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Research Article

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Assessment of the Distribution and Accessibility of Primary Health Care Facilities Using GIS-Based Health Mapping in Taraba State, Nigeria

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Abstract

Equitable access to Primary Health Care (PHC) is fundamental to achieving Universal Health Coverage, yet significant spatial inequities persist in regions characterised by difficult terrain and dispersed populations. Taraba State, Nigeria, exemplifies these challenges, with mountainous topography, poor road networks, and uneven facility distribution limiting physical access to essential services. This study assesses the spatial distribution and accessibility of PHC facilities across eight Local Government Areas (LGAs) in Taraba State, integrating Geographic Information System (GIS) modelling with Electronic Immunization Register (EIR) data. A mixed-methods design combined quantitative spatial analysis with facility and community surveys.

Eight high-patronage PHC facilities were purposively selected across Ardo-Kola, Bali, Gassol, Jalingo, Kurmi, Sardauna, Yorro, and Zing LGAs. GIS-based buffer analysis (0–3 km, 3–5 km, 5–10 km) and network analysis (15, 30, and 45-minute isochrones) were used to delineate catchment areas and measure physical accessibility against WHO thresholds. Kernel density estimation mapped immunization coverage, while EIR data validated theoretical access against actual service uptake. Statistical analyses included one-way ANOVA, correlation tests, and one-sample t-tests. Approximately 65% of the sampled population resided beyond the WHO-recommended 3 km radius of a PHC facility. The mean catchment population per facility was 11,352, exceeding the national benchmark of 10,000, with Turaki-A PHCC (20,956) and Gassol PHC (18,364) serving nearly twice the recommended standard ($t = 1.42$, $p = 0.098$).

Village coverage ranged from 35.2% (Gassol) to 100% (Zing-Z, Baissa, and Kofi). One-way ANOVA confirmed significant disparities in spatial distribution across LGAs ($F = 3.42$, $p = 0.001$). EIR validation demonstrated high completeness (94.2%) and accuracy (91.7%), revealing that communities within 3–5 km of a facility still exhibited low immunization rates due to stockouts and follow-up failures. The correlation between facility altitude and immunization uptake was not significant ($r = 0.008$, $p > 0.05$), indicating that terrain impedance, rather than elevation alone, is the more relevant barrier.

PHC facilities in Taraba State are unevenly distributed, with mountainous and dispersed rural LGAs experiencing the most severe service gaps. The integration of GIS and EIR proved effective in quantifying accessibility inequities and identifying priority communities. The study recommends targeted facility construction in underserved wards, rural road upgrades, expansion of digital health monitoring, and financial protection mechanisms to advance health equity.

Keywords: Primary Health Care, Geographic Information Systems, Spatial Accessibility, Electronic Immunization Register, Taraba State, Universal Health Coverage

1. Introduction

Access to primary health care (PHC) is a foundational determinant of population health and a critical pathway to Universal Health Coverage (UHC). The World Health Organization identifies PHC as the most cost-effective approach to improving health outcomes and reducing inequalities [1]. Yet, globally, at least half of the world's population still lacks access to essential health services, with the burden disproportionately borne by rural and underserved communities [2]. In Sub-Saharan Africa, a continent-wide geocoded analysis found that 29% of the population lived more than two hours from the nearest public hospital as of 2015, with only 16 of 48 countries meeting the benchmark of having 80% of their population within that threshold [3,4].

Nigeria exemplifies this challenge. Despite significant investments in PHC reforms, including the Primary Health Care Under One Roof (PHCUOR) policy and the National Health Act of 2014, many communities continue to experience inadequate access to facilities and services. Taraba State, located in North-East Nigeria, presents a particularly acute case.

Its diverse geography ranging from lowland savanna to the mountainous Mambilla Plateau combined with poor road infrastructure and widely dispersed settlements, creates formidable barriers to physical access [5]. In early 2025, a Lassa fever outbreak spread across eleven LGAs in the state, infecting 70 people and killing 37, with a case fatality rate above 50% [6]. Such outbreaks underscore the consequences of facility distribution, surveillance, and workforce coverage that are not matched to where people live.

Geographic Information Systems (GIS) have emerged as indispensable tools for addressing these spatial inequities. GIS integrates hardware, software, and geographically referenced data to analyse and visualise complex spatial patterns, enabling planners to move beyond descriptive statistics to actionable evidence [7]. The Spatio-Temporal Accessibility Model, originally advanced by Joseph and Phillips, provides the theoretical foundation for understanding how distance, travel time, and terrain influence healthcare utilization [8].

Later adaptations, such as the Two-Step Floating Catchment Area (2SFCA) method, have operationalised these concepts within GIS environments to measure accessibility by simultaneously considering supply, demand, and travel impedance [9]. The WHO's Service Availability and Readiness Assessment (SARA) framework complements this spatial lens by assessing whether facilities are equipped to deliver services once reached, ensuring that accessibility is understood not only as proximity but as functional capacity.

