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Impact of Topography on Routine Immunization Coverage in Taraba State Nigeria

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ABSTRACT

Routine immunization (RI) remains one of the most effective strategies for reducing childhood morbidity and mortality from vaccine-preventable diseases, yet coverage in Nigeria and Taraba State in particular continues to fall short, particularly in rural and hard-to-reach areas. This study examined the influence of topography on RI coverage in Taraba State, a region with diverse terrain and seasonal accessibility challenges. A cross-sectional design was employed, integrating geospatial and statistical analyses. Immunization data were obtained from Primary Health Care Centres (PHCCs) across selected wards, while Digital Elevation Models (DEMs), road networks, and hydrological datasets provided information on terrain. ArcGIS was used to overlay immunization records with topographic features, and Pearson correlation was applied to test the relationship between altitude and vaccination turnout. Results showed that PHCCs located in lowland and accessible areas recorded higher immunization coverage, while those in elevated or rugged terrains had lower turnout. However, correlation analysis ($r = 0.008$) indicated no significant association between altitude and coverage, suggesting that other factors such as road conditions, flooding, and service delivery mechanisms play a more decisive role. The study concludes that topography indirectly influences RI coverage through its interaction with infrastructural and systemic barriers, and recommends improved transport infrastructure, mobile outreach, and geospatially informed planning to promote equitable vaccine access.

Keywords: Geographic Accessibility; Routine Immunization; Topography; Taraba State & Vaccine Coverage

Abbreviations: RI: Routine immunization; VPDs: Vaccine-Preventable Diseases; WHO: World Health Organization; EPI: Expanded Programme on Immunization; BCG: Bacillus Calmette-Guérin; LGAs: Local Government Areas; TSPHCDA: Taraba State Primary Health Care Development Agency; PHCCs: Health Care Centres; SRTM: Shuttle Radar Topography Mission; DEMs: Digital Elevation Models; PHC: Primary Health Care; DEM: Digital Elevation Model

Introduction

Routine immunization (RI) remains one of the most cost-effective public health strategies for preventing vaccine-preventable diseases (VPDs) and reducing childhood morbidity and mortality globally. Since the World Health Organization (WHO) launched the Expanded Programme on Immunization (EPI) in 1974, vaccination coverage has improved significantly, saving millions of lives annually (Ogunniyi, et al. [1]). Nigeria adopted the EPI in 1978, targeting children under two years of age with vaccines such as Bacillus Calmette-Guérin (BCG), oral polio vaccine, pentavalent, measles-containing vaccine, and yellow fever vaccine. Despite this commitment, immunization coverage in Nigeria remains below expectations, with persistent gaps that compromise child health outcomes (WHO [2]). National reports reveal that only about 64% of children aged 12–23 months in Nigeria are fully immunized, leaving a substantial proportion partially immunized or unvaccinated (WHO [2]). These gaps are particularly pronounced in rural and hard-to-reach communities, where barriers such as poor road infrastructure, long travel distances, socio-economic constraints, and service delivery inefficiencies hinder access to vaccines (Ogunniyi, et al. [1]). Recent geospatial studies also highlight that physical accessibility, especially terrain, transportation costs, and travel time, significantly influences immunization uptake, particularly in disadvantaged households (Lawson, et al. [3]).

Taraba State, located in north-eastern Nigeria, presents a unique case for examining these challenges. The state is characterized by diverse topographical features, including mountainous highlands,

rolling hills, river valleys, and seasonal floodplains (Wikipedia, n.d.). Such terrain frequently restricts physical access to healthcare, particularly during the rainy season when flooding cuts off many communities from primary health care facilities. While national and subnational studies in Nigeria have broadly examined infrastructural and socio-economic determinants of immunization coverage, the specific influence of topography on RI in Taraba State remains underexplored. This gap is significant, as inadequate understanding of how physical geography shapes vaccine delivery risks perpetuating inequities in immunization coverage. Against this background, the present study investigates the impact of topography on routine immunization coverage in Taraba State. The objectives are to characterize the state's major topographical features, assess immunization coverage across different terrain zones, analyze the relationship between topography and immunization uptake, identify geographic "cold spots" where difficult terrain limits access, and recommend targeted interventions to improve accessibility. By integrating geospatial analysis with public health data, this study seeks to generate evidence for equitable immunization planning, strengthen health system resilience, and support Nigeria's progress toward universal immunization coverage in line with national and global health goals.t

Description of Study Area

The study was conducted in Taraba State, located in the north-eastern geopolitical zone of Nigeria, between latitudes 6°25′N and 9°30′N and longitudes 9°30′E and 11°45′E. The state shares an international boundary with the Republic of Cameroon to the east and is bordered by Adamawa State to the north, Benue State to the west, Gombe and Bauchi States to the northwest, and Plateau State to the southwest (Figure 1). Covering an estimated land area of 54,473 km^2, Taraba is one of the largest states in Nigeria by geographic size. According to NPC [4] projections, the state has a population of over 3 million people, distributed across 16 Local Government Areas (LGAs). Topographically, Taraba is among the most physically diverse states in Nigeria. It features the elevated Mambilla Plateau, which rises above 1,800 meters above sea level, along with undulating hills, extensive lowlands, and wide river valleys. The Benue River and its tributaries, including the Taraba and Donga Rivers, traverse the state, contributing to seasonal flooding in adjoining communities (Wikipedia, n.d.). The climate is tropical, with two distinct seasons: the wet season (April–October) and the dry season (November–March). Rainfall ranges from about 1,000 mm annually in the lowlands to over 2,500 mm in the highlands (Nigerian Meteorological Agency [NiMet] [5]).

