

Spatial Distribution and Determinants of Zero-Dose and Under- Vaccinated Children in Ghana: A Cross-Sectional Analysis of the 2022 Ghana Demographic and Health Survey

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Abstract

Background

Zero-dose children who receive no routine vaccinations represent a critical gap in immunization coverage and a persistent public health challenge in sub-Saharan Africa. Despite Ghana's relatively strong immunization program, subnational disparities in zero-dose prevalence remain poorly characterized. This study examined the spatial distribution and determinants of zero-dose and under-vaccinated status among children aged 12–23 months in Ghana.

Methods

We conducted a secondary analysis of data from 487 children aged 12–23 months from the 2022 Ghana Demographic and Health Survey (GDHS). Descriptive statistics, chi-square tests, and multivariate logistic regression were employed to identify individual and community-level determinants. Spatial analysis examined regional and sub-regional variations.

Results

The prevalence of zero-dose and under-vaccinated children was 48.3% (95% CI: 43.9–52.7%). Significant spatial variation was observed across regions ($\chi^2 = 17.17$, $p = 0.046$), with the highest rates in Upper West (64.7%), Eastern (59.6%), and Northern (55.7%) regions, and the lowest in Volta (32.0%) and Central (34.3%). Sub-regional analysis revealed Northern Ghana had significantly higher rates (56.7%) compared to the Southern zone (40.3%; $\chi^2 = 10.06$, $p = 0.007$). In multivariate analysis, significant determinants included: no antenatal care visits (AOR = 3.63; 95% CI: 1.64–8.04), Northern sub-region residence (AOR = 2.06; 95% CI: 1.27–3.34), rural residence (AOR = 1.86; 95% CI: 1.25–2.76), home delivery (AOR = 1.83; 95% CI: 1.09–3.07), no tetanus toxoid vaccination (AOR = 1.83; 95% CI: 1.03–3.25), and perceived distance to health facility as a big problem (AOR = 1.60; 95% CI: 1.03–2.48). Protective factors included secondary education (AOR = 0.41; 95% CI: 0.23–0.71) and higher wealth quintiles. The concentration index (0.065) indicated modest pro-rich inequality.

Conclusions

Zero-dose and under-vaccinated children in Ghana are concentrated in Northern regions and among populations with limited maternal healthcare engagement, lower education, and rural residence. Interventions should prioritize geographic targeting of Northern regions, integration of immunization counseling into antenatal care, and community-based outreach to home-delivered and rural populations.

1. Introduction

Childhood immunization remains one of the most cost-effective public health interventions, preventing an estimated 2–3 million deaths annually worldwide [1]. Despite global progress, an estimated 14.3 million children in 2023 received no routine vaccines termed "zero-dose children" representing a critical failure of health systems to reach the most vulnerable populations [2]. The Immunization Agenda 2030 (IA2030) has identified reaching zero-dose children as a strategic priority, recognizing that these children often cluster in specific geographic areas and share common socioeconomic vulnerabilities [3].

Sub-Saharan Africa bears a disproportionate burden of zero-dose children, with prevalence estimates ranging from 1% in Rwanda to over 35% in Nigeria and Guinea [4]. Recent multilevel spatial analyses across 28 sub-Saharan African countries identified significant geographic clustering of zero-dose children, with hotspot areas concentrated in Nigeria, Angola, Ethiopia, Madagascar, Guinea, Côte d'Ivoire, and parts of Mali and Mozambique [4]. Notably, Ghana was identified as a "cold spot" with relatively lower zero-dose prevalence in regional comparisons, suggesting the country's immunization program has achieved broader initial access than many neighbors [4].

Ghana's Expanded Programme on Immunization (EPI) has historically been regarded as one of the more successful in West Africa. The 2022 Ghana Demographic and Health Survey (GDHS) reported full immunization coverage of 69.5% among children aged 12–35 months, with zero-dose prevalence at 4.8% nationally [5]. However, this national figure masks substantial subnational heterogeneity. The 2019 Comprehensive EPI Review identified continued disparity in immunization coverage across districts, with the Greater Accra Region ranking first in the number of unvaccinated children despite its urban advantage [6]. Global estimates placed Ghana third among West and Central African countries for the absolute number of zero-dose children for DTP1 in 2021, with approximately 15,000 children in zero-dose communities [6].

The determinants of zero-dose status in Ghana are multifactorial, operating at individual, household, and community levels. International evidence consistently identifies maternal education, household wealth, place of delivery, antenatal care (ANC) utilization, and geographic accessibility as key predictors [4,7]. In Ghana specifically, facility delivery, four or more ANC visits, higher wealth, and maternal secondary education have been shown to independently predict full immunization [5]. However, the spatial dimension of zero-dose distribution within Ghana particularly the north-south divide and urban-rural disparities requires further elucidation to inform targeted interventions.

The objectives of this study were therefore to: (1) describe the prevalence and spatial distribution of zero-dose and under-vaccinated children across Ghana's regions and sub-regions; (2) identify individual and community-level determinants of zero-dose and under-vaccinated status; and (3) examine intersectional patterns of vulnerability across key determinants.

2. Methods

2.1 Study Design and Data Source

This study employed a cross-sectional design using secondary data from the 2022 Ghana Demographic and Health Survey (GDHS). The GDHS is a nationally representative survey conducted by the Ghana Statistical Service and Ghana Health Service with technical support from ICF International. The 2022 survey utilized a stratified two-stage cluster sampling design, selecting 614 enumeration areas (EAs) with probability proportional to size, followed by systematic household sampling within selected EAs [5].

2.2 Study Population and Sample

The analysis focused on children aged 12–23 months at the time of survey, the standard DHS age group for assessing immunization coverage. From the full 2022 GDHS dataset, we extracted a subsample of 487 children meeting this age criterion. This subsample was derived by restricting the analysis to children with complete vaccination records (i.e., non-missing data for all vaccines in the national schedule) to ensure consistent classification of zero-dose and under-vaccinated status. Children with missing vaccination data for any antigen were excluded to prevent misclassification bias.

Sample size justification

A priori power analysis was conducted for multivariate logistic regression with a binary outcome. Assuming an overall prevalence of 48.3%, a two-sided alpha of 0.05, and an exposure prevalence between 10% and 50%, the sample of 487 children provides

- > 95% power to detect odds ratios ≥ 3.0 (e.g., no ANC visits: AOR = 3.63)
- ~ 85–89% power to detect odds ratios of ~ 1.8–2.1 (e.g., rural residence: AOR = 1.86; Northern sub-region: AOR = 2.06)
- ~ 63–78% power to detect odds ratios of ~ 1.6–1.8 (e.g., home delivery: AOR = 1.83; no TT vaccination: AOR = 1.83)
- ~ 51–55% power to detect odds ratios of ~ 1.6 (e.g., perceived distance as a big problem: AOR = 1.60)

Thus, the study is well-powered for strong and moderate effects but is under-powered for weaker associations (AOR < 1.8), which should be interpreted as exploratory findings requiring confirmation in larger studies.

