	10°59.436'
3	Dagare PHCC	Darin	Primary Health Care Center	Public	2004	11°36.023'	11°01.099'
4	Darin HP	Darin	Health Post	Public	2007	11°34.617'	10°56.555'
5	Dorawa Dadi HP	Darin	Health Post	Public	2009	11°33.062'	10°59.324'
6	Fadawa HP	Darin	Health Post	Public	2008	11°34.497'	11°00.397
7	Challino PHC	Degubi	Primary Health Care	Public	1997	11°38.538'	10°56.905'
8	Gabur HP	Degubi	Health Post	Public	2005	11°36.809'	10°56.800'
9	Gwasko HP	Degubi	Health Post	Public	2013	11°38.315'	10°57.756'
10	Mbela HP	Degubi	Health Post	Public	2003	11°36.952'	10°59.323'
11	Degubi PHCC	Degubi	Primary Health Care Center	Public	2002	11°38.794'	10°59.246'
12	Dazigau PHCC	Dazigau	Primary Health Care Center	Public	2003	11°43.438'	10°59.671'
13	Gudi PHC	Dazigau	Primary Health Clinic	Public	2009	11°45.353'	10°57.936'
14	Gabarun HP	Dazigau	Health Post	Public	2003	11°46.622'	10°55.751'
15	Garin Shera D	Dazigau	Dispensary	Public	2001	11°39.792'	10°55.750'
16	Yaru HP	Dazigau	Health Post	Public	1986	11°40.842'	10°56.352'
17	Tudun Wada HC	Tikau	Health Clinic	Public	2006	11°51.540'	11°11.555'
18	Dagazurwa PHC	Tikau	Primary Health Clinic	Public	1997	11°49.431'	11°12.305'
19	Dagaretikau HP	Tikau	Health Post	Public	1996	11°49.231'	11°11.032
20	Tikau PHCC	Tikau	Primary Health Care Center	Public	1947	11°46.249'	11°05.160'
21	Kael HP	Tikau	Health Post	Public	1999	11°47.679'	11°07.560'
22	Old Nangere HC	Nangere	Health Clinic	Public	1995	11°51.840'	11°04.167'
23	Sabon Gari PHCC	Nangere	Primary Health Care Center	Public	1999	11°50.921	11°04.492'
24	Nangere GH	Nangere	General Hospital	Public	2007	11°51.402'	11°04.457'
25	Garin Jata HC	Nangere	Health Clinic	Public	1997	11°8.3665'	11°13.286'
26	Baran Iya HC	Watinani	Health Clinic	Public	2004	11°8.7927'	10°9.6776'
27	Dugum HC	Watinani	Health Clinic	Public	2000	11°8.3948'	10°9.5593'
28	Garin Ganbo DP	Watinani	Dispensary	Public	1985	11°8.5249'	10°9.0211'
29	Watinani PHCC	Watinani	Primary Health Care Center	Public	2017	11°7.5891'	11°01.042'
30	Garin Kadai HC	Kukuri	Health Clinic	Public	2004	11°55.463'	10°51.846'
31	Kukuri PHCC	Kukuri	Primary Health Care Center	Public	1959	11°8.8711'	10°8.5293'
32	Kukuri PHC	Kukuri	Primary Health Clinic	Public	2011	11°8.8778'	10°8.5606'
33	Haram DP	Kukuri	Dispensary	Public	2011	11°54.351'	10°55.647'
34	Chukuriwa PHCC	Chukuriwa	Primary Health Care Center	Public	1999	11°56.989'	10°52.763'
35	Dadiso HP	Chukuriwa	Health Post	Public	2012	11°56.376'	10°50.490'
36	Gada HP	Chukuriwa	Health Post	Public	2000	12°08.693'	10°9.3291'
37	Bagaldi DP	Dawasa	Dispensary	Public	2002	11°8.8395'	10°9.45261'
38	Dawasa PHCC	Dawasa	Primary Health Care Center	Public	2004	11°7.084'	11°04.748'