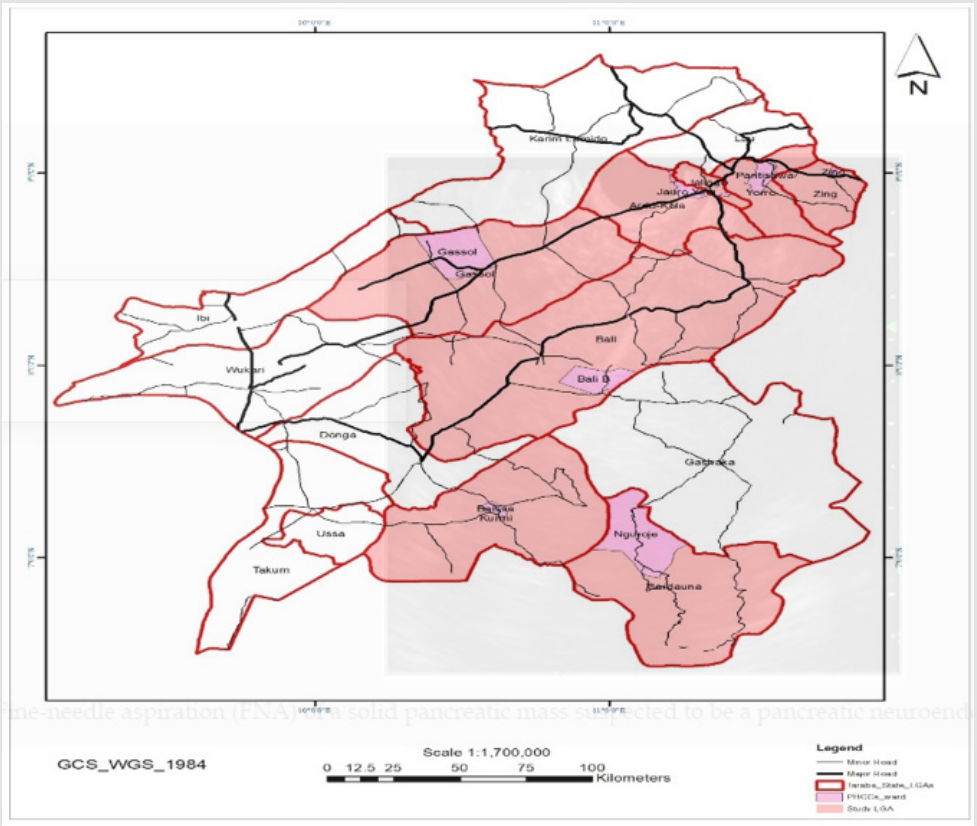

Figure 1: Map of the Study Area Showing Sampled PHCC Communities.

These geographical and climatic features significantly influence accessibility and service delivery. During the rainy season, road networks often become impassable, isolating many rural communities from health and social services. Administratively, healthcare delivery in Taraba State is coordinated by the State Ministry of Health and the State Primary Health Care Development Agency (TSPHCDA), with immunization services provided through fixed, outreach, and mobile strategies. However, the state's rugged terrain, limited road infrastructure, and dispersed settlement patterns remain critical barriers to routine immunization coverage, particularly in hard-to-reach areas (NPC, et al. [4,5]).

Methodology

Study Design

The study adopted a cross-sectional design integrating quantitative immunization data with geospatial analysis to investigate the effect of topography on routine immunization (RI) coverage in Taraba State, Nigeria. This design was chosen because cross-sectional approaches are effective in capturing spatial variations in health outcomes and linking them with environmental and infrastructural determinants at a given point in time (Ebener, et al. [6]). The use of geospatial analysis is particularly relevant, as it enables visualization of disparities, identification of geographic "cold spots," and generation of evidence for equity-driven planning in healthcare delivery (Lawson, et al. [3]).

Data Sources

Data were drawn from multiple sources to ensure robustness and reliability.

1. Routine Immunization Records: Data on the number of children vaccinated were collected from selected Primary Health Care Centres (PHCCs) across sampled wards in Taraba State. These data, obtained through the Taraba State Primary Health Care Development Agency (TSPHCDA), included records of children immunized with key RI antigens such as BCG, pentavalent, oral polio, measles-containing vaccine, and yellow fever.

2. Geospatial Datasets: Topographic data were sourced from the Shuttle Radar Topography Mission (SRTM), which provides high-resolution Digital Elevation Models (DEMs). Additional geospatial layers such as road networks, hydrological features, and settlement distribution were obtained from the online resources at high spatial resolution (typically 100m) and validated through field reconnaissance surveys.

3. Demographic and Climate Data: Population estimates were obtained from the National Population Commission (NPC [4]) and gridded population estimates for Taraba State, while climate records including rainfall distribution were drawn from the Nigerian Meteorological Agency (NiMet [5]). These datasets provided essential contextual information for understanding how population distribution and seasonal variations influence service accessibility.

Data Processing and Geospatial Analysis

Data analysis was conducted using ArcGIS 10.8 and QGIS 3.28 software packages. The analytical process involved several steps:

1. DEM Processing: The DEM of Taraba State was clipped and classified into elevation zones (lowland: 0–600 m, midland: 601–1,200 m, highland: >1,200 m) to represent varying topographic conditions across the state.

2. Overlay Analysis: Immunization data from PHCCs were spatially joined to their geographic coordinates. These were overlaid with elevation, slope, hydrological features, and road networks to visualize accessibility patterns. This allowed comparisons of immunization uptake across topographically distinct zones.

3. Hotspot Identification: Spatial autocorrelation tools (Getis-Ord Gi statistics) were applied to identify clusters of low immunization coverage, particularly in rugged or flood-prone areas. These "cold spots" highlighted where topography posed significant barriers to vaccine access.

4. Ward-Level Mapping: Detailed overlay maps were produced for selected wards (e.g., Zing, Pantisawa, Turaki B, Jauro Yinu, Gassol, Bali B, Baissa, and Nguroje). These maps revealed consistent patterns, PHCCs in lowland and accessible locations recorded higher vaccination turnout, while those in elevated or rugged terrains had significantly lower coverage.

Statistical Analysis

To quantify the relationship between topography and RI coverage, statistical analyses were conducted using SPSS v26. Pearson correlation tests were applied to examine the association between altitude and the number of children vaccinated across PHCCs. Results indicated a weak, non-significant correlation ($r = 0.008$), suggesting that while descriptive maps showed disparities, altitude alone was not a significant predictor of immunization uptake. This finding implies that other factors, including road quality, distance to facilities, and socio-economic conditions, may mediate the observed disparities (Ogunniyi, et al. [1,2]).

Validation and Triangulation

To enhance credibility, findings from GIS and statistical analyses were triangulated with secondary literature on RI coverage challenges in Nigeria. Previous studies highlight that geographic accessibility, particularly in rural and mountainous regions, remains a barrier to service utilization (Ogunniyi, et al. [1,3]). Field observations during data collection further confirmed that flooding, poor road conditions, and dispersed settlement patterns frequently hindered community access to PHCCs.

Ethical Considerations

Ethical clearance for the study was obtained from the Taraba State Ministry of Health Research and Ethics Committee. Administrative approvals were also secured from the TSPHCDA. Patient confidentiality was maintained by using aggregated, facility-level immunization data rather than individual records.

Result of the Findings

This chapter presents the findings of the study, derived from the quantitative (GIS-based analysis and statistical analysis of survey data) and qualitative (in-depth interviews and focused group discussions) components.