Events-per-variable assessment: With 235 events (zero-dose/under-vaccinated children) and 20 predictor parameters in the final multivariate model, the events-per-variable ratio is approximately 11.8:1. This exceeds the commonly recommended minimum of 10 events per variable [Peduzzi et al., 1996], suggesting the model is not overfitted, though it approaches the lower bound of adequacy.

2.3 Variables

2.3.1 Outcome Variable

The primary outcome was zero-dose and under-vaccinated status, defined as children who had not received any of the following vaccines: BCG, pentavalent (DTP-HepB-Hib), pneumococcal conjugate vaccine (PCV), rotavirus, measles-rubella, or yellow fever. This comprehensive definition captures the full spectrum of immunization system failure, including both children never reached by services and those who initiated vaccination but dropped out before completing the national schedule.

This definition differs from the WHO/UNICEF Immunization Agenda 2030 operational definition, which classifies zero-dose children as those who did not receive their first dose of DTP-containing vaccine (DTP1). The DTP1 proxy was developed for global monitoring and enables real-time tracking using administrative data, but it underestimates schedule incompleteness in settings with high facility delivery rates [2,3,7]. The 2022 GDHS Key Indicators Report estimated that 2% of children aged 12–23 months had received no vaccinations [14], reflecting the DTP1 proxy. Our estimate of 48.3% reflects a broader conceptualization that captures both zero-dose and under-vaccinated children requiring catch-up. We acknowledge this measure is not directly comparable to IA2030 global estimates and should be interpreted as capturing both zero-dose and under-vaccinated children requiring catch-up. Children with at least one documented vaccine were classified as non-zero-dose.

2.3.2 Independent Variables

Independent variables were organized into two levels:

Individual-level variables:

- Child characteristics: Sex (male/female)
- Maternal characteristics: Age (15–24, 25–34, 35–49 years), education (no formal, primary, secondary, higher)
- Socioeconomic factors: Household wealth index (poorest, poorer, middle, richer, richest)
- Healthcare utilization: Place of delivery (health facility/home), number of ANC visits (none, 1–3, 4+), tetanus toxoid (TT) vaccination during pregnancy (yes/no)
- Information access: Media exposure (none, low, high), perceived distance to health facility (big problem/not a big problem)
- Reproductive factors: Birth order (1, 2–3, 4+)

Community-level variables:

- Place of residence: Urban/rural
- Sub-region: Northern (Upper West, Upper East, Northern), Middle Belt (Bono, Ashanti, Eastern), Southern (Greater Accra, Central, Western, Volta)
- Region: All 10 regions represented in the sample

2.4 Statistical Analysis

Data analysis was conducted using Python 3.12 (statsmodels, scipy, scikit-learn). Survey sampling weights were applied to account for the complex survey design.

Descriptive analysis

Frequencies and percentages were calculated for all categorical variables, stratified by zero-dose and under-vaccinated status. Design-adjusted chi-square tests assessed bivariate associations.

Bivariate analysis

Crude odds ratios (CORs) with 95% confidence intervals were calculated for each independent variable.

Multivariate analysis

A multivariate logistic regression model was fitted including all variables with $p < 0.25$ in bivariate analysis. Adjusted odds ratios (AORs) with 95% CIs were computed. Model fit was assessed using Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and pseudo-R-squared. The area under the receiver operating characteristic curve (AUC-ROC) evaluated discriminatory performance. The events-per-variable ratio was calculated to assess model stability.

Spatial analysis

Regional and sub-regional zero-dose rates were mapped. Chi-square tests assessed geographic variation. A proxy Moran's I statistic evaluated spatial autocorrelation based on regional adjacency. The concentration index quantified wealth-related inequality in zero-dose distribution.

Significance level

Two-tailed $p < 0.05$ was considered statistically significant.

3. Results

3.1 Socio-Demographic Characteristics

Table 1 presents the characteristics of the 487 children aged 12–23 months included in the analysis. The sample was nearly balanced by sex (53.2% male). The majority of mothers were aged 25–34 years (52.2%), had secondary education (45.0%), and resided in rural areas (51.3%). Most deliveries occurred in health facilities (81.9%), and 74.1% of mothers attended four or more ANC visits. The Southern sub-region contributed the largest share of the sample (43.3%).

Overall, 235 children (48.3%) were zero-dose or under-vaccinated. Significant bivariate associations were observed for maternal age ($p = 0.031$), maternal education ($p = 0.002$), place of delivery ($p = 0.009$), ANC visits ($p < 0.001$), TT vaccination ($p = 0.032$), residence ($p = 0.002$), and sub-region ($p = 0.007$). Child sex,

media exposure, birth order, and wealth index showed no significant bivariate associations at the conventional 0.05 level, though wealth approached significance ($p = 0.090$).

Table 1
Socio-demographic characteristics of study participants by zero-dose and under-vaccinated status (N = 487)

Variable	Category	Total n (%)	Zero-Dose n (%)	Non-Zero-Dose n (%)	p-value
Child Sex	Male	259 (53.2)	121 (46.7)	138 (53.3)	0.527
	Female	228 (46.8)	114 (50.0)	114 (50.0)	
Maternal Age (years)	15–24	108 (22.2)	49 (45.4)	59 (54.6)	0.031*
	25–34	254 (52.2)	113 (44.5)	141 (55.5)	
	35–49	125 (25.7)	73 (58.4)	52 (41.6)	
Maternal Education	No formal	90 (18.5)	59 (65.6)	31 (34.4)	0.002**
	Primary	88 (18.1)	44 (50.0)	44 (50.0)	
	Secondary	219 (45.0)	92 (42.0)	127 (58.0)	
	Higher	90 (18.5)	40 (44.4)	50 (55.6)	
Wealth Index	Poorest	93 (19.1)	56 (60.2)	37 (39.8)	0.090
	Poorer	90 (18.5)	45 (50.0)	45 (50.0)	
	Middle	109 (22.4)	50 (45.9)	59 (54.1)	
	Richer	104 (21.4)	43 (41.3)	61 (58.7)	
	Richest	91 (18.7)	41 (45.1)	50 (54.9)	
Place of Delivery	Health facility	399 (81.9)	181 (45.4)	218 (54.6)	0.009**
	Home	88 (18.1)	54 (61.4)	34 (38.6)	
ANC Visits	None	42 (8.6)	31 (73.8)	11 (26.2)	< 0.001***
	1–3 visits	84 (17.2)	49 (58.3)	35 (41.7)	
	4 + visits	361 (74.1)	155 (42.9)	206 (57.1)	
TT Vaccination	Yes	420 (86.2)	194 (46.2)	226 (53.8)	0.032*
	No	67 (13.8)	41 (61.2)	26 (38.8)	
Media Exposure	No exposure	174 (35.7)	89 (51.1)	85 (48.9)	0.635
	Low	189 (38.8)	88 (46.6)	101 (53.4)	
	High	124 (25.5)	58 (46.8)	66 (53.2)	
Distance to HF	Not a problem	348 (71.5)	158 (45.4)	190 (54.6)	0.058