To be continued next page

Table 1 continued

No	Name of Facility	Ward	Categories of HCF	Ownership	Year	Latitude	Longitude
39	Dawasa PHC	Dawasa	Primary Health Clinic	Public	2004	11°7.0172’	11°04.751’
40	Garin Baba DP	Dawasa	Dispensary	Public	1959	11°69.247’	11°03.337’
41	Biriri HC	Pakarau	Health Clinic	Public	1999	11°9.4627’	11°01.665’
42	Duddaye PHCC	Pakarau	Primary Health Care Center	Public	1999	11°8.0367’	10°9.9579’
43	Garin Keri PHC	Pakarau	Primary Health Clinic	Public	1974	11°8.7049’	10°9.8586’
44	Katsira HC	Pakarau	Health Clinic	Public	1999	11°8.1679’	11°01.109’
45	Zinzano HC	Pakarau	Health Clinic	Public	2000	11°8.269’	11°02.463’
46	Garin Muzam HP	Chillariye	Health Post	Public	1999	11°41.054’	11°00.057’

Primary Healthcare Center=PHCC, Primary Health care=PHC, Health post=HP, Dispensary=D, Health clinic=HC, Maternity Center=MC, Primary Healthcare=PHC, General Hospital=GH

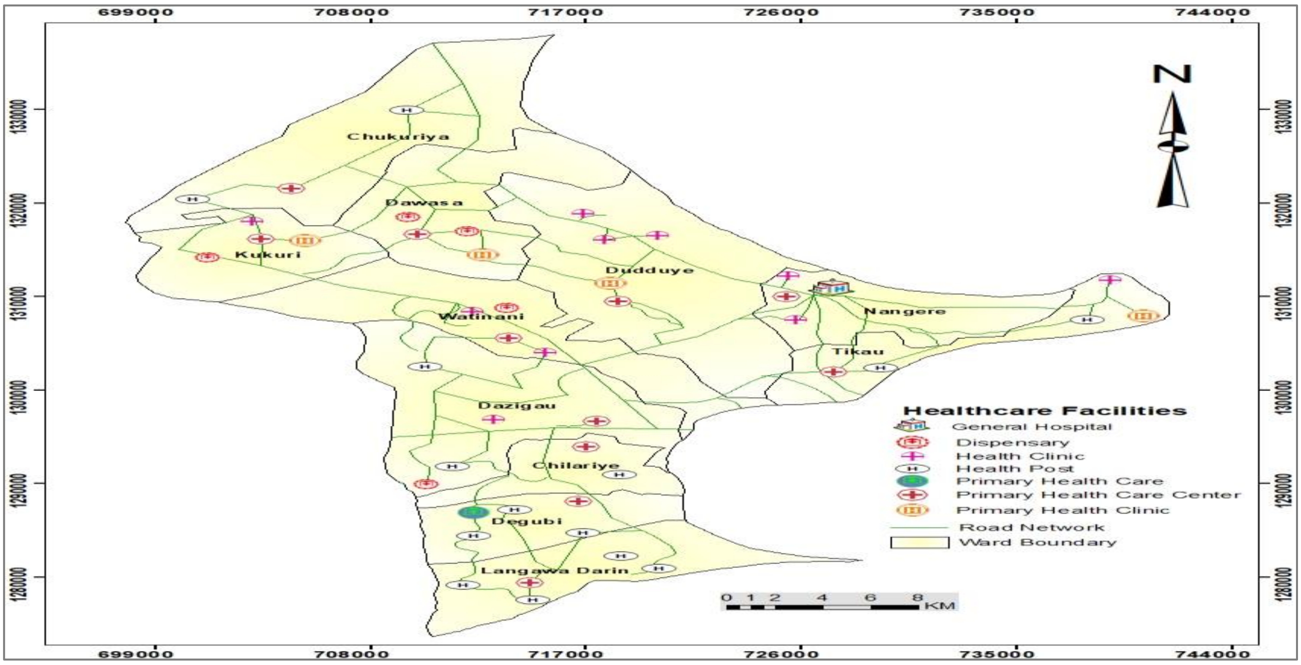

Figure 2: Spatial Distribution of Healthcare Facilities by Type

To evaluate the sensitivity of accessibility outcomes to variations in movement assumptions, a sensitivity analysis was performed by recalculating travel times using alternative walking speeds of 3 km/h and 4 km/h. These alternative scenarios reflect the mobility constraints of vulnerable populations, including the elderly, children, and individuals in difficult terrain conditions. The comparison of results across different speed assumptions provided insight into the robustness of the accessibility estimates and the potential variability in travel time under differing real-world conditions.