Digital Elevation Model (DEM) Map 0f Taraba State

To understand how terrain influences accessibility to Primary Health Care (PHC) services in the State, Digital Elevation Model (DEM) map of Taraba State was produced as shown in Figure 2. Figure 2 reveals that the state features varied topography, including highland areas like the Mambilla Plateau and low-lying river valleys. These elevation differences affect how easily residents can reach health facilities. Steep and mountainous regions often lack adequate road infrastructure, making travel to PHCs more difficult and time-consuming, while some lowland areas may become inaccessible during seasonal flooding. By overlaying the DEM with PHC locations, road networks, and population data, the analysis identifies underserved communities where physical barriers limit access to care. This helps pinpoint where new facilities should be located or where mobile services and road improvements are needed. The DEM thus enhances spatial planning by allowing more accurate modeling of travel time and service coverage, leading to more equitable distribution of health resources across Taraba State.

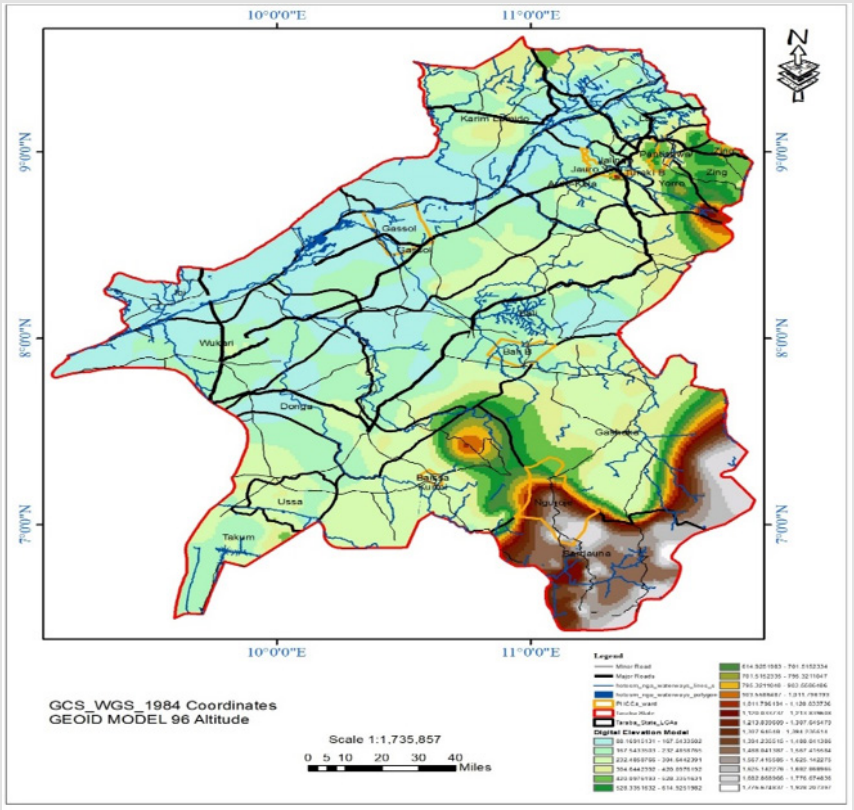

Figure 2: Digital Elevation Model Map of Taraba State.

Effect of Altitude on Number of Children Vaccinated

The study made effort to assess the relationship between elevation and population of children vaccinated from each PHCCs in the study area. This was achieved by overlaing the topographic map over the number of people vaccinated per each PHCCs. The resultant maps are presented below; Figure 3 presents a spatial overlay of topographic elevation and the number of children vaccinated at various Primary Health Care Centres (PHCCs) in Zing Ward. This analysis reveals key insights into the relationship between terrain (elevation) and service utilization (vaccination coverage) across the ward. The result of the finding in Figure 4 reveals that PHCCs in lowland areas recorded higher vaccination turnout, while those in highland terrains had lower numbers. This indicates that topography influences access to healthcare, with difficult terrain limiting service utilization. The analysis supports the use of GIS in identifying geographic barriers to PHC accessibility in Taraba State. Figure 4 presents a spatial overlay of topographic elevation and the number of children vaccinated at various Primary Health Care Centres (PHCCs) in Pantisawa Ward. The overlay of elevation and vaccination data in Pantisawa Ward reveals that PHCCs in accessible low-lying areas had higher vaccination numbers, while those in elevated or rugged terrains recorded lower turnout. This suggests that elevation affects access to PHC services, reinforcing the relevance of GIS-based analysis in identifying and addressing geographic barriers to healthcare delivery.