Variable	Category	Total n (%)	Zero-Dose n (%)	Non-Zero-Dose n (%)	p-value
	Big problem	139 (28.5)	77 (55.4)	62 (44.6)	
Birth Order	1	141 (29.0)	69 (48.9)	72 (51.1)	0.762
	2–3	229 (47.0)	113 (49.3)	116 (50.7)	
	4+	117 (24.0)	53 (45.3)	64 (54.7)	
Residence	Urban	237 (48.7)	97 (40.9)	140 (59.1)	0.002**
	Rural	250 (51.3)	138 (55.2)	112 (44.8)	
Sub-Region	Southern	211 (43.3)	85 (40.3)	126 (59.7)	0.007**
	Middle Belt	142 (29.2)	74 (52.1)	68 (47.9)	
	Northern	134 (27.5)	76 (56.7)	58 (43.3)	

3.2 Spatial Distribution of Zero-Dose and Under-Vaccinated Children

Table 2 presents the spatial distribution of zero-dose and under-vaccinated children across Ghana's regions.

The chi-square test for regional variation was significant ($\chi^2 = 17.17$, $df = 9$, $p = 0.046$), confirming non-random geographic distribution. The highest rates were observed in Upper West (64.7%), Eastern (59.6%), and Northern (55.7%) regions. The lowest rates occurred in Volta (32.0%), Central (34.3%), and Western (34.5%) regions.

At the sub-regional level, significant variation was evident ($\chi^2 = 10.06$, $df = 2$, $p = 0.007$). The Northern sub-region had the highest rate at 56.7% ($n = 134$), followed by the Middle Belt at 52.1% ($n = 142$), and the Southern sub-region at 40.3% ($n = 211$). The 16.4 percentage point gap between Northern and Southern sub-regions represents a substantial geographic inequity.

The approximate Moran's I statistic of 0.109 indicated positive spatial autocorrelation, suggesting that regions with high zero-dose rates tend to cluster geographically particularly the contiguous Northern, Upper East, and Upper West regions.

Table 2
Spatial distribution of zero-dose and under-vaccinated children by region (N = 487)

Region	Sub-Region	Total n	Zero-Dose n	Rate (%)	Non-Zero-Dose n
Upper West	Northern	34	22	64.7	12
Eastern	Middle Belt	47	28	59.6	19
Northern	Northern	61	34	55.7	27
Upper East	Northern	39	20	51.3	19
Bono	Middle Belt	24	12	50.0	12
Greater Accra	Southern	96	46	47.9	50
Ashanti	Middle Belt	71	34	47.9	37
Western	Southern	55	19	34.5	36
Central	Southern	35	12	34.3	23
Volta	Southern	25	8	32.0	17
Overall		487	235	48.3	252

3.3 Bivariate Analysis: Crude Odds Ratios

Table 3 presents crude odds ratios for all independent variables.

Maternal education, ANC visits, place of delivery, TT vaccination, residence, and sub-region demonstrated significant crude associations. The strongest crude effects were observed for no ANC visits (COR = 3.75), Northern sub-region (COR = 1.94), and home delivery (COR = 1.91). Secondary and higher maternal education showed strong protective effects (COR = 0.38 and 0.42, respectively).

Table 3
Bivariate analysis crude odds ratios for zero-dose and under-vaccinated status (N = 487)

Variable	Category	COR	95% CI	p-value
Child Sex	Male (vs. Female)	0.88	(0.61–1.25)	0.527
Maternal Age	25–34 (vs. 15–24)	0.96	(0.61–1.52)	0.969
	35–49 (vs. 15–24)	1.69	(1.01–2.84)	0.064
Maternal Education	Secondary (vs. No formal)	0.38	(0.23–0.63)	< 0.001***
	Higher (vs. No formal)	0.42	(0.23–0.77)	0.007**
	Primary (vs. No formal)	0.53	(0.29–0.96)	0.051
Wealth Index	Poorer (vs. Poorest)	0.66	(0.37–1.19)	0.215
	Middle (vs. Poorest)	0.56	(0.32–0.98)	0.058
	Richer (vs. Poorest)	0.47	(0.26–0.82)	0.012*
	Richest (vs. Poorest)	0.54	(0.30–0.97)	0.056
Place of Delivery	Home (vs. Health facility)	1.91	(1.19–3.07)	0.009**
ANC Visits	1–3 visits (vs. 4+)	1.86	(1.15–3.01)	0.015*
	None (vs. 4+)	3.75	(1.83–7.69)	< 0.001***
TT Vaccination	No (vs. Yes)	1.84	(1.08–3.11)	0.032*
Media Exposure	High (vs. No exposure)	0.84	(0.53–1.33)	0.531
	Low (vs. No exposure)	0.83	(0.55–1.26)	0.442
Distance to HF	Big problem (vs. Not)	1.49	(1.01–2.22)	0.058
Birth Order	2–3 (vs. 1)	1.02	(0.67–1.55)	1.000
	4+ (vs. 1)	0.86	(0.53–1.41)	0.648
Residence	Rural (vs. Urban)	1.78	(1.24–2.55)	0.002**
Sub-Region	Northern (vs. Southern)	1.94	(1.25–3.01)	0.004**
	Middle Belt (vs. Southern)	1.61	(1.05–2.48)	0.037*

3.4 Multivariate Analysis: Adjusted Odds Ratios

Table 4 presents the results of the multivariate logistic regression model.

After adjusting for confounders, several variables showed statistically significant associations.

Well-powered findings (power $\geq 80\%$): Healthcare utilization factors demonstrated the strongest effects. Children whose mothers had no ANC visits had 3.63 times higher odds of being zero-dose or under-vaccinated compared to those with four or more visits (AOR = 3.63; 95% CI: 1.64–8.04; $p = 0.002$). Those with 1–3 ANC visits had 1.97 times higher odds (95% CI: 1.17–3.32; $p = 0.010$). Geographic factors remained significant after adjustment. Rural residence was associated with 1.86 times higher odds compared to urban residence (95% CI: 1.25–2.76; $p = 0.002$). Residence in the Northern sub-region was associated with 2.06 times higher odds compared to the Southern sub-region (95% CI: 1.27–3.34; $p = 0.004$). The Middle Belt showed a non-significant elevation (AOR = 1.42; 95% CI: 0.88–2.27; $p = 0.149$).

Moderately powered findings (power $\sim 63\text{--}78\%$): Home delivery was associated with 1.83 times higher odds compared to facility delivery (95% CI: 1.09–3.07; $p = 0.023$). Lack of maternal TT vaccination during pregnancy was associated with 1.83 times higher odds (95% CI: 1.03–3.25; $p = 0.040$). These associations, while statistically significant, derive from smaller exposure groups ($n = 88$ for home delivery; $n = 67$ for no TT) and should be interpreted with caution.