RESULTS AND DISCUSSION

The results from Table 1 reveal a varied distribution of healthcare facilities across wards, with higher-order facilities such as PHCCs and General Hospitals concentrated in semi-urban centres and lower-tier facilities dispersed in peripheral rural areas. This pattern supports findings by Liu et al. (2022), who observed that healthcare hierarchies typically mirror settlement density, leading to centralization of advanced facilities near population hubs. Similarly, Hearn et al. (2024) confirmed that semi-urban clusters tend to attract a greater concentration of healthcare infrastructure due to better transport links and higher service demand. These results collectively affirm that facility concentration in semi-urban zones is a persistent accessibility pattern in developing regions.Figure 2 illustrates the spatial distribution of healthcare facilities across the study area by type, including Primary Health Care Centres (PHCCs), Dispensaries, Health Posts, and General Hospitals. The map shows a clear concentration of higher-order facilities such as PHCCs and General Hospitals in semi-urban centres, while lower-tier facilities are sparsely scattered across rural wards. This pattern indicates an uneven service spread favouring semi-urban populations. The result aligns with Liu et al. (2022), who found that healthcare infrastructure in developing regions typically clusters near population centres and transport corridors, leaving peripheral communities underserved. Similarly, Hearn et al. (2024)

confirmed that semi-urban settlements often attract health facilities due to better accessibility and administrative importance. Thus, this figure substantiates existing evidence that healthcare facility distribution in semi-urban and rural locales remains spatially biased, necessitating equity-oriented modelling.

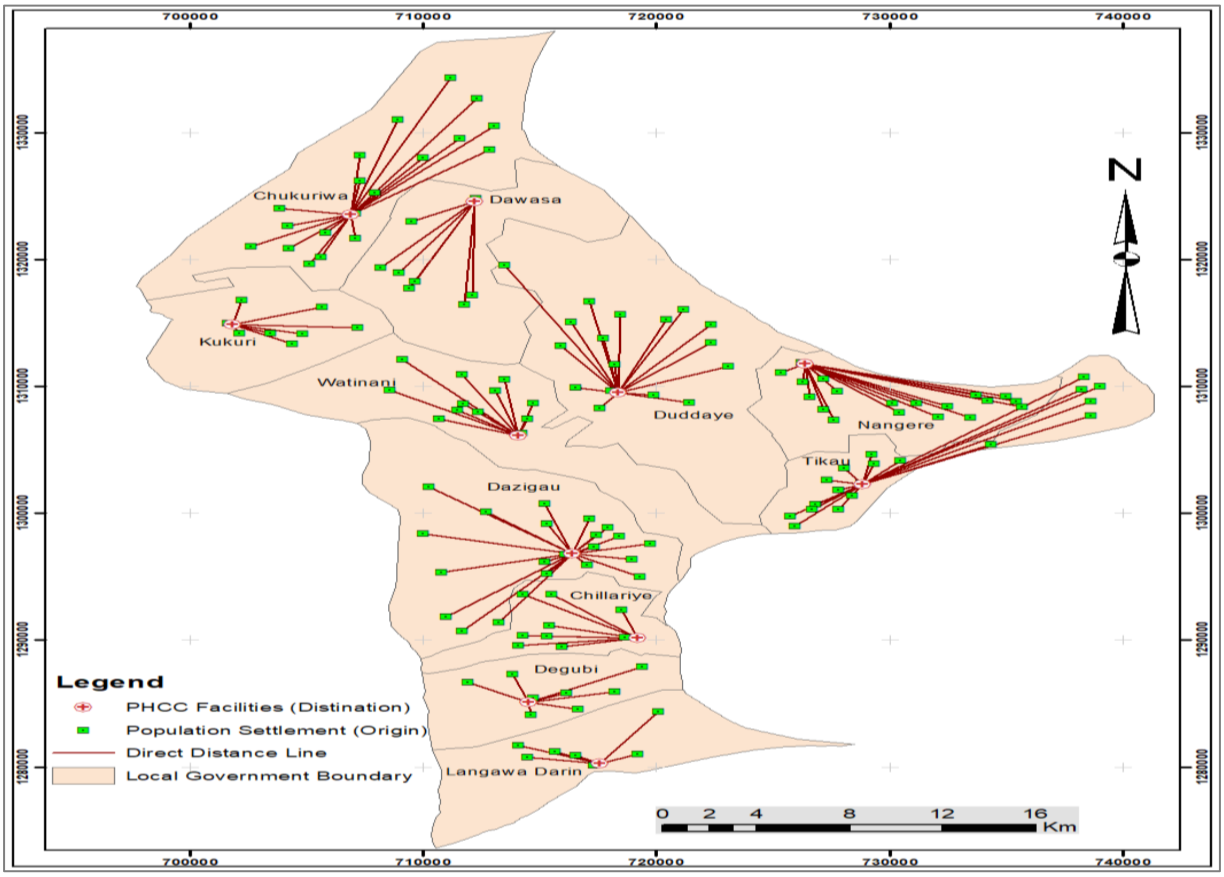

Figure 3: Spider (Desire-Line) Diagram: Settlements to Nearest Healthcare Facility