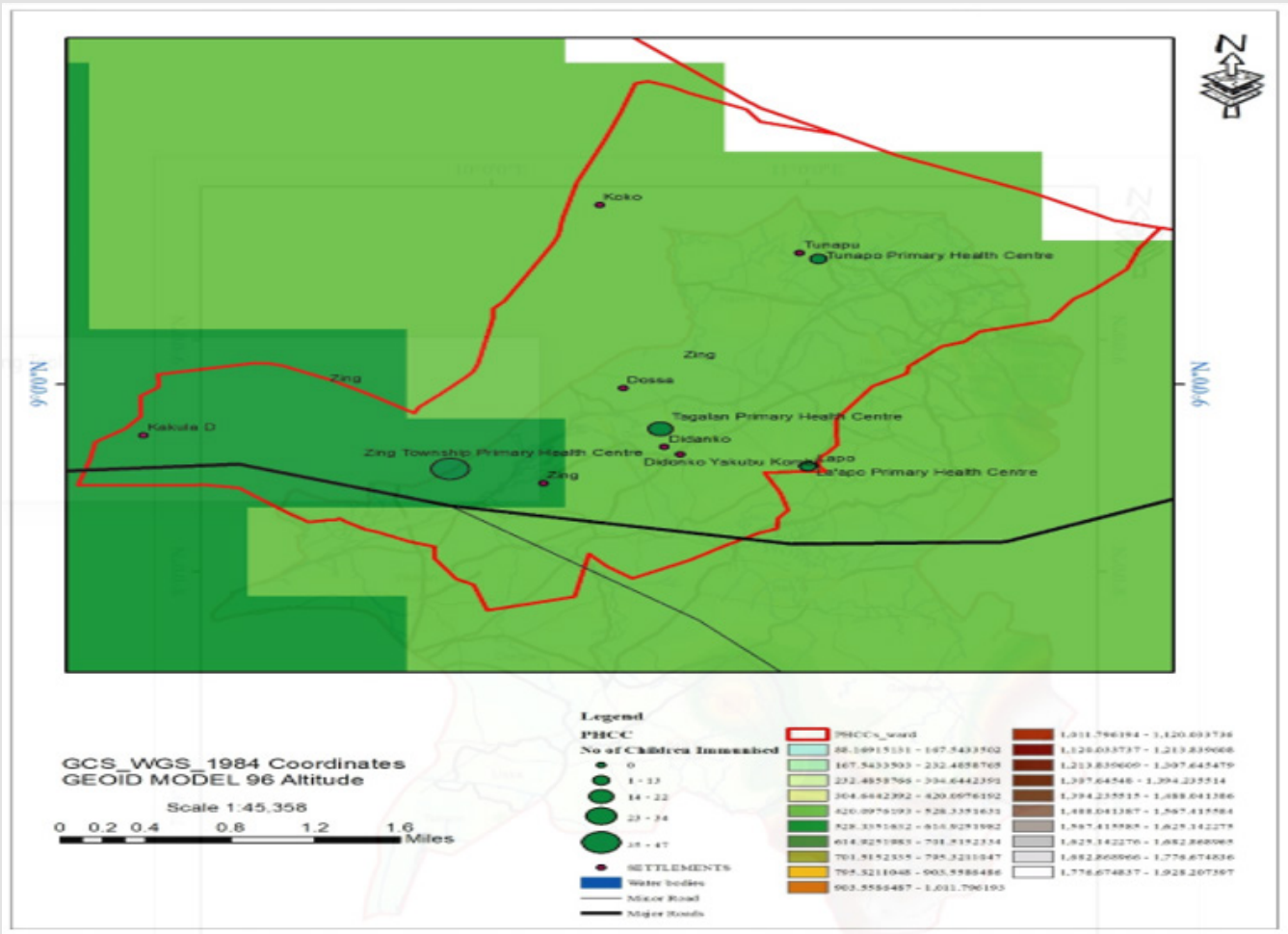

Figure 3: Overlaid Topographic and number of people vaccinated in Zing ward.

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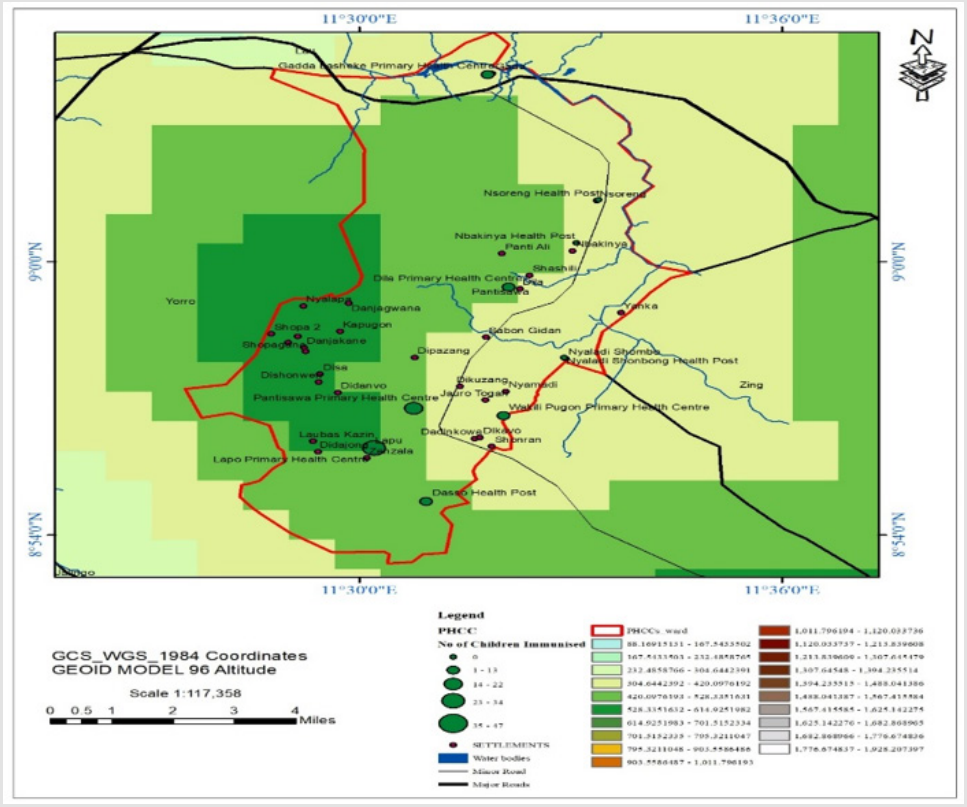

Figure 4: Overlaid Topographic and number of people vaccinated in Pantisawa ward.

The overlaid map of topography and vaccination data in Turaki B Ward (Figure 5) shows a clear spatial pattern where PHCCs in lower elevation areas recorded higher numbers of vaccinated children, while those in higher or more rugged terrains had lower figures. This suggests that residents in elevated areas face greater physical barriers such as longer travel distances, steep slopes, and poor road access which reduce their ability to utilize health services. The findings demonstrate how terrain plays a significant role in healthcare accessibility and highlight the need for improved outreach or strategically located facilities in less accessible parts of the ward. This further validates the use of GIS-based models in identifying underserved areas and informing equitable healthcare planning in Taraba State. The overlay of topographic and vaccination data in Jauro Yinu Ward (Figure 6) indicates that PHCCs located in flatter, low-lying areas recorded higher vaccination coverage, while those in elevated or less accessible terrains had lower turnout. This trend suggests that topography influences community access to PHC services, with rugged or elevated areas presenting physical barriers. The result reinforces the importance of using GIS-based analysis to identify such disparities and guide interventions aimed at improving healthcare accessibility in the ward and across Taraba State.

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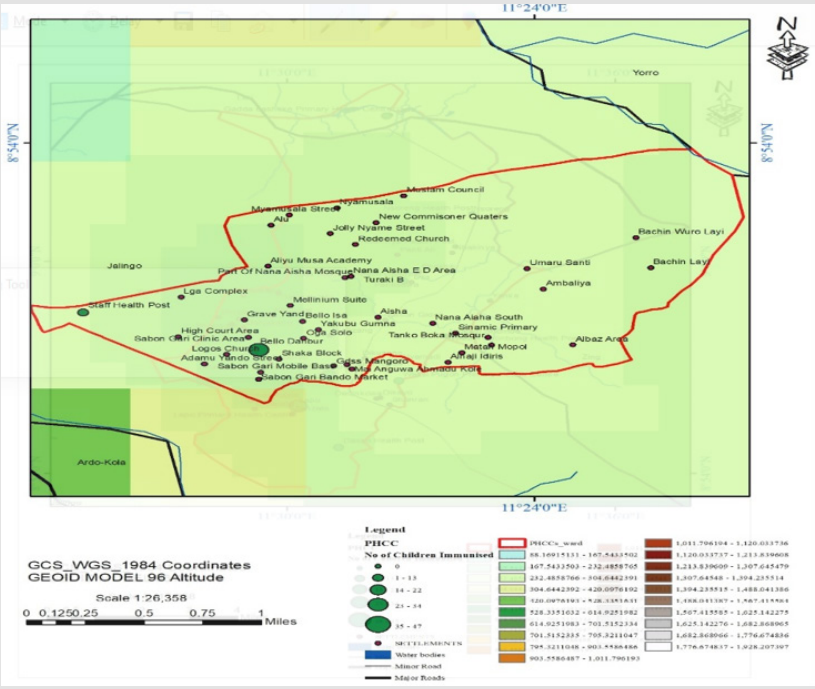

Figure 5: Overlaid Topographic and number of people vaccinated in Turaki B ward.