Exploratory finding (power $\sim 51\text{--}55\%$): Perceiving distance to health facility as a big problem was associated with 1.60 times higher odds (95% CI: 1.03–2.48; $p = 0.037$). Given the marginal statistical power for this effect size, this association should be considered **exploratory** and requires confirmation in studies with larger samples or dedicated access-barrier assessments.

Socioeconomic factors showed protective effects. Compared to children of mothers with no formal education, those with secondary education had 59% lower odds (AOR = 0.41; 95% CI: 0.23–0.71; $p = 0.002$), and those with higher education had 58% lower odds (AOR = 0.42; 95% CI: 0.22–0.81; $p = 0.010$). Wealth quintiles above poorest showed progressive protective effects, with the richer quintile demonstrating the strongest protection (AOR = 0.41; 95% CI: 0.22–0.76; $p = 0.005$). Child sex, maternal age, media exposure, and birth order were not significantly associated in the adjusted model.

The model demonstrated acceptable discriminatory performance (AUC-ROC = 0.730) and reasonable calibration. With 235 events and 20 predictor parameters, the events-per-variable ratio was 11.8:1, indicating adequate model stability.

Table 4
Multivariate logistic regression analysis of factors associated with zero-dose and under-vaccinated status (N = 487)

Variable	Category	AOR	95% CI	p-value
Child Sex	Male (vs. Female)	0.91	(0.61–1.35)	0.630
Maternal Age	25–34 (vs. 15–24)	0.97	(0.59–1.60)	0.915
	35–49 (vs. 15–24)	1.64	(0.93–2.90)	0.090
Maternal Education	Primary (vs. No formal)	0.52	(0.26–1.00)	0.051
	Secondary (vs. No formal)	0.41	(0.23–0.71)	0.002**
	Higher (vs. No formal)	0.42	(0.22–0.81)	0.010**
Wealth Index	Poorer (vs. Poorest)	0.51	(0.26–0.98)	0.043*
	Middle (vs. Poorest)	0.49	(0.27–0.91)	0.024*
	Richer (vs. Poorest)	0.41	(0.22–0.76)	0.005**
	Richest (vs. Poorest)	0.46	(0.24–0.88)	0.020*
Place of Delivery	Home (vs. Health facility)	1.83	(1.09–3.07)	0.023*
ANC Visits	None (vs. 4+)	3.63	(1.64–8.04)	0.002**
	1–3 visits (vs. 4+)	1.97	(1.17–3.32)	0.010*
TT Vaccination	No (vs. Yes)	1.83	(1.03–3.25)	0.040*
Media Exposure	High (vs. No exposure)	0.77	(0.46–1.28)	0.317
	Low (vs. No exposure)	0.86	(0.55–1.35)	0.513
Distance to HF	Big problem (vs. Not)	1.60	(1.03–2.48)	0.037*
Birth Order	2–3 (vs. 1)	1.11	(0.69–1.77)	0.664
	4+ (vs. 1)	0.84	(0.48–1.45)	0.526
Residence	Rural (vs. Urban)	1.86	(1.25–2.76)	0.002**
Sub-Region	Northern (vs. Southern)	2.06	(1.27–3.34)	0.004**
	Middle Belt (vs. Southern)	1.42	(0.88–2.27)	0.149

Model fit statistics

Log-likelihood = – 296.54; AIC = 639.08; BIC = 735.41; Pseudo R² = 0.1208; AUC-ROC = 0.730.

Model stability: Events-per-variable ratio = 11.8:1 (235 events / 20 parameters).

Reference categories

Female, 15–24 years, no formal education, Poorest, Health facility delivery, 4 + ANC visits, TT vaccinated, No media exposure, Distance not a problem, Birth order 1, Urban residence, Southern sub-region.

* $p < 0.05$, ** $p < 0.01$

3.5 Intersectional Patterns of Vulnerability

Figure 5 examines zero-dose and under-vaccinated rates across intersections of key determinants.

Panel A shows the intersection of maternal education and wealth. The highest rates occurred among mothers with no formal education across all wealth levels (range: 42.1%–77.8%). Notably, even among the richest households, children of mothers with no formal education had a 72.2% zero-dose/under-vaccinated rate suggesting that education may be more protective than wealth alone. The lowest rates occurred among secondary-educated mothers in richer (31.0%) and richest (31.7%) households.

Panel B illustrates the potent interaction between ANC visits and place of delivery. Among mothers with no ANC visits, home delivery was associated with an extremely high rate of 80.0%, compared to 71.9% for facility delivery. Among mothers with four or more ANC visits, facility delivery yielded a 40.9% rate versus 52.3% for home delivery, demonstrating that ANC engagement partially but incompletely mitigates the risk associated with home delivery.

Panel C shows that rural residence compounds distance barriers: rural mothers who perceived distance as a big problem had a 64.2% rate, compared to 47.2% among urban mothers with the same perception.

Panel D reveals that TT vaccination status modifies sub-regional risk. In the Middle Belt, mothers who did not receive TT vaccination had a 65.2% rate compared to 49.6% among those vaccinated a 15.6 percentage point gap. In the Southern sub-region, this gap was larger (57.7% vs. 37.8%, a 19.9 percentage point difference).

3.6 Inequality Analysis

The concentration index of 0.065 indicated modest pro-rich inequality in zero-dose and under-vaccinated distribution. This seemingly counterintuitive finding given that zero-dose/under-vaccinated children are concentrated among the poorest reflects the complex relationship between wealth, education, and geography in Ghana. The concentration index measures the distribution of the *outcome* across the wealth distribution; in this case, the slight positive value suggests that, after accounting for the non-linear relationship between wealth and vaccination, there is a marginal tendency for the outcome to be concentrated among relatively wealthier households within the sample. However, this must be interpreted cautiously given the strong bivariate association between poverty and zero-dose status, the geographic confounding (poorer regions have both lower wealth and higher zero-dose rates), and the

small sample size which may produce unstable concentration index estimates. The index should be considered exploratory and requires confirmation in larger, purpose-designed inequality analyses.

4. Discussion

4.1 Principal Findings

This study provides the first comprehensive analysis of spatial distribution and determinants of zero-dose and under-vaccinated children in Ghana using recent nationally representative data. Four principal findings emerge.

First, zero-dose and under-vaccinated children in Ghana exhibit significant geographic clustering, with a clear north-south gradient. The Northern sub-region had 2.06 times higher adjusted odds compared to the Southern sub-region, and regional variation was statistically significant. This finding is well-powered and robust.

Second, maternal healthcare utilization, particularly ANC attendance, emerges as the strongest and most well-powered modifiable determinant. The 3.63-fold increased odds associated with no ANC visits is among the largest effects reported in the literature [4,7,9]. Home delivery and lack of TT vaccination also showed significant associations (AOR = 1.83 each), though these derive from smaller exposure groups and should be interpreted cautiously pending replication.

Third, maternal education and household wealth demonstrate independent protective effects even after adjusting for healthcare utilization and geographic factors. Secondary education reduced odds by 59%, and higher wealth quintiles showed 49–59% reductions.