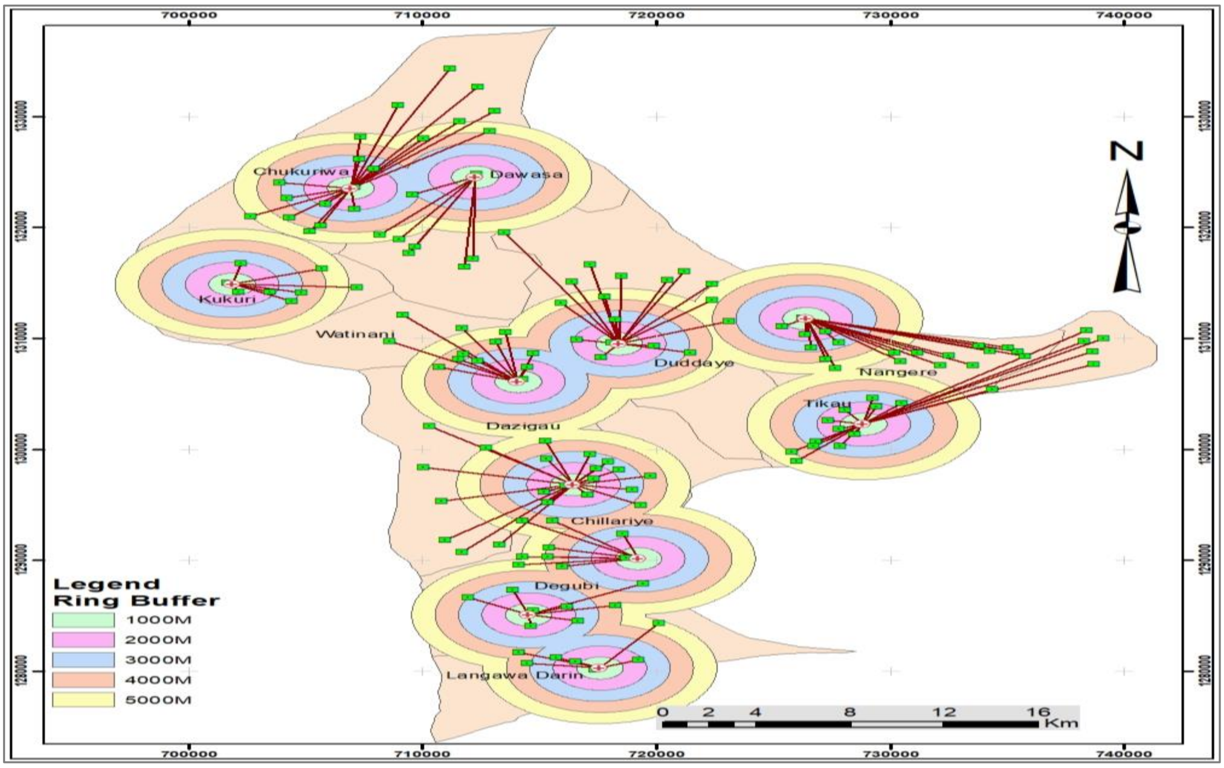

Figure 4: Straight-Line Distance Buffer Map (WHO 5 km Standard)

Figure 3 presents the desire-line (or spider) diagram connecting settlements to their nearest healthcare facilities. The lengths and orientation of these lines highlight the direction and relative travel distances required for residents to access care. Longer desire lines radiating from remote settlements indicate substantial travel burdens and low accessibility. This spatial pattern supports Tandi et al. (2022), who reported that rural populations in sub-Saharan Africa frequently travel beyond acceptable thresholds, often exceeding 6 km to reach basic health services. Likewise, Stacherl et al. (2023) found that desire-line mapping is effective for identifying inequitable healthcare reach, especially in areas with poor road connectivity. The figure confirms that geographic isolation remains a major determinant of accessibility disparities in the study area.