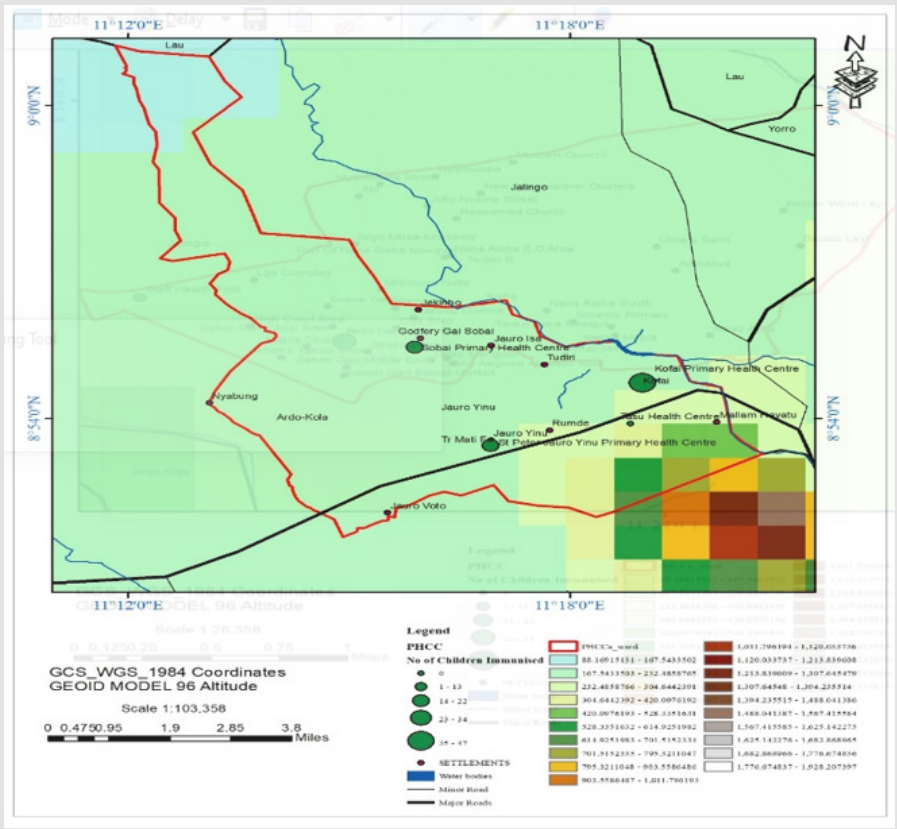

Figure 6: Overlaid Topographic and number of people vaccinated in Jauro Yinu ward.

The overlaid map of elevation and vaccination data in Gassol Ward (Figure 7) reveals a strong spatial relationship between terrain and access to primary health care services. PHCCs situated in low-lying and well-connected areas recorded significantly higher numbers of vaccinated children, suggesting better accessibility and ease of movement for residents. In contrast, PHCCs located in highland or rugged terrain had much lower vaccination figures, pointing to the physical challenges faced by communities in these areas when attempting to access healthcare. These include poor road conditions, long walking distances, and steep slopes, all of which can discourage or delay visits to health facilities. The observed pattern underscores how elevation acts as a barrier to equitable health service delivery and highlights the need for targeted interventions such as improving rural transport infrastructure, deploying mobile clinics, or establishing new PHCCs in underserved highland areas. This further supports the application of GIS-based models in identifying critical spatial gaps and guiding strategic healthcare planning in Taraba State. The overlay of topography and vaccination data in Bali B Ward (Figure 8) shows a clear pattern where PHCCs in flat or low-elevation areas recorded higher vaccination turnout, while those in elevated or topographically challenging locations had lower numbers. This suggests that physical terrain significantly affects community access to primary health care services.

