BMJ Global Health

Geospatial disparities in infant mortality in Ghana: evidence from national data

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To cite: Osei KM, Han W, Kang S, *et al*. Geospatial disparities in infant mortality in Ghana: evidence from national data. *BMJ Glob Health* 2026;**11**:e023249. doi:10.1136/bmjgh-2025-023249

Handling editor Luca Nelli

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bmjgh-2025-023249).

Received 16 December 2025
Accepted 23 April 2026

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ABSTRACT

Background Infant mortality remains a major public health concern in Ghana, with progress occurring unevenly across population groups and locations. Understanding both the determinants and the spatial distribution of infant deaths is essential for designing targeted interventions and reducing persistent inequalities.

Methods We analysed nationally representative data from multiple rounds of the Ghana Demographic and Health Surveys, comprising 19 558 infant survivors and 3464 infant deaths. Local Indicators of Spatial Association and kernel density estimation were applied to produce cluster and spatial risk maps, respectively. A shared frailty Cox proportional hazards model, accounting for unobserved heterogeneity at the regional level, was used to estimate adjusted HRs.

Results Infant mortality exhibited significant spatial autocorrelation, while regional quantile maps revealed distinct yet overlapping geographic patterns for both neonatal and infant mortality. Infant mortality showed substantial clustering. Elevated risks were observed in Upper West, parts of Savannah and Ashanti, whereas lower risks were evident in Greater Accra, North East and Eastern regions. Factors associated with lower hazards included tertiary maternal education (adjusted HR (aHR)=0.66; 95% CI 0.48 to 0.89), health insurance coverage (aHR=0.86; 95% CI 0.80 to 0.94), early initiation of antenatal care (aHR=0.88; 95% CI 0.83 to 0.93) and completion of ≥4 antenatal visits (aHR=0.90; 95% CI 0.82 to 0.98). Socioeconomic gradients were apparent, with infants in relatively richer households experiencing lower mortality hazards. Infant-level characteristics strongly predicted survival, including normal birth weight (aHR=0.60; 95% CI 0.45 to 0.75), breastfeeding (aHR=0.39; 95% CI 0.31 to 0.47), longer birth intervals (aHR=0.63; 95% CI 0.57 to 0.70) and vaccination (aHR=0.42; 95% CI 0.32 to 0.53).

Conclusions Infant mortality in Ghana displays marked spatial heterogeneity and regional-level effects. Strengthening maternal and newborn services in hot-spot regions, expanding early antenatal and postnatal care and targeting high-risk maternal profiles may accelerate progress toward equitable child survival.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Prior studies identified key maternal and household determinants but offered limited evidence on spatial patterns or regional-level influences on infant mortality.

WHAT THIS STUDY ADDS

⇒ This study provides the first national analysis in Ghana that jointly applies spatial hotspot detection and multilevel survival modelling across multiple Demographic and Health Survey rounds.

⇒ It identifies significant geographic clusters of high and low infant mortality and quantifies the unobserved regional heterogeneity that influences infant survival.

⇒ Findings demonstrate that infant mortality risk is shaped by both individual characteristics and broader contextual factors that vary across regions.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Results highlight the need for geographically targeted maternal and newborn health interventions in high-risk areas.

⇒ Routine spatial monitoring can guide efficient resource allocation and support efforts to reduce persistent regional disparities in infant mortality.

BACKGROUND

Infant mortality serves as a fundamental indicator of population health and the effectiveness of healthcare systems, particularly in sub-Saharan Africa, where rates persistently exceed global averages.[1–3] The WHO defines infant mortality as the death of a live-born child before 12 months of age. Since 1990, public health initiatives aimed at reducing child mortality have been largely influenced by the Millennium Development Goal and the Sustainable Development Goals, which sought to decrease the mortality rate of children under five by two-thirds between 1990 and 2015 and end preventable deaths of newborns and children under 5 years of age by 2030, respectively.[1 4 5]

Child mortality rates are commonly expressed as the number of deaths per 1000 live births, encompassing neonatal deaths (within the first month of life), infant deaths and children aged 1–59 months.[6] Premature birth and complications during delivery are the primary global causes of neonatal death. Nearly half of all deaths in children under 5 years of age occur within the neonatal period, which is the most vulnerable phase for child survival.[3 6] While there has been notable progress in reducing under-five mortality over the past three decades, declines in infant deaths have lagged behind those seen in children aged 1–59 months. Although infant survival has improved overall, significant inequalities persist both between and within countries.[3] Children born in sub-Saharan Africa continue to face the highest risk of dying in infancy, with the region experiencing the highest infant mortality rates (IMRs).[3 7] Currently, about 1 in every 14 children in sub-Saharan Africa dies before the age of five, 14 times the rate observed in high-income countries, accounting for approximately 56% of all under-five deaths globally.[8 9]