Despite the growing application of GIS in healthcare planning globally and within Nigeria, limited studies have comprehensively examined the spatial accessibility of PHC facilities in Taraba State [10]. Previous work has focused on facility distribution or socio-economic determinants in isolation, without integrating spatial analysis, outpatient utilisation data, service readiness indicators, and community involvement within a single framework. This study addresses this gap by applying a GIS-based accessibility model, integrated with Electronic Immunization Register (EIR) data, to assess the spatial and functional accessibility of PHC services across eight purposively selected LGAs in Taraba State [11]. The specific objectives were to:

(i) Examine the Available PHC Facilities
(ii) Assess Catchment Areas and Estimate Populations Served
(iii) Analyse Outpatient Records
(iv) Identify Spatial and Non-Spatial Determinants of Accessibility
(v) Assess Service Effectiveness
(vi) Apply Gis-Based Health Mapping and
(vii) Identify Underserved Communities to Guide Equitable Resource Allocation.

1.1. Theoretical Framework

This Study is Underpinned by Three Complementary Theoretical Frameworks: The Spatio-Temporal Accessibility Model, the Health Belief Model (HBM), and Andersen's Behavioural Model of Health Service Utilization. Together, these theories provide a comprehensive lens for understanding the factors influencing healthcare accessibility, utilisation, and service delivery effectiveness.

1.2. Spatio-Temporal Accessibility Model

The Spatio-Temporal Accessibility Model, originally advanced by Joseph and Phillips, is a theoretical construct within medical geography that emphasises the spatial and temporal dimensions of access to health services [12]. At its core lies the distance decay principle, which posits that the likelihood of utilising a health facility declines as distance or travel time increases. This relationship is especially evident in rural and low-resource environments where physical distances, poor infrastructure, lack of transportation, and difficult terrain present major barriers to accessing care.

Building upon this foundation, scholars such as Guagliardo and Luo and Wang have expanded the model using GIS, making it an operational framework for evaluating health service accessibility. Luo and Wang introduced the Two-Step Floating Catchment Area (2SFCA) method, which calculates spatial accessibility by simultaneously considering the supply of health services, population demand, and travel impedance, providing a more nuanced understanding of access barriers across space and time.

The model's key propositions are: first, that access to health services is not uniformly distributed in space and is influenced by the interplay between population distribution, service location, and transportation networks; second, that both physical distance and travel time act as deterrents to service utilisation; and third, that accessibility can be quantitatively measured and mapped using GIS-based tools to support evidence-informed planning and equitable resource allocation. In Taraba State, the physical geography, encompassing mountainous areas, valleys, rivers, and

poorly developed road networks significantly impede community access to PHC services, making this model particularly relevant.

1.3. Health Belief Model (HBM)

The Health Belief Model (HBM), developed by Rosenstock, explains and predicts health-related behaviours by proposing that individuals are more likely to utilise health services when they perceive themselves to be susceptible to a health condition, believe that the condition has serious consequences, perceive benefits in seeking healthcare, and identify few barriers to accessing services [13].

In the context of Taraba State, community members may perceive barriers such as distance, transportation costs, poor facility conditions, lack of medicines, or negative staff attitudes as deterrents to utilising PHC services. The HBM highlights the importance of individual perceptions and attitudes in determining whether healthcare services are utilised, complementing the spatial focus of the Spatio-Temporal Accessibility Model.

1.4. Andersen's Behavioural Model of Health Service Utilization

Andersen's Behavioural Model (Andersen) is one of the most widely used frameworks for studying healthcare accessibility and utilization [14]. The model suggests that healthcare utilisation is influenced by three major categories of factors: predisposing factors (demographic characteristics such as age, gender, education, and cultural beliefs), enabling factors (resources that facilitate or hinder healthcare access, including income, transportation, health insurance, and availability of healthcare facilities), and need factors (the individual's perception of illness and actual health status). For this study, Andersen's model is particularly important because it provides a framework for examining both spatial and non-spatial determinants of healthcare accessibility. Variables such as distance to facilities, transportation availability, socio-economic status, education level, and community participation can all be examined within this framework.

1.5. Integration of Theoretical Perspectives

The integration of the Spatio-Temporal Accessibility Model, the Health Belief Model, and Andersen's Behavioural Model provides a holistic framework for understanding healthcare accessibility in Taraba State. While the Spatio-Temporal Accessibility Model explains how distance and travel time influence access, the Health Belief Model explains how perceptions influence healthcare utilisation, and Andersen's Behavioural Model provides insight into the socio-economic and institutional determinants of healthcare access. Together, these theories support the study's objective of assessing healthcare accessibility, community participation, facility effectiveness, and the role of GIS in identifying underserved communities and improving healthcare service delivery [15].