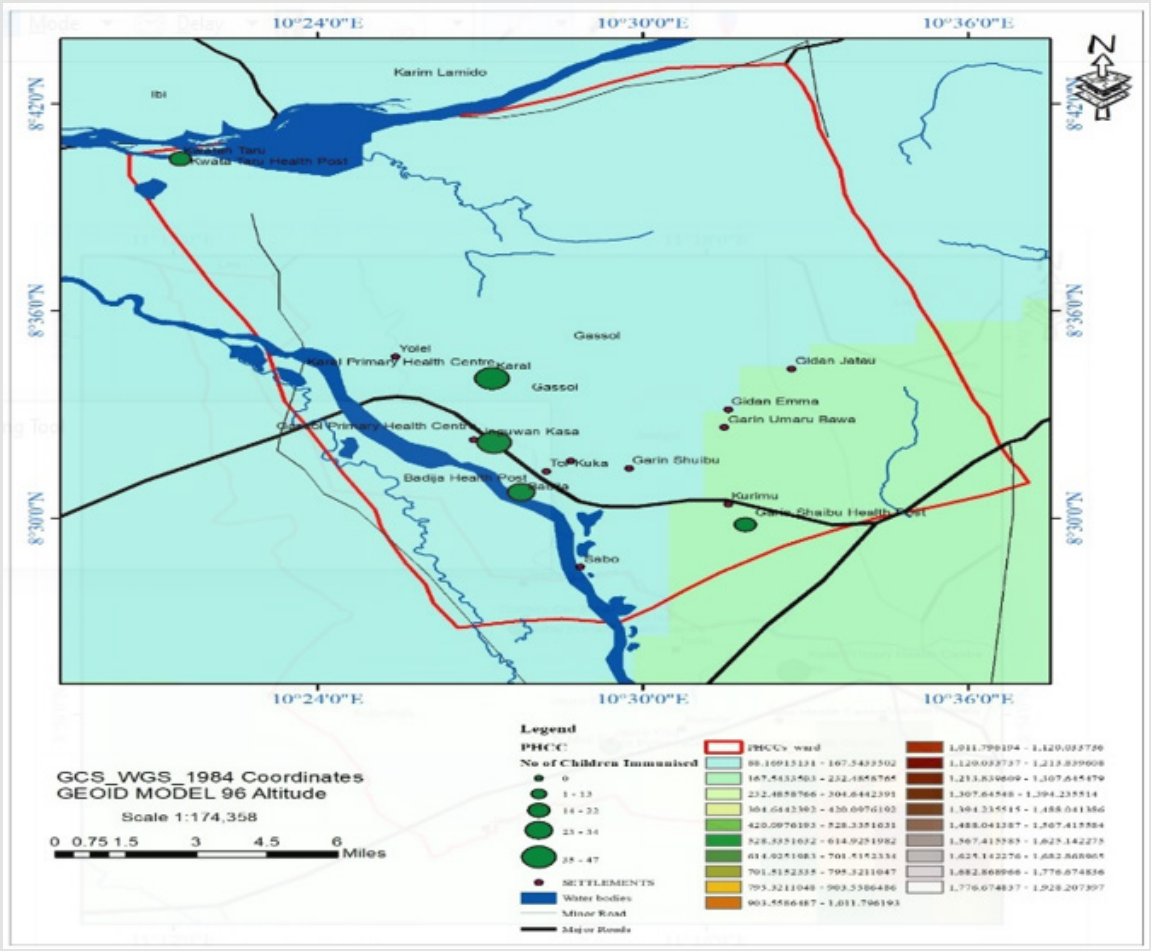

Figure 7: Overlaid Topographic and number of people vaccinated in Gassol ward.

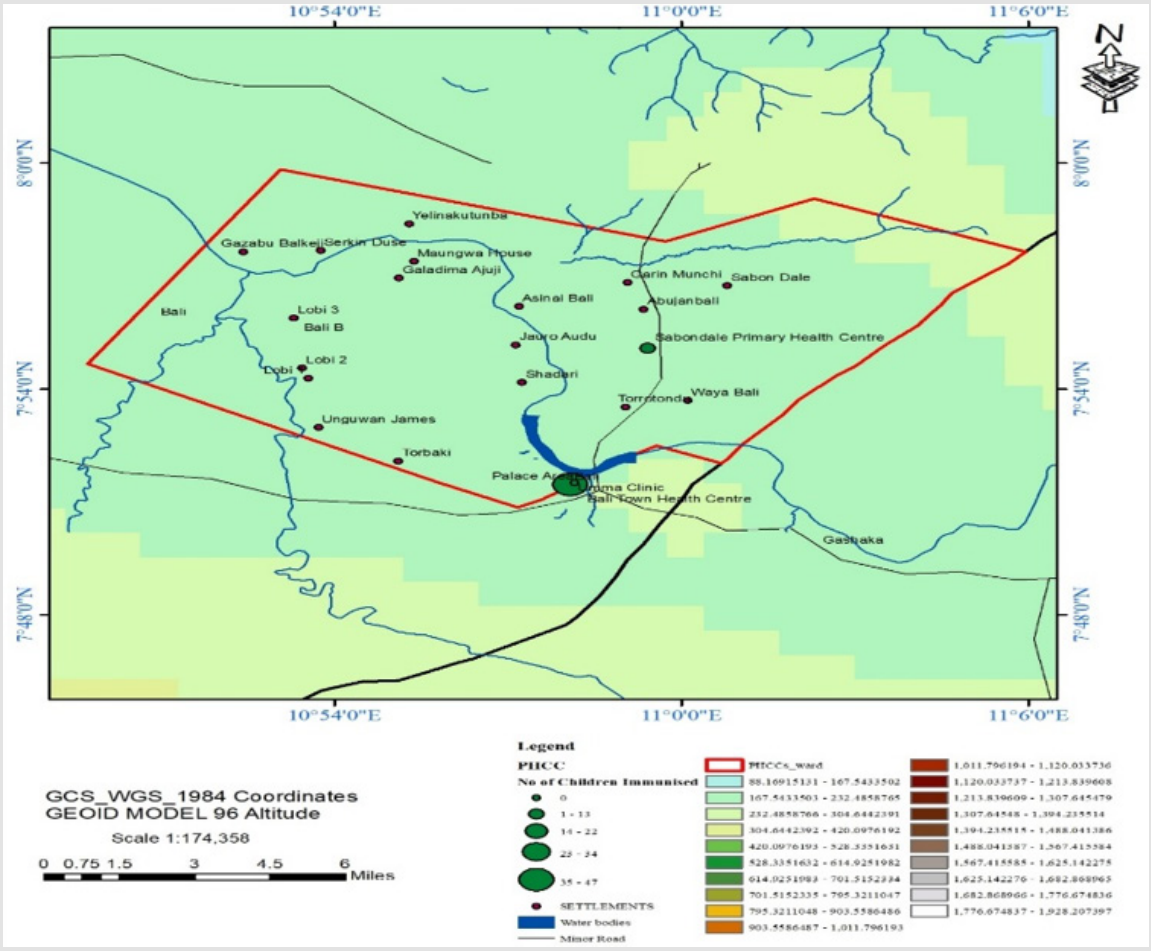

Figure 8: Overlaid Topographic and number of people vaccinated in Bali B ward.

In areas with steep or rugged terrain, residents may face longer travel times, lack of motorable roads, and transportation difficulties, all of which can hinder their ability to seek timely healthcare. The findings highlight the critical role of terrain in shaping healthcare utilization patterns and reinforce the usefulness of GIS tools in identifying spatial inequalities. This evidence supports the need for location-specific strategies to improve access, especially for populations living in hard-to-reach areas of Bali B Ward and similar settings across Taraba State. The overlay of topographic elevation and vaccination data in Baissa Ward (Figure 9) reveals that PHCCs in low-lying, easily accessible areas reported higher numbers of vaccinated individuals, while those located in elevated or rugged terrains recorded lower vaccination figures. This pattern indicates that topography plays a key role in influencing access to primary health care services, as difficult terrain can discourage travel and reduce service uptake. The results emphasize the need for targeted interventions, such as improving transport infrastructure, deploying mobile health units, or strategically locating new PHCCs in underserved highland communities. This reinforces the relevance of GIS-based spatial analysis in assessing healthcare accessibility and guiding equitable service delivery in Taraba State.

The overlay of topography and vaccination data in Nguroje Ward (Figure 10) shows that PHCCs located in elevated and mountainous areas recorded lower vaccination turnout compared to those in flatter, more accessible locations. This suggests that steep terrain and poor accessibility in highland areas hinder community access to health services. The pattern reinforces the role of elevation as a barrier to effective healthcare delivery and highlights the importance of using GIS-based analysis to identify such disparities. These insights are essential for planning targeted interventions to improve PHC access in difficult-to-reach areas of Nguroje Ward and similar highland communities in Taraba State.