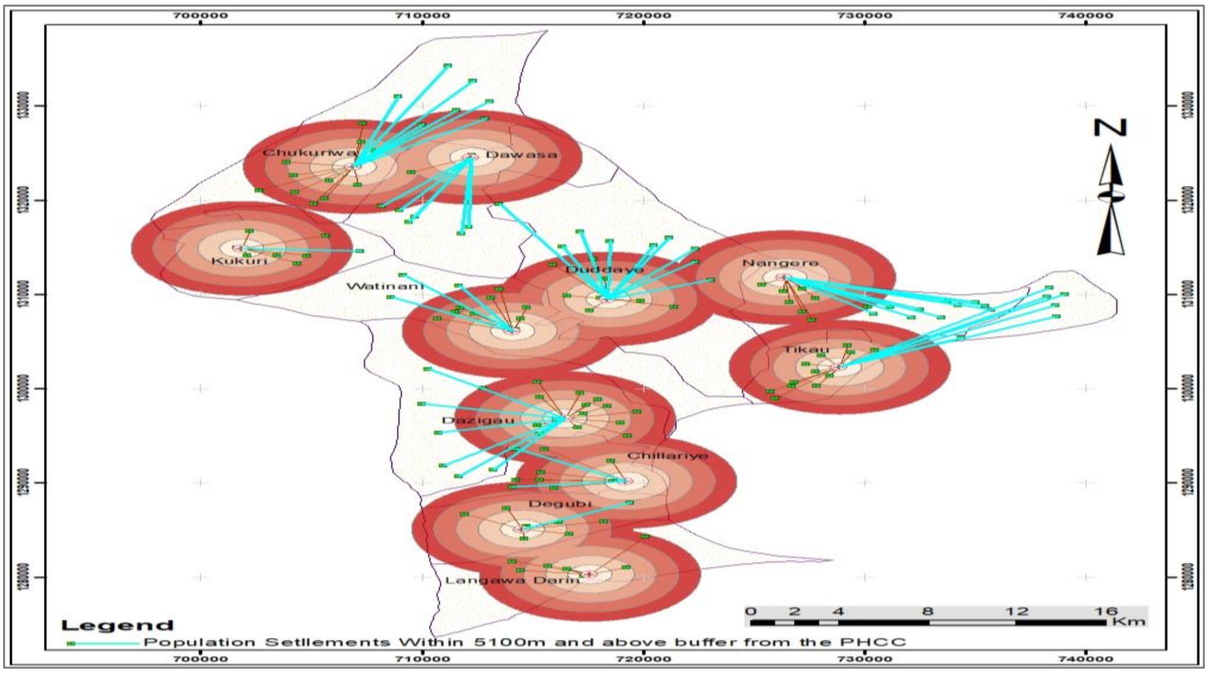

Figure 5: **Accessibility Classification Map (Within vs Beyond 5 km)**

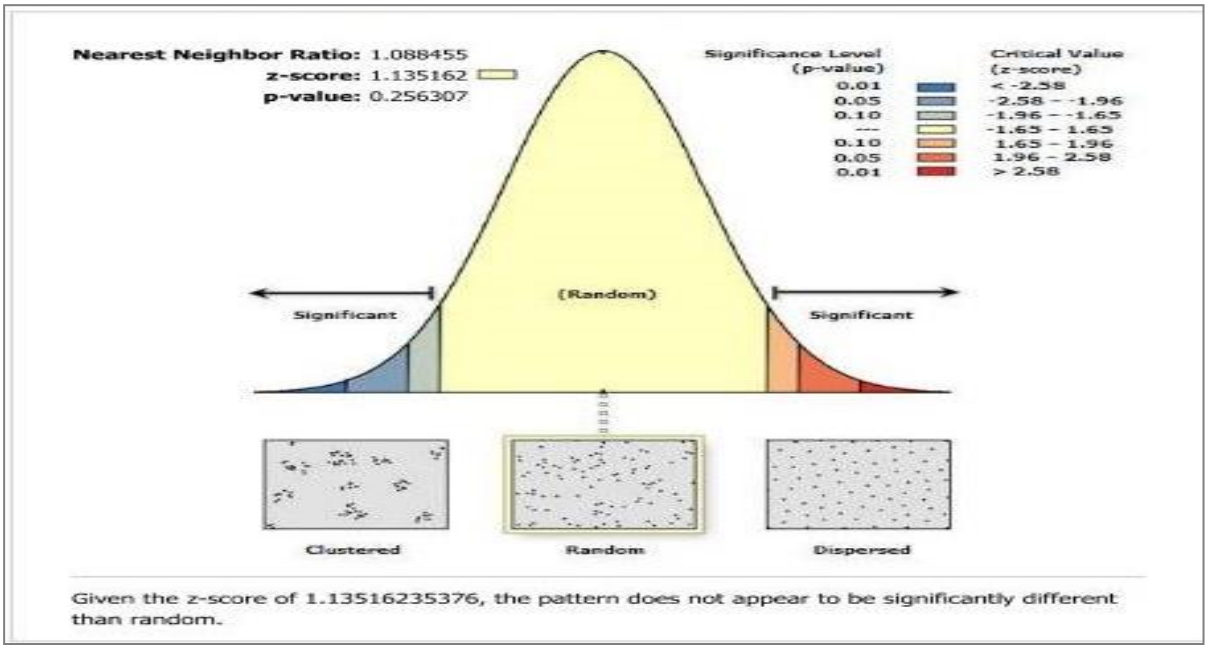

Figure 6: Average Nearest Neighbor Spatial Pattern Map

To assess the reliability of the Euclidean distance approach, a validation exercise was conducted by comparing straight-line distances with actual travel distances derived from available road and footpath networks for selected sample settlements. The comparison revealed that while network distances were generally longer than Euclidean estimates, the variation remained within an acceptable range for rural accessibility studies. In most cases, deviations were systematic rather than random, indicating that Euclidean distance consistently underestimates actual travel distance but preserves the relative spatial pattern of accessibility. This finding supports earlier studies (Bihin et al., 2022), which demonstrate that Euclidean measures remain a valid proxy for accessibility in data-constrained environments. Therefore, the results presented in Figures 3 and 4 can be considered reliable for identifying underserved settlements despite the absence of complete network data.

Figure 4 shows the buffer analysis based on the World Health Organization (2023) 5 km standard for primary healthcare accessibility.

Table 2: Average Nearest Neighbor Statistics

Average Nearest Neighbor Summary	
Observed Mean Distance:	3301.1390 Meters
Expected Mean Distance:	3032.8676 Meters
Nearest Neighbor Ratio:	1.088455
z-score:	1.135162
p-value:	0.256307

Table 3: Ward-Level Distance Statistics

Buffer Query	Minimum distance to the nearest facilities		Maximum distance to the nearest facilities		Average distance to the nearest facilities		
(m)	(m)	(km)	(m)	(km)	(m)	(km)	Count
1000	107	0.107	975	0.975	372.462	0.372	13