1.6. Conceptual Framework

This study is anchored on two complementary conceptual frameworks: Human-Centred Design (HCD) and the Service Availability and Readiness Assessment (SARA) framework. Together, these frameworks ensure that the study addresses both the demand side (the people the PHC system is meant to serve) and the supply side (whether facilities are actually ready to deliver services).

1.7. Human-Centred Design (HCD)

HCD treats the people a system is built for, rather than the system itself, as the starting point for any intervention (Tsekleves & Cooper, Wildevuur) [16]. Bijl-Brouwer and Dorst describe HCD as a deliberately humane and creative response to complexity, one that works by understanding what people actually need before attempting to design around that need [17]. A design built this way, Norman argues, is one that functions well, feels intuitive, and does what it sets out to do without asking the user to adapt to it.

'Design' in this sense is no longer confined to physical products. It now extends to services, procedures, strategies, and policy - essentially any intervention meant to move a situation from where it is to where it should be (Dul Boeijen). A wide range of methods support this work, from the shadowing and contextual inquiry used to surface a problem to the co-creation and usability testing used to refine a solution. Several related fields, among them design thinking (Dorst), service design (Stickdorn), experience-based design (Bate & Robert), and participatory systems design (Jun draw on the same principles without always using the HCD label.

Healthcare has increasingly looked to this way of working. Erwin and Krishnan, writing in the BMJ, argue that the task is not to make people fit their care delivery system but to design that system around where people actually live, work, and receive care. A recent scoping review confirms that HCD continues to shape how patient experience is studied and improved across health systems. Adopting HCD as the conceptual anchor for this study is therefore less a theoretical preference than a practical one: it keeps the analysis oriented toward the people the Taraba State PHC system is meant to serve, not just the facilities and figures that describe it.

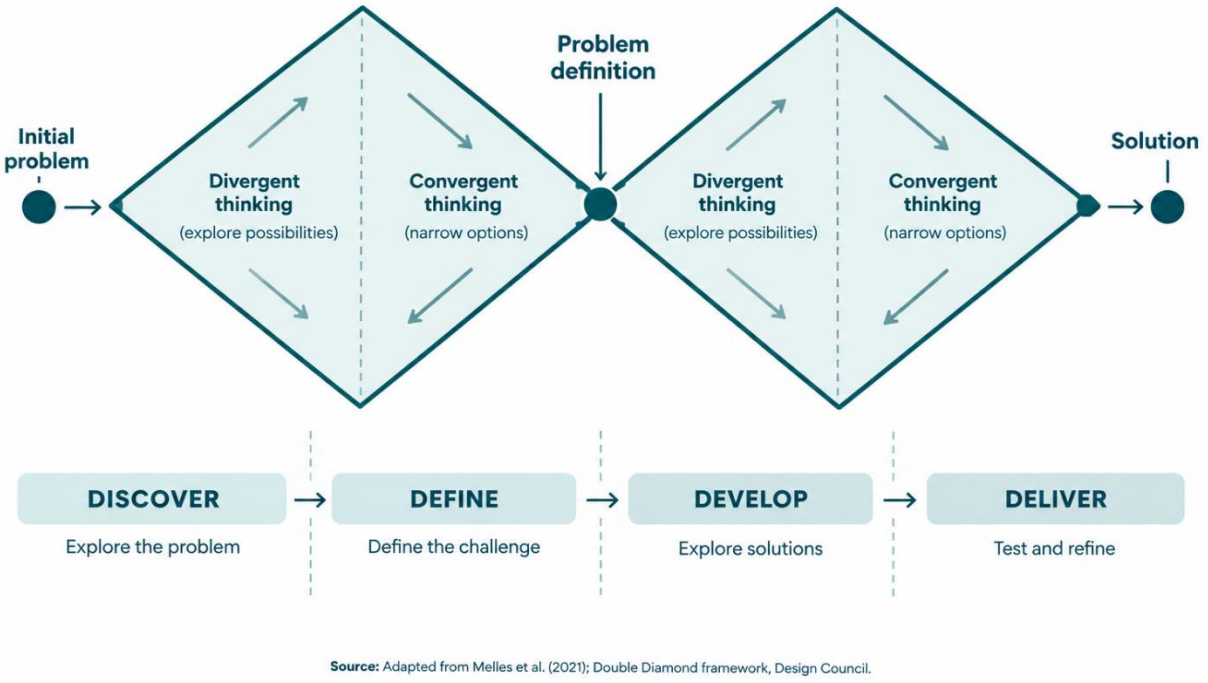


Figure 1: Double Diamond Model (Source: Melles et al., 2021) [18]

The Double Diamond Model (Figure 1), as described by Melles, visualises the HCD process: the first diamond is the diverge-converge cycle that pins down the real problem, and the second is the diverge-converge cycle that settles on the right solution to it. Four activities carry the process through both diamonds: Discover, Define, Develop, and Deliver. The fieldwork, facility surveys, and literature review that established PHC accessibility in Taraba State as genuinely constrained by terrain, distance, and incomplete immunization data sit in the Discover and Define phases. Building the GIS-based accessibility model and testing it through correlation analysis, hypothesis testing, and ward-level ground-truthing sit in the Design and Validate phases. The recommendation that the Taraba State Primary Health Care Development Agency adopt this GIS-EIR approach in its routine planning is the Implementation stage.