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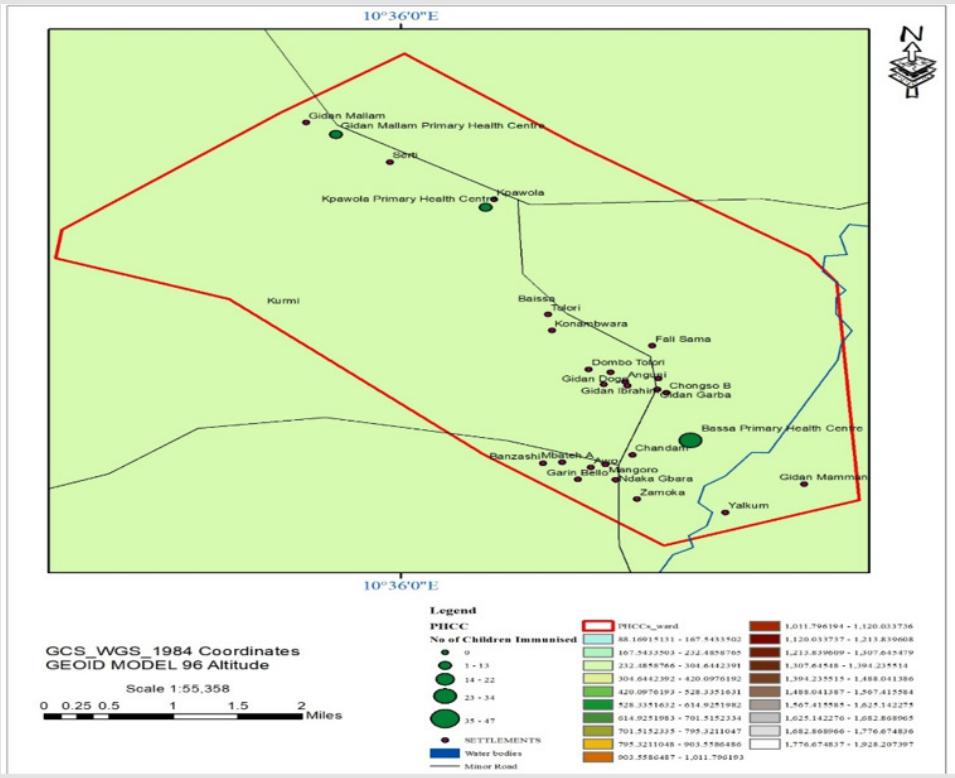

Figure 9: Overlaid Topographic and number of people vaccinated in Baissa ward.

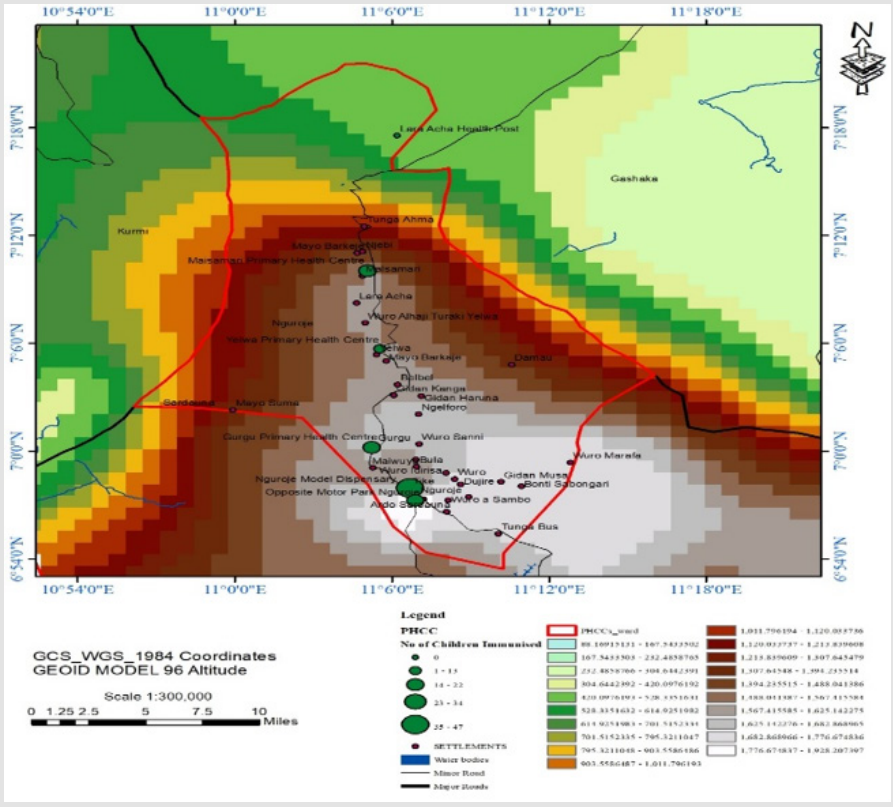

Figure 10: Overlaid Topographic and number of people vaccinated in Nguroje ward.

Correlation Between Altitude and Routine Immunization

The correlation analysis between the altitude of health facility locations and the number of routine immunizations administered yielded a correlation coefficient of r = 0.008 (Table 1). This value is extremely close to zero, indicating no meaningful relationship between altitude and routine immunization performance. In other words, the elevation at which a health facility is located does not significantly influence the number of people receiving routine immunizations. This finding suggests that geographic elevation is not a limiting factor in immunization access or delivery within the study area, and attention should instead be directed toward other determinants such as staffing, outreach, supply chain efficiency, or community engagement. The correlation analysis between the altitude of PHC locations and the number of routine immunizations administered yielded a Pearson coefficient of r = 0.008, indicating no significant relationship. This result implies that elevation is not a limiting factor for immunization service delivery within the study area. Consequently, geographic altitude does not significantly affect community access to primary health care services in the context of immunization. This finding supports the view that accessibility challenges are likely due to socio-economic, infrastructural, or operational issues rather than natural terrain or elevation. Therefore, GIS-based accessibility models for PHC planning in Taraba State should focus on network analysis, service catchments, and health system indicators rather than elevation alone.

Table 1: Correlation of Altitude and Routine immunization.