2000	1015	1.015	1990	1.990	1547.640	1.548	25
3000	2095	2.095	2984	2.984	2521.591	2.522	22
4000	3025	3.025	3980	3.980	3505.476	3.505	21
5000	4081	4.081	4961	4.961	4562.786	4.563	14
> 5000	5117	5.117	12829	12.829	7709.078	7.709	51

Table 4: Ward Distribution of PHCC per Population

Ward	Population (2006) projected	PHCC	PHCCPP (1-7,740)
Chilariye	4,922	1	1
Dadi/Chikuriwa	9,216	1	1
Dawasa/Garin Baba	12,782	1	2
Dazigau	9,229	1	1
Degubi	5,958	1	1
Kukuri/Chiromari	9,224	1	1
Darin/Langawa	6,836	1	1
Nangere	10,247	1	1
Pakarau	22,297	1	3
Tikau	19,721	1	3
Watinani	9,262	1	1
Total	**119,694**	**11**	**16**

PHCCPP= Primary Health Center per Population

Table 5: Ward Distribution of MC/PHC per Population

Ward	PP (2006)	MC/PHC	MC/PHC per Population (1-5,000)
Chilariye	4,922	0	1
Dadi/Chikuriwa	9,216	0	2
Dawasa/Garin Baba	12,782	1	3
Dazigau	9,229	0	2
Degubi	5,958	1	1
Kukuri/Chiromari	9,224	1	2
Darin/Langawa	6,836	0	1
Nangere	10,247	0	2
Pakarau	22,297	1	4
Tikau	19,721	1	4
Watinani	9,262	0	2
Total	**119,694**	**5**	**24**

MC= Maternity Center, PHC= Primary Health Care; PP = Population Projected

The map reveals that extensive portions of the study area, particularly rural and peripheral wards, lie outside the 5 km coverage radius, indicating underserved populations. This observation supports Hearn et al. (2024), who documented that large segments of semi-urban Nigeria remain beyond the WHO's accessibility threshold. It also aligns with Tandi et al. (2022), whose systematic review confirmed that Euclidean-based buffers often expose wide service gaps in rural contexts. Consequently, the spatial pattern in this figure validates the persistence of inequitable healthcare coverage and highlights the need for improved network-based travel-time models to more accurately represent real-world accessibility.