1.8. Hypotheses

Based on the theoretical and conceptual frameworks, and in response to the research objectives, the following five null hypotheses were formulated to guide the study:

Ho1: There is no significant disparity in the spatial distribution and accessibility of primary health care facilities across the selected Local Government Areas in Taraba State.

Ho2: The catchment population served by each primary health care centre does not significantly exceed the recommended service capacity standards.

Ho3: The use of Electronic Immunization Registers (EIR) does not significantly improve the accuracy and monitoring of immunization coverage in the study area.

Ho4: Travel time and road network connectivity do not significantly influence access to primary health care services in Taraba State.

Ho5: GIS-based modelling is not an effective tool for identifying underserved areas or optimizing the allocation of primary healthcare resources.

2. Materials and Methods

2.1. Study Design and Setting

A mixed-methods survey design was employed, integrating quantitative spatial analysis with structured facility and community surveys. The study was conducted in eight Local Government Areas (LGAs) of Taraba State, North-East Nigeria: Ardo-Kola, Bali, Gassol, Jalingo, Kurmi, Sardauna, Yorro, and Zing (Figure 2). These LGAs were purposively selected based on routine immunization data indicating high client density and service demand, and they span the state's three senatorial districts, capturing its geographic and ecological diversity—from the lowland savanna of the north to the highland montane zones of the south.

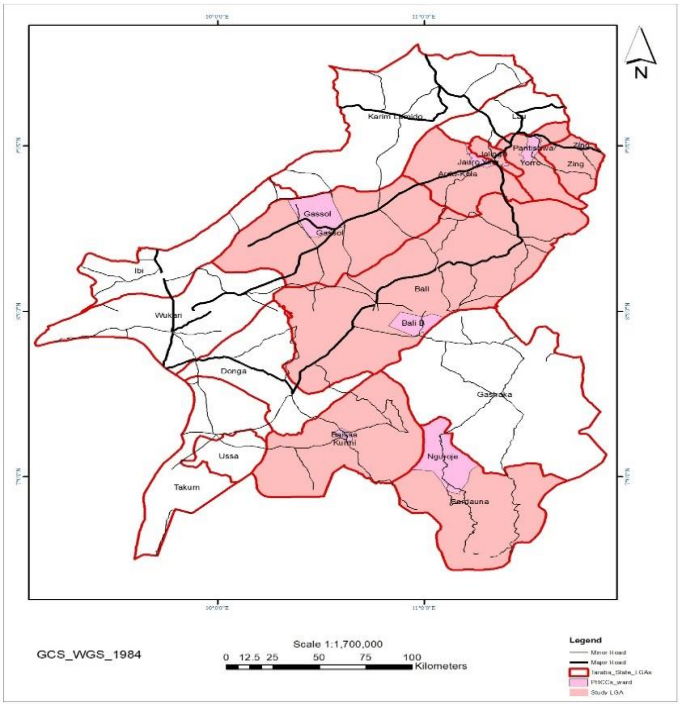


Figure 2: Map of Taraba State Showing Study Area Wards

2.2. Sampling and Data Collection

Within each LGA, one high-patronage government-owned PHC Centre (PHCC) offering routine immunization was purposively selected, yielding eight facilities: Turaki-A PHCC (Jalingo), Bali-B PHCC (Bali), Gassol PHCC (Gassol), Nguroje PHCC Sardauna, PHCC Kofai (Ardo-Kola), Pantisawa PHCC (Yorro), Baissa PHCC (Kurmi), and Zing-Z PHCC (Zing). A community survey was administered to 639 adult respondents (aged 18+) across the eight LGAs, selected through a four-stage sampling procedure: purposive selection of LGAs; purposive selection of wards containing the facility; random selection of settlements within wards; and systematic random selection of households. The sample size was determined using Cochran's formula ($Z = 1.96$, $p = 0.5$, $e = 0.05$), adjusted for a design effect of 1.5 and a 10% non-response rate, yielding a final target of approximately 639.

Qualitative data were collected through 16 key informant interviews (KIIs) with health facility staff, LGA health officials, and community leaders, and 16 focus group discussions (FGDs) with community members (8–12 participants per group). Observational checklists recorded facility infrastructure, road conditions, and settlement patterns.