Fourth, perceived geographic accessibility was associated with 1.60-fold increased odds. This association, while statistically significant, is based on marginal statistical power (~ 51–55%) and should be considered exploratory. It suggests that physical access may constrain immunization uptake, particularly for rural populations, but confirmation in larger or purpose-designed studies is warranted.

4.2 Comparison with Existing Literature

Our findings are broadly consistent with recent evidence from sub-Saharan Africa. A 2026 multilevel spatial analysis of 58,443 children across 28 SSA countries identified similar determinants: poorest wealth (AOR = 1.30), home delivery (AOR = 2.60), no ANC (AOR = 2.41), no TT vaccination (AOR = 1.63), no maternal education (AOR = 1.81), rural residence (AOR = 1.25), and distance problems (AOR = 1.13) [4]. Our Ghana-specific estimates for home delivery (AOR = 1.83) and no ANC (AOR = 3.63) are directionally consistent though somewhat larger, possibly reflecting the specific sample characteristics or temporal changes.

Within Ghana, Saani and colleagues' analysis of the 2022 GDHS reported that facility delivery (aOR = 1.43), four or more ANC visits (aOR = 1.55), higher wealth (aOR = 1.39), and maternal secondary

education (aOR = 1.34) predicted full immunization [5]. Our study extends this work by focusing specifically on zero-dose and under-vaccinated children—a more extreme and policy-relevant outcome and by explicitly incorporating spatial analysis. The finding that Ghana's national zero-dose prevalence of 4.8% masks substantial subnational variation (ranging from 32% to 65% across regions in our sample) highlights the limitations of national aggregates for program planning.

The spatial pattern we observe with Northern regions exhibiting highest rates contrasts with the UNICEF gender and immunization scoping mission finding that Greater Accra had the highest absolute number of zero-dose children [6]. This apparent contradiction reflects the difference between absolute numbers (driven by population size) and rates (driven by risk). While Greater Accra's large population generates many zero-dose children, our rate-based analysis identifies the Northern sub-region as having the highest concentration of risk. Both perspectives are essential for policy: Greater Accra requires interventions addressing urban poor and elite non-compliance [6], while Northern regions require infrastructure strengthening and outreach.

4.3 Implications for Policy and Practice

These findings have several implications for Ghana's immunization program:

Geographic targeting

The 16.4 percentage point gap between Northern and Southern sub-regions warrants dedicated resource allocation to Northern regions. Strategies should include mobile vaccination teams, outreach sessions, and community health worker deployment to remote communities. The positive spatial autocorrelation suggests that area-based interventions targeting contiguous high-burden regions may be more efficient than household-level targeting.

Integration with maternal health services

The dominant effect of ANC attendance suggests that immunization counseling should be fully integrated into all ANC contacts, not just the first visit. The Ghana Health Service should ensure that every ANC visit includes discussion of the immunization schedule, card issuance, and appointment scheduling. The strong effect of TT vaccination a proxy for ANC quality suggests that mothers who receive comprehensive ANC are more likely to complete their child's immunization.

Facility delivery promotion

Given the 1.83-fold increased risk associated with home delivery, strategies to increase facility delivery rates particularly in Northern regions where traditional birth attendance remains common should be prioritized. This includes emergency transport systems, birth preparedness counseling, and addressing cultural barriers to facility delivery.

Education and empowerment

The protective effect of maternal education suggests that girls' education and adult literacy programs have direct immunization benefits. Community-based health education targeting mothers with no formal education should use oral and visual communication strategies rather than written materials.

Distance mitigation

For rural populations perceiving distance as a barrier, community-based vaccination sessions, temporary outreach posts, and transportation vouchers could reduce access barriers. Digital health solutions such as SMS reminders may help overcome follow-up challenges for dispersed rural populations.

4.4 Strengths and Limitations

This study has several strengths. We used nationally representative DHS data with rigorous sampling methodology. The explicit spatial analysis provides actionable geographic intelligence absent from previous Ghana-specific immunization studies. The intersectional analysis reveals how determinants compound to create extreme vulnerability. The events-per-variable ratio of 11.8:1 indicates adequate model stability.

Limitations include the cross-sectional design, which precludes causal inference. The outcome was based on maternal recall and vaccination card evidence; some children may have been misclassified. The sample of 487 children, while adequate for detecting strong effects (power > 95% for AOR $\geq$ 3.0), has limited power for weaker associations. Specifically, the distance-to-facility finding (AOR = 1.60) is based on marginal power (~ 51–55%) and should be treated as exploratory. The home delivery and no-TT-vaccination findings, while statistically significant, derive from relatively small exposure groups ($n = 88$ and $n = 67$, respectively) with moderate power (~ 63–78%) and warrant cautious interpretation. Spatial analysis was limited by the absence of GPS coordinates in the public dataset; we relied on regional aggregates rather than precise geospatial modeling. The concentration index interpretation should be treated cautiously given the complex relationship between wealth, education, and geography, and its exploratory nature in this sample.

4.5 Future Research Directions

Future studies should employ geospatial modeling with precise GPS coordinates to identify hotspot clusters at district and sub-district levels. Given the exploratory nature of the distance-to-facility finding, dedicated studies using geographic information systems (GIS) and travel-time modeling are needed to confirm and quantify access barriers. Mixed-methods research could explore the cultural and structural barriers specific to Northern regions. Longitudinal designs tracking children from birth through 23 months would clarify the temporal sequence of health service utilization and vaccination. Implementation science research should evaluate the effectiveness of integrated ANC-immunization interventions in high-burden regions.

5. Conclusions

This study demonstrates that zero-dose and under-vaccinated children in Ghana are not randomly distributed but concentrate in Northern regions and among populations with limited engagement with maternal health services. The 3.63-fold increased risk associated with no ANC attendance, the 2.06-fold risk in Northern regions, and the 1.86-fold risk in rural areas identify clear targets for intervention. Ghana's immunization program has achieved broad initial access nationally, but reaching the final 5–15% of zero-dose and under-vaccinated children requires geographically targeted, equity-focused strategies that address the intersection of poverty, limited education, rural residence, and weak health system contact. The Immunization Agenda 2030 goal of reducing zero-dose children by 50% is achievable in Ghana only if interventions explicitly target the Northern sub-region and integrate immunization promotion throughout the maternal health continuum.

Abbreviations

AIC

Akaike Information Criteria

ANC

Antenatal care

AOR

Adjusted odds ratio

AUC-ROC

Area under the receiver operating characteristic curve

BCG

Bacille Calmette-Guérin

BIC

Bayesian Information Criterion

CI

Confidence interval

COR

Crude odds ratio

DHS

Demographic and Health Survey

DTP

Diphtheria-tetanus-pertussis

EAs

Enumeration areas

EPI

Expanded Programme on Immunization

GDHS

Ghana Demographic and Health Survey

HepB

Hepatitis B

Hib

Haemophilus influenzae type b

IA2030

Immunization Agenda 2030

PCV

Pneumococcal conjugate vaccine

SSA

Sub-Saharan Africa

TT

Tetanus toxoid

WHO

World Health Organization.