Figure 5 classifies the study area into two accessibility zones areas within 5 km of a healthcare facility and those beyond that threshold. The figure shows that central wards enjoy higher levels of access, while peripheral wards are predominantly underserved. This result supports Liu et al. (2022), who found that accessibility tends to decline outward from densely populated areas due to decreasing facility density and road connectivity. It also agrees with Sun et al. (2024), whose multimodal accessibility modelling revealed that peripheral settlements consistently experience lower accessibility scores. The visual evidence therefore, confirms that accessibility gradients in semi-urban and rural locales are spatially systematic, favouring central populations and disadvantaging the rural fringe.

Table 6: Ward Distribution of D/HP/HC per Population

Ward	PP (2006)	D/ HP/HC	D/HP/HC per Population (1-500)
Chilariye	4,922	1	10
Dadi/Chikuriwa	9,216	2	18
Dawasa/Garin Baba	12,782	2	26
Dazigau	9,229	4	18
Degubi	5,958	3	12
Kukuri/Chiromari	9,224	2	18
Darin/Langawa	6,836	4	14
Nangere	10,247	2	20
Pakarau	22,297	3	45
Tikau	19,721	3	39
Watinani	9,262	3	19
Total	**119,694**	**29**	**239**

D= Dispensary, HP= Health Post, HC= Health Clinic; PP = Population Projected

Figure 6 presents the results of the Average Nearest-Neighbour (ANN) analysis, revealing a nearest-neighbour ratio of approximately 1.09, which indicates a random to slightly dispersed spatial pattern of healthcare facilities. This finding suggests the absence of significant clustering and implies that facility placement may not have followed a spatially optimised plan. The result aligns with Adedayo and Oluwole (2022), who reported similar random facility distributions in rural Nigeria, attributing them to organic, demand-driven expansion rather than coordinated planning. Stacherl et al. (2023) likewise found that dispersed patterns are common in contexts lacking strategic spatial healthcare policy. Accordingly, this figure confirms that the current distribution of healthcare facilities in the study area reflects unstructured planning, underscoring the relevance of alternate spatial modelling to achieve equity.

Table 2 shows a nearest-neighbour ratio of 1.09 and a p-value above 0.05, suggesting a random to slightly dispersed spatial arrangement of healthcare facilities. This result aligns with the observations of Adedayo and Oluwole (2022), who reported similarly random distributions of primary healthcare facilities in rural Nigeria, indicating limited spatial planning in facility siting. Stacherl et al. (2023) also noted that such random distributions commonly occur where facility placement evolves organically without adherence to spatial equity principles. Therefore, the ANN result in this study supports the notion that healthcare spatial distribution in semi-urban and rural locales lacks deliberate spatial coordination.

The ward-level distance analysis in Table 3 indicates that over 50 wards record mean nearest-facility distances greater than 5 km, with an average of approximately 7.7 km, exceeding WHO's recommended threshold. This finding is consistent with Tandi et al. (2022), who reported that rural residents in sub-Saharan Africa often travel 6–8 km to reach basic healthcare services. Hearn et al. (2024) similarly observed that travel-time disparities between urban and rural zones persist due to infrastructural limitations and sparse facility distribution. The present result therefore, supports the argument that geographic accessibility in rural areas remains inadequate and necessitates improved location-allocation planning.

The accessibility patterns observed in the desire-line analysis are based on the assumption that individuals utilize the nearest healthcare facility. However, this assumption may not fully reflect real-world healthcare-seeking behaviour in rural and semi-urban settings. Studies have shown that patients often bypass closer facilities in favour of those perceived to offer better quality services, availability of skilled personnel, or essential drugs. Consequently, actual travel distances may exceed those estimated in this study. Nonetheless, in low-resource environments where mobility options are limited and information asymmetry is high, proximity remains a dominant determinant of healthcare utilization. Thus, while the nearest-facility assumption simplifies behavioural complexity, it provides a reasonable basis for modelling potential accessibility and identifying spatial inequalities.