2.3. Spatial Data Sources and Processing

Spatial datasets included GPS coordinates of all PHC facilities, settlement points, road networks (classified into major, minor, and footpaths), elevation data from the Shuttle Radar Topography Mission (SRTM) digital elevation model (30 m resolution), and administrative boundaries at LGA and ward levels. These were obtained from GRID3 Nigeria, OpenStreetMap, and field surveys. Population data were derived from GRID3's high-resolution gridded population estimates and projected to 2022 using National Population Commission figures and state growth rates [19]. All datasets were harmonised and reprojected to WGS 1984 UTM Zone 32N.

2.4. GIS-Based Accessibility Analysis

Two complementary spatial analysis approaches were employed:

i. **Buffer (Euclidean) Analysis:** Three concentric buffer zones were created around each facility: 0–3 km (served), 3–5 km (less served), and 5–10 km (underserved), consistent with WHO recommendations that people should be able to travel 3 km to a PHC for vaccination. This method provides a straightforward measure of how many settlements and people fall within specified distances of a facility.

ii. **Network Analysis:** Service area polygons (isochrones) were generated for each PHC facility using the Service Area tool in ArcGIS Network Analyst, with travel time thresholds of 15, 30, and 45 minutes. Travel speeds were assigned to each road type based on road class and field observations. In locations where terrain posed significant barriers, cost-distance modelling incorporating slope and vegetation was used to model least-cost paths. The WHO threshold of 5 km or 30 minutes' travel time to a PHC facility was used as the reference standard.

Catchment areas were delimited using network analyst tools based on road and path connectivity. Overlay analysis superimposed population density maps onto the buffer zones to examine how well existing PHC infrastructure aligned with population needs. Settlements were classified as underserved if they exhibited high population density but were located outside high-accessibility buffer zones.

2.5. Electronic Immunization Register (EIR) Integration and Validation

An Electronic Immunization Register was developed using App Sheet and Comm Care platforms to digitise routine immunization processes. The system allowed health workers to enrol children, record immunization history, track visit dates, and log vaccine types, with SMS-based reminders to reduce dropout rates. Historical data from manual registers were migrated after cleaning and validation. Each immunization entry included attributes such as Facility_ID, Child_ID, Community, Latitude, Longitude, Immunization Status, and Date_Visit. Geocoded EIR points were spatially joined to catchment areas to analyse immunization completion and dropout rates [20].

To assess EIR data reliability, a validation exercise compared a random sample of 120 EIR records against corresponding paper registers at the eight facilities (15 per facility). The validation checked completeness, accuracy, duplicates, and timeliness. Results showed a completeness rate of 94.2%, an accuracy rate of 91.7% for key fields, identification and removal of 3.3% duplicate records, and a median entry lag of 1 day. These results supported the use of EIR data for validating spatial accessibility findings.

2.6. Hypothesis Testing Framework

Each of the five null hypotheses was tested using specific statistical and analytical procedures, as summarized in Table 1.

Hypothesis	Verification Method	Justification
Ho1: No significant disparity in spatial distribution and accessibility across LGAs	One-way ANOVA on ward-level accessibility indicators (catchment population per facility, OPD utilisation per 1,000, and % villages covered)	ANOVA is appropriate for comparing means across more than two groups (eight LGAs) to determine whether observed differences are statistically significant.
Ho2: Catchment population does not significantly exceed recommended standards	One-sample t-test comparing the mean catchment population per facility against the national benchmark of 10,000 people per PHC	A one-sample t-test determines whether the sample mean differs significantly from a known population benchmark.
Ho3: EIR does not significantly improve accuracy and monitoring	EIR validation results (completeness, accuracy, and duplicate rates) and comparison of immunization coverage estimates derived from EIR versus paper records	Validation metrics provide direct quantitative evidence of data quality improvements attributable to EIR.
Ho4: Travel time and road connectivity do not significantly influence access	Chi-square tests on individual-level survey data (perceived barriers) and ward-level buffer analysis (proportion of population within 3 km and 5 km)	Chi-square tests examine associations between categorical variables; buffer analysis provides spatial evidence of travel-time effects.
Ho5: GIS-based modelling is not effective for identifying underserved areas	Convergence of evidence from buffer analysis, kernel density estimation, and hotspot analysis, validated against ground-truthing observations	Where a formal statistical test is not appropriate, the hypothesis is evaluated based on the weight of convergent GIS evidence.
Source: Author's conceptualisation (2025).		

Table 1: Summary of Hypotheses and Verification Methods

2.7. Statistical Analysis

Quantitative data were analysed using SPSS version 26 and R. Descriptive statistics summarised facility characteristics and catchment populations. One-way ANOVA tested for disparities in spatial distribution and accessibility across LGAs (Ho1). A one-sample t-test compared mean catchment population per facility against the national benchmark of 10,000 (Ho2). Chi-square tests examined associations between socio-demographic characteristics and reported barriers to access. Pearson and Spearman correlation coefficients assessed relationships between accessibility indicators, altitude, and immunization coverage. Kernel density estimation and hotspot analysis (Getis-Ord Gi) identified clusters of low immunization and poor access. Statistical significance was set at $p < 0.05$.