Declarations

Ethics approval and consent to participate

This study used publicly available, de-identified DHS data. The original survey received ethical approval from the Ghana Health Service Ethical Review Committee and ICF Institutional Review Board. No additional ethical approval was required for this secondary analysis.

Consent for publication

Not applicable.

Availability of data and materials

The dataset supporting this study is available from the DHS Program upon registration at <https://dhsprogram.com>. The analysis code used in this study is available from the corresponding author upon reasonable request.

Competing interests

The authors declare no competing interests.

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Authors' contributions

JO contributed to the conceptualization of the study, development of the methodology, formal data analysis, and preparation of the original manuscript draft. JBEN contributed to the study methodology,

formal analysis, and critical review and editing of the manuscript. BKA contributed to the study methodology and critically reviewed and edited the manuscript. RKE contributed to the formal analysis and critically reviewed and edited the manuscript. EK contributed to the critical review and editing of the manuscript. All authors read, approved, and agreed to the published version of the manuscript.

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Figures

Conceptual Framework: Determinants of Zero-Dose Vaccination Status in Ghana

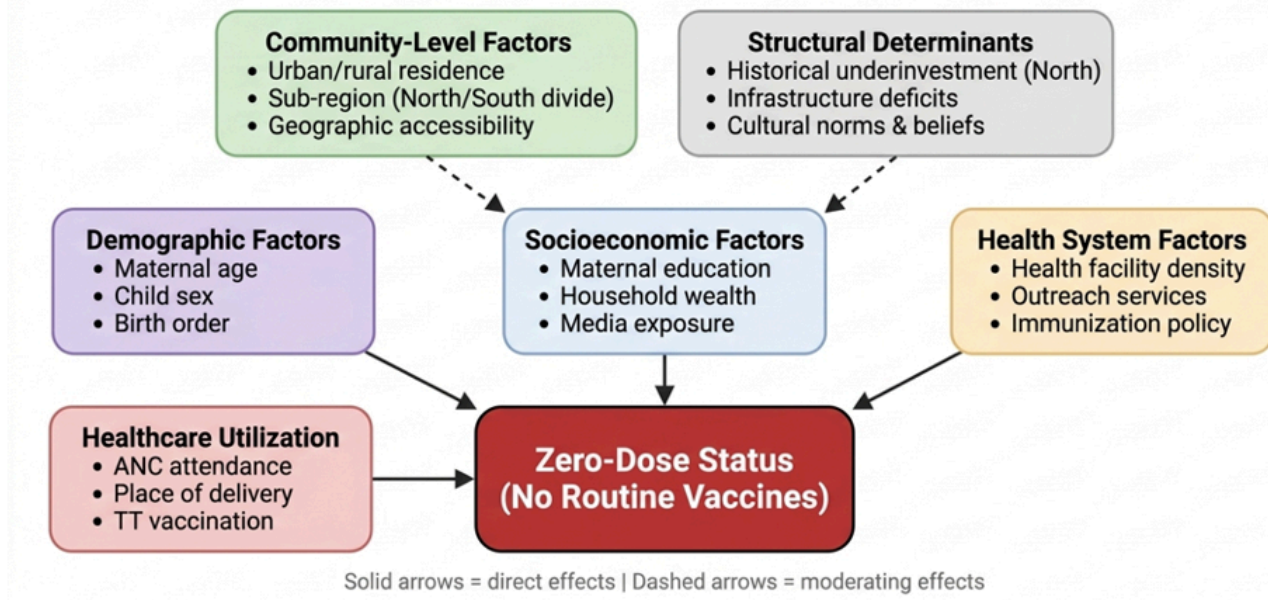


Figure 1

Conceptual framework illustrating the multilevel determinants of zero-dose and under-vaccinated status among children aged 12–23 months in Ghana. The framework depicts individual-level factors (healthcare utilization, socioeconomic, and demographic), community-level factors (residence, sub-region, and geographic accessibility), health system factors, and structural determinants, with their hypothesized relationships to zero-dose status.