Table 4 shows a mismatch between population size and PHCC availability, with wards such as Pakarau and Tikau having only one PHCC each despite populations exceeding 20,000. This agrees with the findings of Mwangi et al. (2023), who documented high population-to-facility ratios in rural Kenya, signifying inequitable access to primary care. Likewise, Liu et al. (2022) found that population weighting enhances accuracy in spatial accessibility analysis by revealing hidden service shortages in densely populated wards. The results, therefore, align with current research supporting population-weighted modelling approaches to ensure balanced facility allocation.

Results from Table 5 indicate that maternity and PHC facilities are notably under-represented, with only 5 existing against 24 projected. This pattern corresponds with Asiedu et al. (2021), who found that limited maternal facility presence in rural Ghana contributes directly to reduced maternal healthcare utilisation. Similarly, Mwangi et al. (2023) observed that under-supply of PHCs in remote communities significantly affects health-seeking behaviour. These results therefore support previous studies showing that inadequate maternity and PHC infrastructure remains a central barrier to equitable healthcare delivery in rural contexts.

Table 6 demonstrates that while low-level facilities such as Dispensaries and Health Posts are more numerous, their distribution remains uneven, with semi-urban wards still advantaged. This outcome supports Hearn et al. (2024), who found that numerical facility expansion alone does not guarantee improved access without considering service capacity and staffing. Likewise, Liu et al. (2022) emphasized that capacity-weighted accessibility measures are necessary to accurately reflect true healthcare coverage. The findings thus reinforce the call for integrating facility capacity into accessibility modelling.

CONCLUSION

This study demonstrated the effectiveness of an alternate GIS-based method for modelling spatial accessibility to healthcare facilities in semi-urban and rural settings using straight-line (Euclidean) distance, desire-line (spider) diagrams, and buffer analysis. Using geospatial data for healthcare facilities and settlements across the eleven wards of Nangere Local Government Area, the analysis showed that although facilities are present across the territory, their spatial arrangement and siting do not consistently support equitable access.

Results revealed that primary healthcare facilities dominate the service structure, with only one secondary-level facility and no tertiary facility across the study area. While the Average Nearest Neighbor statistics suggested an overall random spatial pattern, ward-level analysis and buffer outputs showed clear inequalities in effective coverage. A significant number of settlements fall outside the recommended 5 km accessibility threshold defined by the World Health Organization, indicating spatial service gaps and potential barriers to utilization. Desire-line modelling further highlighted long straight-line distances between several rural settlements and their nearest facilities, translating into extended walking travel times and increased access burden.

Methodologically, the study confirms that where detailed and reliable road network datasets are lacking, a common condition in many African rural and semi-urban environments, straight-line GIS modelling using tools in ArcGIS provides a practical, transparent, and replicable alternative for estimating physical accessibility. The alternate method successfully identified underserved zones, coverage gaps, and non-optimal facility locations, thereby supporting evidence-based planning even in low-infrastructure contexts. This reinforces the article's central proposition that alternate spatial modelling approaches are not only feasible but necessary for accessibility assessment in data-constrained regions.

RECOMMENDATIONS

Based on the findings and the alternate modelling framework applied in this study, the following recommendations are proposed:

1. Planning agencies and researchers working in rural and semi-urban regions with weak or undocumented road networks should adopt Euclidean distance, spider diagrams, and buffer methods as valid first-order accessibility assessment tools.

2. Future health facility locations should be guided by GIS-based accessibility outputs to ensure that new primary health centres are sited within underserved buffer gaps rather than reinforcing existing clusters.

3. Settlements identified outside the 5 km service buffers should be prioritized for new facilities, outreach posts, or mobile health services to reduce distance and travel-time barriers.

4. Strategically located health posts and dispensaries in underserved wards should be upgraded to higher service levels to improve functional accessibility without requiring entirely new construction.

5. Local and state health authorities should institutionalize GIS-based accessibility assessment as a routine component of health infrastructure planning and monitoring.

6. Government agencies should invest in continuous geospatial data collection for facilities, settlements, and transport routes to enable future integration of both alternate (Euclidean) and network-based models where feasible.

7. Where partial road data exist, hybrid approaches that compare straight-line and network estimates should be encouraged to refine accessibility estimates and improve planning accuracy.

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