2.8. Ethical Considerations

Ethical approval was obtained from the Taraba State Ministry of Health Research Ethics Committee. Informed consent was obtained from all participants, and confidentiality was maintained throughout. All datasets used were either open-source or collected through officially sanctioned routine immunization programmes.

3. Result of the Findings

3.1. Distribution of PHC Facilities

The eight sampled LGAs had a total of 40 government-owned PHC facilities in routine service. Their distribution was uneven: Yorro LGA had the highest number (7), while Ardo-Kola, Bali, and Jalingo had the lowest (4 each). The eight selected facilities served an average catchment population of 11,352 persons (range: 5,028 at Bali-B PHCC to 20,956 at Turaki-A PHCC). The mean catchment population exceeded the national benchmark of 10,000, though a one-sample t-test showed this difference was only marginally significant ($t = 1.42$, $p = 0.098$). Two facilities; Turaki-A PHCC (20,956) and Gassol PHC (18,364) served close to or more than twice the recommended standard, indicating significant overburdening.

3.2. Catchment Coverage and Utilization

Table 2 presents facility-level data on catchment population, monthly outpatient department (OPD) attendance, OPD attendance per 1,000 population, and village coverage. The average number of catchment villages per facility was 16 (range: 4 to 34), and the average number of villages actually accessing the facility per month was 15, indicating a slight gap between theoretical catchment and actual service delivery. Village coverage ranged from 35.2% (Gassol PHC) to 100% (PHCC Kofai, Baissa PHCC, and Zing-Z PHCC).

LGA	Facility	Catchment Population	Monthly OPD Attendance	OPD per 1,000	Village Coverage (%)
Jalingo	Turaki-A PHCC	20,956	720	34.36	62.5
Bali	Bali-B PHCC	5,028	22	4.38	90.0
Ardo-Kola	PHCC Kofai	6,243	35	5.61	100.0
Gassol	Gassol PHC	18,364	585	31.85	35.2
Yorro	Pantisawa PHCC	7,865	500	63.59	61.5
Kurmi	Baissa PHCC	10,529	249	23.65	100.0
Sardauna	Nguroje PHCC	12,835	178	13.87	38.5
Zing	Zing-Z PHCC	9,000	400	44.44	100.0
Source: Field Data Analysis (2025).					

Table 2: Catchment Population, OPD Utilization, and Village Coverage by Sampled Facility (N = 8)

Facilities with high OPD utilisation included Pantisawa PHCC (63.59 per 1,000), Zing-Z PHCC (44.44 per 1,000), and Turaki-A PHCC (34.36 per 1,000). Facilities with low utilisation included Bali-B PHCC (4.38 per 1,000) and PHCC Kofai (5.61 per 1,000). The low utilisation at some facilities despite proximity to settlements suggests that non-spatial factors such as service quality, awareness, or cultural preferences may be influencing healthcare-seeking behaviour.

3.3. Spatial Accessibility: Buffer and Network Analysis

The buffer analysis revealed that only about 35% of the sampled population lived within the WHO-recommended 3 km radius of a PHC facility. A significant proportion of settlements were located in the 3–5 km (less served) and 5–10 km (underserved) zones. Network analysis showed that travel times to facilities varied considerably, with some communities requiring more than 30 minutes to reach the nearest PHC, particularly in highland areas of Kurmi, Sardauna, and Yorro LGAs. Seasonal variation exacerbated these challenges, with many rural roads becoming impassable during the rainy season.

3.4. Immunization Coverage and EIR Validation

EIR data revealed that immunization coverage varied widely across facilities. Kernel density mapping identified vaccination "cold spots" in Nguroje (Sardauna, LGA) and Baissa (Kurmi LGA), while higher uptake was observed in Zing and Turaki-A (Jalingo). Vaccine density declined sharply beyond 5 km from facilities, demonstrating an inverse relationship between distance and immunization coverage. The EIR validation (completeness 94.2%, accuracy 91.7%) enabled the identification of communities within 3–5 km of a PHC that still showed low immunization rates due to vaccine stockouts or poor follow-up, revealing gaps that proximity measures alone would miss.

3.5. Determinants of Accessibility and Hypothesis Testing

Hypothesis	Test Used	Test Statistic	p-value	Decision
Ho1: No significant disparity in spatial distribution across LGAs	One-way ANOVA	F = 3.42	0.001	Rejected
Ho2: Catchment population does not significantly exceed recommended standards	One-sample t-test	t = 1.42	0.098	Not rejected (marginally)
Ho3: EIR does not significantly improve accuracy and monitoring	EIR validation results	-	-	Rejected
Ho4: Travel time and road connectivity do not significantly influence access	Chi-square and buffer analysis	-	-	Partially rejected
Ho5: GIS-based modelling is not effective for identifying underserved areas	Convergence of GIS evidence	-	-	Rejected
Source: Field Data Analysis (2025).				