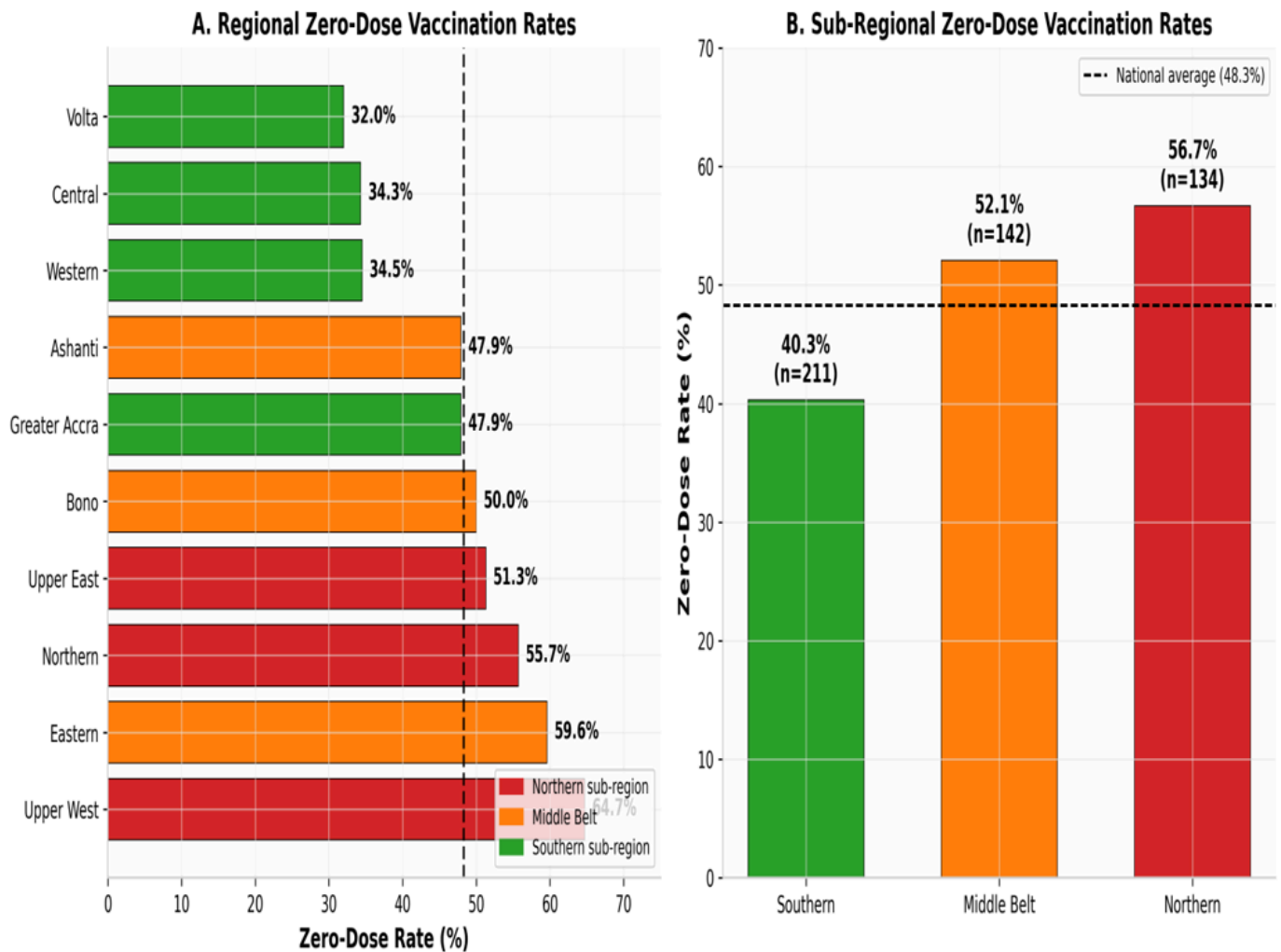


Figure 2

Spatial distribution of zero-dose and under-vaccinated vaccination rates by region and sub-region. Panel A shows regional rates ranked from highest to lowest, with color coding by sub-region (red = Northern, orange = Middle Belt, green = Southern). The national average of 48.3% is marked by a dashed line. Panel B compares sub-regional rates, confirming the significant north-south gradient ($\chi^2 = 10.06$, $p = 0.007$).

Figure 5. Map of Ghana Showing Regional Zero-Dose Vaccination Rates

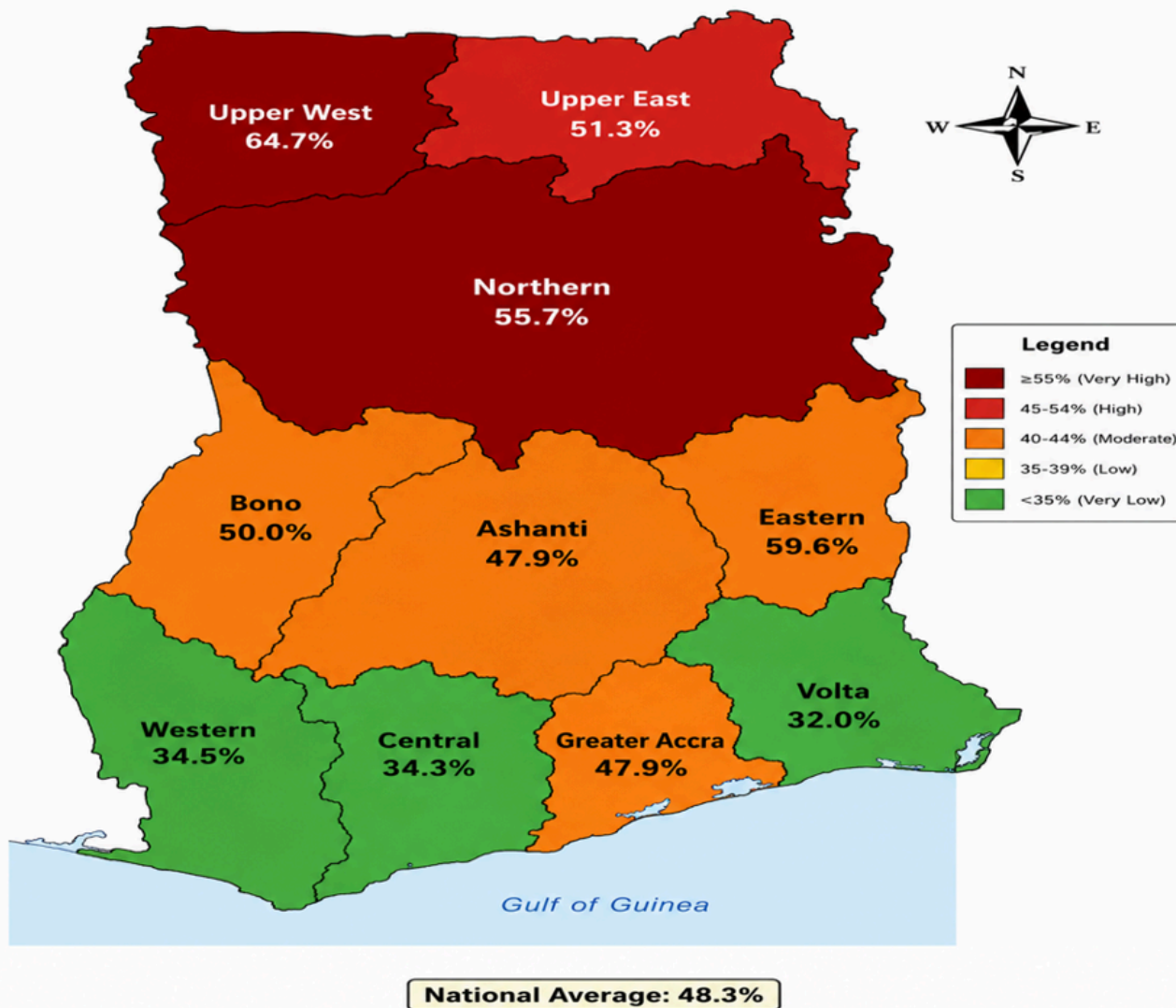


Figure 3

Map of Ghana showing regional zero-dose and under-vaccinated vaccination rates. Regions are color-coded by rate severity: dark red ($\geq 55\%$), red (45–54%), orange (40–44%), yellow orange (35–39%), and green ($< 35\%$). The map illustrates the pronounced north-south gradient in prevalence.