	Routine immunization	Altitude
Routine immunization	1	
Altitude	0.007811327	1

Discussion of Results

This study examined the influence of topography on routine immunization (RI) coverage in Taraba State, Nigeria, using geospatial and statistical analyses. The findings revealed that PHCCs located in lowland and more accessible areas recorded higher immunization coverage, whereas those situated in highland and rugged terrains generally reported lower turnout. However, correlation analysis indicated no statistically significant relationship between altitude and immunization uptake (r = 0.008), suggesting that while descriptive spatial patterns exist, elevation alone may not be the primary determinant of vaccination coverage. These findings align with previous studies that emphasize the importance of physical accessibility in shaping immunization outcomes. Lawson, et al. [3] demonstrated through geospatial modeling that difficult terrain and long travel times significantly reduce the likelihood of full immunization in Nigeria, particularly in rural communities. Similarly, Oladokun, et al. [7] found that distance to health facilities and poor transport infrastructure were critical barriers to vaccination in northern Nigeria. The present study supports these conclusions by showing that communities in low-lying areas with better connectivity had higher vaccination coverage compared to those in mountainous regions. However, the weak statistical correlation between altitude and immunization turnout contrasts with some earlier research.

For example, Gething, et al. [8] reported that elevation and slope were strong predictors of reduced healthcare accessibility in East Africa, especially for maternal and child health services. The divergence may be explained by contextual differences: in Taraba State, physical elevation alone does not fully capture accessibility challenges, as road conditions, flooding during rainy seasons, and dispersion of settlements often play more critical roles. This suggests that while topography influences health access, it operates in conjunction with infrastructural and socio-economic factors, a point emphasized by Ebener, et al. [6] in their global review of maternal and newborn health geography. Another point of agreement with earlier studies lies in the identification of immunization "cold spots" in hard-to-reach areas. For instance, Wiysonge, et al. [9] noted that sub-Saharan Africa continues to face pockets of under-immunization driven by geographic, economic, and social inequities. Similarly, Ogunniyi, et al. [1] observed that rural Nigerian communities remain disproportionately underserved, often due to terrain-related challenges combined with health system limitations. The present study adds to this evidence by highlighting how rugged and flood-prone areas in Taraba State recorded consistently lower coverage despite national immunization efforts. The lack of a significant statistical relationship between altitude and immunization coverage in this study may also reflect the increasing reliance on outreach and mobile immunization strategies in Taraba State.

According to WHO [2], outreach services remain vital for reaching populations in remote or topographically challenging environments. Thus, while elevation itself was not strongly correlated with turnout, the influence of terrain likely manifests indirectly through travel difficulty, flooding, and poor transport infrastructure rather than elevation alone. Overall, this study contributes to the growing literature on spatial inequalities in immunization coverage by providing evidence from a unique Nigerian context where physical geography intersects with infrastructural and socio-economic constraints. It underscores the need for multifaceted interventions that go beyond considering altitude, focusing instead on improving road networks, expanding mobile immunization teams, and strengthening community engagement in geographically disadvantaged areas.

Implications for Policy and Practice

The findings of this study have several important implications for health policy and practice in Taraba State and Nigeria more broadly. First, while descriptive analyses revealed disparities in immunization coverage across different terrain zones, the lack of a statistically significant correlation between altitude and vaccine uptake suggests that geographic barriers are multidimensional. This highlights the need for immunization strategies that combine geographical considerations with infrastructural and socio-economic interventions (Lawson, et al. [1,3]). One key implication is the urgent need to strengthen transport and road infrastructure in rural and mountainous parts of Taraba State. Poor road networks and seasonal flooding remain crit-

ical barriers to service delivery. Previous studies have shown that reducing travel time to health facilities substantially increases immunization coverage and service utilization (Gething, et al. [8,9]). Targeted investments in rural transport infrastructure would therefore improve equitable access to vaccines. Second, the study underscores the importance of mobile and outreach immunization services in hard-to-reach areas. The absence of a strong correlation between altitude and coverage may reflect the mitigating effect of outreach efforts by the Taraba State Primary Health Care Development Agency (TSPHCDA).

Expanding these outreach strategies, particularly during the rainy season when physical access is limited, could ensure continuity of services and minimize geographic disparities (WHO [2]). Third, findings point to the need for geospatially informed health planning. By integrating routine immunization data with topographical and infrastructural layers, health managers can identify underserved "cold spots" and allocate resources more effectively. The use of geospatial tools has been shown to enhance the equity and efficiency of immunization programs by ensuring that no population is left behind (Ebener, et al. [3,6]). Finally, addressing immunization inequities requires community-level interventions. Socio-economic barriers such as poverty, cultural norms, and low awareness interact with geographic challenges to limit service uptake. Strengthening community engagement, health education, and partnerships with local leaders can help overcome these barriers and build trust in immunization services (Ogunniyi, et al. [1,9,10]). In sum, this study highlights the need for an integrated approach to immunization planning in Taraba State, one that accounts for both physical geography and systemic barriers. By improving infrastructure, scaling outreach services, leveraging geospatial analytics, and engaging communities, policymakers can advance Nigeria's goal of universal immunization coverage and contribute to global health targets.

Conclusion

This study examined the influence of topography on routine immunization (RI) coverage in Taraba State, Nigeria, using geospatial and statistical approaches. The findings revealed that while PHCCs located in lowland and accessible areas recorded higher vaccination coverage, those in highland and rugged terrains consistently had lower turnout. However, statistical analysis showed no significant correlation between altitude and immunization uptake, indicating that elevation alone is not a decisive factor. Instead, barriers such as poor road infrastructure, flooding, dispersed settlements, and health system constraints likely mediate the observed disparities. These results highlight the need for integrated strategies that combine infrastructural development, mobile outreach, geospatially informed planning, and community engagement to address immunization inequities. Strengthening such interventions will be essential for improving equitable vaccine access in Taraba State and supporting Nigeria's broader goal of achieving universal immunization coverage in line with national and global health targets.

Recommendations

1. Improve rural road and transport infrastructure: Upgrading road networks and providing reliable transport systems will reduce travel time and improve year-round access to PHCCs, particularly in flood-prone and mountainous communities where physical barriers limit service uptake.

2. Expand mobile and outreach immunization services: Strengthening outreach strategies, especially during the rainy season, can bridge accessibility gaps by bringing vaccines directly to remote populations that cannot regularly access fixed facilities.

3. Adopt geospatial tools in health planning: Using GIS and spatial analysis to map "cold spots" will enable policymakers to identify underserved areas and strategically allocate resources, ensuring more equitable distribution of immunization services.

4. Strengthen community engagement and awareness programs: Mobilizing community leaders and increasing awareness of the benefits of immunization can help overcome cultural, informational, and socio-economic barriers that compound geographic challenges.

5. Integrate multi-sectoral interventions: Coordinating efforts between health authorities, infrastructure agencies, and local governments will foster holistic solutions that address both geographic and systemic determinants of immunization inequities.

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