Table 3: Summary of Hypothesis Testing Results

The one-way ANOVA confirmed that differences between wards were statistically significant ($F = 3.42$, $p = 0.001$), leading to the rejection of Ho1. Ho2 was not rejected (marginally), though Turaki-A PHCC and Gassol PHC served populations close to or exceeding twice the recommended standard, indicating that overburdening is a real issue for specific facilities even if the overall mean is not significantly different from the benchmark. Ho3 was rejected based on the high EIR completeness and accuracy rates. Ho4 was partially rejected: individual self-reported complaints about road condition ($\chi^2 = 2.133$, $p = 0.344$) and terrain ($\chi^2 = 0.788$, $p = 0.375$) were not statistically significant, yet the ward-level buffer analysis showed real, systematic variation in settlement coverage within 3 km. Ho5 was rejected as the GIS outputs successfully identified underserved settlements with a precision that routine facility registers alone could not provide.

3.6. Correlation Analysis

Correlation analysis revealed a negligible linear relationship between total ward population and total immunised individuals ($r = -0.005$, $p > 0.05$). More importantly, there was a strong negative correlation ($r = -0.817$, $p < 0.05$) between total population and the percentage immunised, suggesting that more populous wards tend to achieve lower immunisation coverage. The correlation between facility altitude and routine immunisation was extremely weak ($r = 0.008$, $p > 0.05$), indicating that facility altitude alone is not a good predictor of performance.

This apparent contradiction with the visual interpretation of topographic maps which suggested that lowland facilities had higher vaccination turnout, can be explained by the fact that altitude at the facility location is not the same as terrain difficulty or travel impedance for the communities the facility serves.

3.7. Identification of Underserved Communities

Based on buffer analysis, vaccination density, and village coverage, the study identified the following communities and wards as underserved:

- **Nguroje Ward (Sardauna LGA):** Only a small proportion of settlements fell within the 0–3 km zone; many were in the 5–10 km zone. Village coverage was only 38.46%, and the ward's mountainous terrain posed significant challenges.
- **Gassol Ward (Gassol LGA):** Village coverage was only 35.2%, despite serving 34 catchment villages, indicating significant access barriers in this widely dispersed rural area.
- **Baissa Ward (Kurmi LGA):** Although village coverage was 100%, the ward is in a highland area with difficult terrain, and vaccination density was low in remote areas.
- **Bali B Ward (Bali LGA):** Although village coverage was 90%, OPD utilisation was very low (4.38 per 1,000), suggesting that proximity alone does not guarantee utilisation.
- **Pantisawa Ward (Yorro LGA):** Although OPD utilisation was high (63.59 per 1,000), only 61.5% of catchment villages were covered, indicating that some remote settlements were not accessing services.

4. Discussion

This study provides the first comprehensive, ward-level spatial accessibility analysis for eight LGAs in Taraba State, integrating GIS-based modelling with EIR data to move beyond theoretical access to actual service uptake. The findings confirm that PHC facilities in Taraba State are unevenly distributed, with mountainous and dispersed rural LGAs experiencing the most severe service gaps. Approximately 65% of the sampled population resided beyond the WHO-recommended 3 km radius of a PHC facility, a figure that aligns with broader evidence from Sub-Saharan Africa, where 29% of the population lives more than two hours from a hospital.

The rejection of Ho1 (significant disparities in spatial distribution) is consistent with Isah, who found that uneven facility distribution was itself a major driver of inequitable access in Bauchi State [21]. Similar to the findings in Bauchi, urban centres such as Jalingo and Bali had relatively higher facility density and shorter travel times, while rural wards such as Baissa and Nguroje remained underserved due to difficult terrain, poor road connectivity, and sparse facility presence. This validates the utility of GIS tools in identifying spatial gaps and planning targeted interventions, echoing Mokgalaka, whose GIS-based catchment analysis showed that service areas calculated on paper routinely diverge from the populations facilities actually serve once demand outpaces planning [22].

The integration of EIR data substantiates the work of Brown and Gacic-Dobo and Orenstein and Ahmed, who argued that real-time digital health records surface service gaps that proximity measures and paper registers miss [23,24]. In Taraba State, EIR helped identify discrepancies between theoretical accessibility (proximity) and actual service uptake, showing that even communities within 3–5 km of a PHC may still exhibit low immunisation rates due to vaccine stockouts or lack of follow-up. The EIR's completeness (94.2%) and accuracy (91.7%) demonstrate that digital tools can enhance data quality and monitoring in low-resource settings, supporting the call for their institutionalization across PHC systems [25].