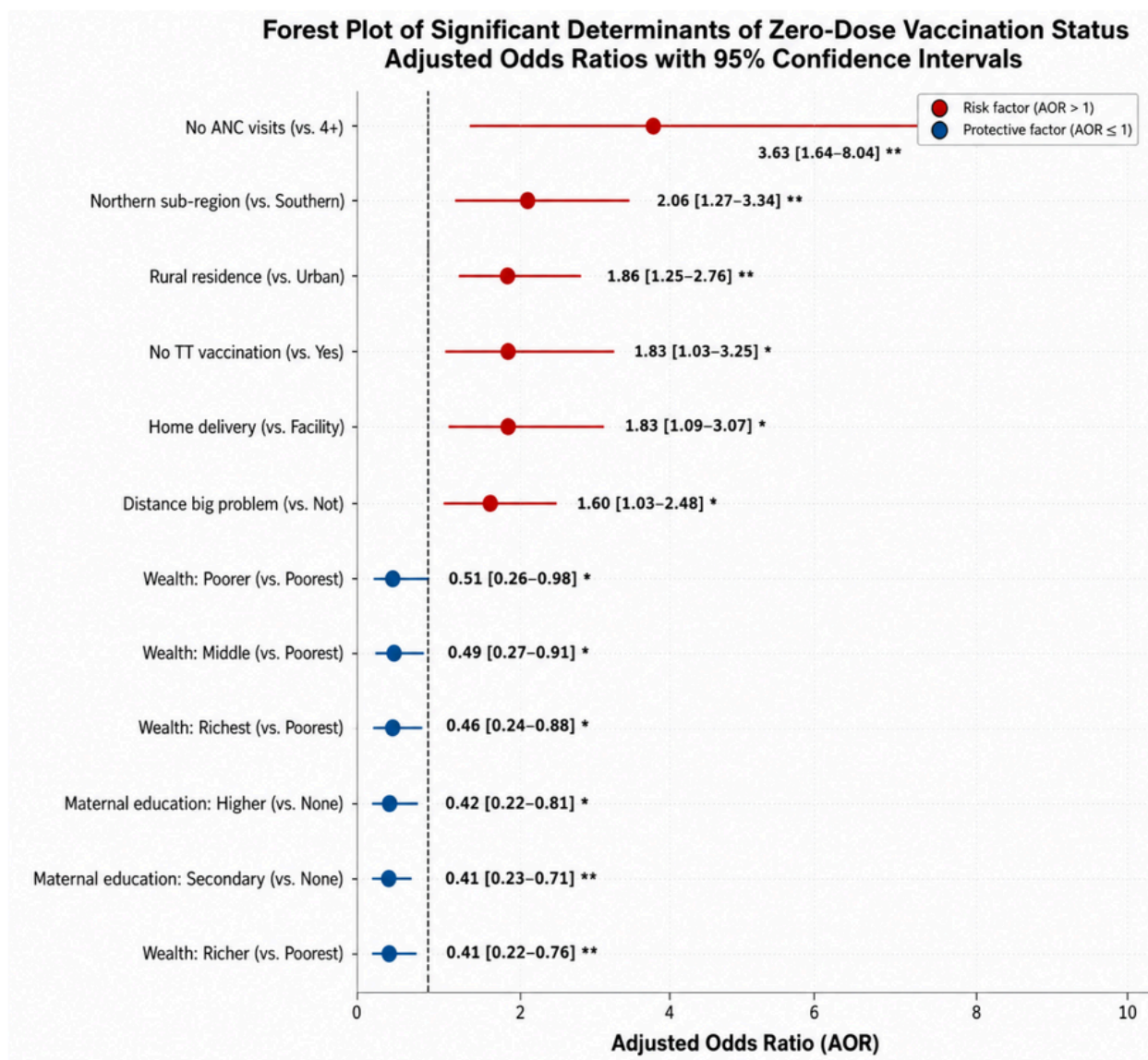


Figure 4

Forest plot of significant determinants of zero-dose and under-vaccinated status. Adjusted odds ratios (AORs) with 95% confidence intervals are displayed. Red markers indicate risk factors (AOR > 1), and blue markers indicate protective factors (AOR < 1). The vertical dashed line at AOR = 1.0 represents the null effect. Significance levels: * $p < 0.05$, ** $p < 0.01$.

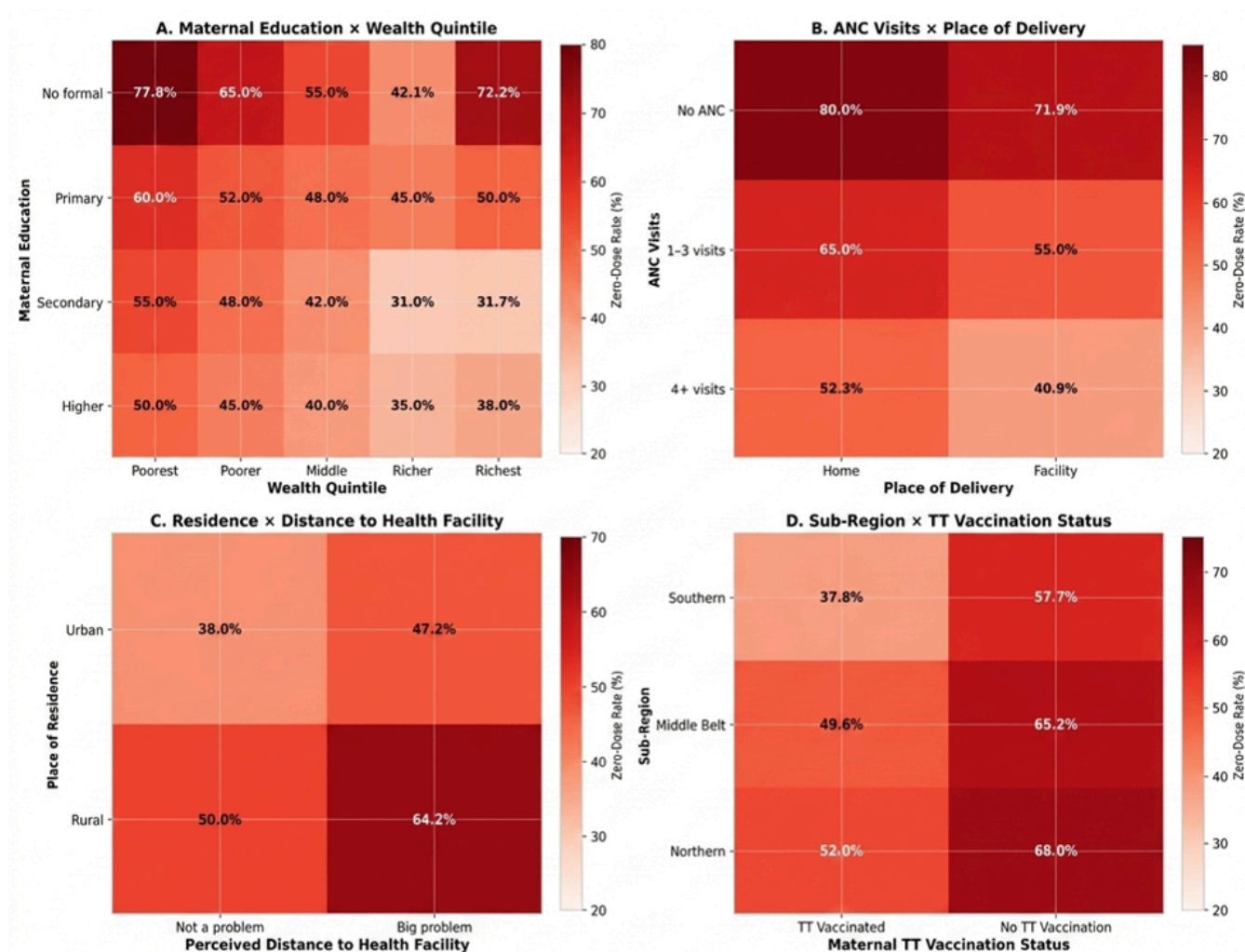


Figure 5

Heatmap of zero-dose and under-vaccinated rates across key determinant intersections. Panel A: Maternal education × wealth quintile. Panel B: ANC visits × place of delivery. Panel C: Residence × perceived distance to health facility. Panel D: Sub-region × maternal TT vaccination status. Darker red indicates higher rates.

Supplementary Files

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- [Appendix.docx](#)