The partial rejection of Ho4 (travel time and road connectivity do not influence access) warrants careful interpretation. Individual self-reported complaints about road condition and terrain were not statistically significant, yet ward-level buffer analysis showed real, systematic variation in settlement coverage within 3 km. This divergence suggests that travel time and connectivity shape accessibility at the population level even where they do not register as the single most-cited individual barrier. This finding compares instructively with Bello and Dogara, whose GIS-based analysis of Keffi LGA found that most patients travelled under 5 km to reach care, with cost rather than distance driving facility choice in that largely urban setting [26]. Taraba State's more rugged, sparsely settled wards tell a different story: terrain and travel time, not cost, are what limit access for a much larger share of the population. This contrast speaks to the importance of calibrating accessibility models to local geography rather than applying them uniformly

nationwide.

The study also found that facility altitude alone was not a significant predictor of immunization performance (r = 0.008), even though topographic maps suggested that lowland facilities had higher vaccination turnout. This apparent contradiction can be explained by the fact that altitude at the facility location is not the same as terrain difficulty or travel impedance for the communities the facility serves. A facility may be located at a relatively low altitude but still serve communities in rugged highland areas, or vice versa. Future research should use more refined measures of terrain impedance, such as travel time from each settlement to the facility, rather than facility altitude alone.

The finding that a strong negative correlation exists between total ward population and percentage immunised ($r = -0.817$) highlights a critical challenge: more populous wards tend to achieve lower immunisation coverage, despite having a larger overall pool of individuals. This disparity points to potential issues with PHC accessibility, outreach, or capacity in larger communities, and it underscores the need for targeted interventions in high-population wards where facilities may be overburdened.

The study's limitations must be acknowledged. The focus on eight purposively selected high-patronage facilities, while representative of their LGAs, may not capture the full range of accessibility conditions across all PHC facilities in the state. The exclusion of private and faith-based providers, which serve large segments of the population, is another limitation. Road network data from OpenStreetMap and GRID3 may not reflect current conditions, particularly during the rainy season. The small sample sizes for some analyses (16 FGD respondents for chi-square tests; 8 wards for correlations) limit statistical power and generalisability. Finally, the study covered the period 2020–2022; conditions may have changed since then, particularly in areas affected by insecurity or population displacement.

5. Conclusion

This study confirms that spatial and infrastructural barriers remain major constraints to equitable access to primary health care services in Taraba State. The integration of GIS-based accessibility modelling with Electronic Immunization Register data proved effective in quantifying these inequities, identifying underserved communities, and providing a replicable, low-cost methodology that state and local governments can adopt to keep their PHC accessibility maps current as facilities, roads, and population distributions change over time.

Recommendations

Based on the findings, the following recommendations are proposed:

i. **Establishment of Additional PHC Facilities in Underserved Areas:** Government and health planners should prioritise the construction of new PHC facilities in wards identified as underserved, particularly Nguroje (Sardauna, LGA), Gassol (Gassol LGA), Baissa (Kurmi LGA), and Pantisawa (Yorro LGA), where many residents live beyond the WHO-recommended 5 km access threshold. Spatial data generated through GIS analysis should guide the siting of these new facilities to ensure maximum population coverage.

ii. **Upgrading Road and Transport Infrastructure:** Investment in rural road infrastructure is urgently needed, particularly in the mountainous and riverine areas of Kurmi, Sardauna, and Yorro LGAs. Upgrading feeder roads and bridges will significantly reduce travel time to PHC facilities and improve emergency response.

iii. **Optimisation of Existing PHC Catchment Areas:** Health authorities should review and, where necessary, redesign the catchment areas of existing PHC centres using GIS-based service area models. Facilities such as Turaki-A PHCC (20,956 catchment population) and Gassol PHC (18,364) should be prioritised for catchment review and resource reinforcement.

iv. **Expansion and Institutionalisation of Electronic Immunization Registers:** The EIR platform should be scaled up and institutionalised across all PHC facilities in the state. Continuous digitisation of immunisation records will enhance real-time data monitoring, reduce dropout rates, and improve vaccine accountability.

v. **Financial Protection for Vulnerable Groups:** Given that financial constraints were the most frequently reported barrier to accessing PHC services, the state government should strengthen financial protection mechanisms, including the Basic Health Care Provision Fund (BHCPF) and National Health Insurance Authority (NHIA) schemes, with targeted subsidies or exemptions for older adults, women, and rural households with limited cash incomes.

vi. **Integration of GIS in Routine Health Planning:** The use of GIS tools should be mainstreamed into the routine operations of the Taraba State Primary Health Care Development Agency (TSPHCDA) and the State Ministry of Health. Regular spatial assessments can guide equitable distribution of health services, optimise outreach campaigns, and support disaster or conflict-related health planning.

Future research should include private and faith-based providers, employ longitudinal designs to track changes in accessibility over time, use refined terrain impedance measures, and conduct qualitative exploration of non-spatial barriers such as cost, language, cultural beliefs, and gender norms.

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