Geographic disparities in infant deaths within and among countries are also more pronounced in sub-Saharan Africa.[7] Based on the most recent data from the 2022 Ghana Demographic and Health Survey (GDHS), Ghana currently reports an infant mortality rate of 28 deaths per 1000 live births, representing a substantial decline from historical levels but still falling short of the United Nations Sustainable Development Goal target of 12 deaths per 1000 live births by 2030.[3] Limited available evidence suggests both regional, rural and urban disparities in IMRs in Ghana, despite efforts being made to reduce child mortality over the past two decades.[10–13] Government interventions such as the Community-based Health Planning and Services (CHPS) initiative, the National Health Insurance Scheme (NHIS) and free maternal and child health services have contributed to progress in child health outcomes. However, persistent implementation challenges, including inadequate healthcare infrastructure, insufficiently trained healthcare workers and continued out-of-pocket costs, limit the effectiveness of these interventions. Due to these implementation challenges, infant mortality remains a significant issue, reflecting persistent disparities across geographic regions and socioeconomic status.[11 14 15] The continued existence of such disparities suggests the need for a more nuanced understanding of the factors influencing infant survival in Ghana.

Most previous studies on child and infant survival in Ghana have primarily focused on individual-level determinants, with limited attention to spatial inequalities and contextual factors influencing mortality patterns.[13 16] This study addresses critical gaps in understanding the determinants and geospatial disparities of infant mortality in Ghana, providing evidence based on national data. By integrating geospatial perspectives, we highlight how the burden of infant mortality varies across regions and populations, underscoring persistent inequities in survival outcomes. We also accounted for geospatial disparities to provide evidence-based recommendations that inform targeted interventions and equitable strategies to reduce infant mortality in Ghana.

METHODS

Study design and data sources

Our study relied on data from three waves of the GDHS,[17] including GDHS 2008, GDHS 2014 and GDHS 2022. The GDHS are nationally representative surveys that provide information on the reproductive history of women 15–49 years of age and health service use.[18] We analysed data on infant mortality, maternal sociodemographic characteristics, maternal health service utilisation, and infant demographic and health factors. The dataset also included geospatial information on the location of survey clusters. For privacy protection, cluster coordinates were randomly displaced by 2–5 km.[18–20] All observations within a given survey were linked to the GPS coordinates of their respective cluster at the time of data collection. The GDHS 2008 and GDHS 2014 were conducted when Ghana had 10 administrative regions; however, post-2019, the administrative regions were increased to 16 (online supplemental figure S1). We analysed 23 022 live births recorded within 5 years preceding each survey to minimise recall bias and improve the accuracy of maternal reporting (online supplemental figure S2).

Variables

Outcome variable

In the geospatial analysis, the outcome variable was infant death, defined as the death of a live-born child before reaching 12 months of age. For the survival analysis, the outcome was time to infant death, with the event coded as death before 12 months. Time was measured in months from birth to age at death for infants who died before their first birthday. For infants who were alive at the time of the survey and had not yet reached 12 months, follow-up time was calculated from birth to age at interview. Infants who survived to 12 months or beyond were administratively right-censored at 12 months, consistent with the study definition of infant mortality.

Explanatory variables

Explanatory variables were selected based on recent literature and grouped into maternal sociodemographic factors, maternal health service utilisation factors and infant demographic and health characteristics.[8 9 11 21 22] Maternal sociodemographic factors included the mother's age group, marital status, wealth index, residence type, employment status, education level, religion, health insurance status, source of drinking water and type of toilet facility accessible to the household. Antenatal care (ANC) visit within the first trimester of pregnancy, completing ≥4 ANC visits, facility-based delivery and postnatal care comprised the maternal health service utilisation factors selected for the study. We included birth weight, breastfeeding, sex of the infant, birth interval and vaccination status as infant demographic and health factors. Vaccination status was defined based on receipt of BCG vaccine, which is typically administered at birth or shortly thereafter, and was used as a proxy for early immunisation exposure. A detailed description of the harmonised variables used in this study is shown in online supplemental table S1.

Statistical analysis

All analyses were conducted using R V.4.5.1 (R Statistical Foundation, Vienna, 2025). To account for the stratified clustered sampling structure of the DHS data, we created a survey design by selecting the primary sampling unit variable, the strata variable and dividing the sampling weight variable by 1 000 000 to ensure appropriate scaling.

We addressed missing data in some explanatory variables by applying multiple imputations by chained equations (MICE). Little's test showed that our data were not missing completely at random (p<0.001), indicating that listwise deletion could lead to bias. Due to the proportion of missing values in key covariates, we employed MICE to handle missingness under the missing-at-random assumption.[23] As the dataset consisted entirely of categorical indicators, we applied variable-specific imputation models: binary logistic regression for dichotomous variables, ordered logistic regression for ordinal variables and polytomous (multinomial) regression for nominal variables. We generated 10 imputed datasets with 10 iterations per chain. Final estimates were pooled using Rubin's rules to incorporate within- and between-imputation variance.[24] Additional details on the variables with missing data and convergence diagnostics for MICE are provided in online supplemental table S2 and figure S3. Statistical significance was defined as p<0.05 across all analyses, including Shared Frailty Cox proportional hazards regression and spatial autocorrelation tests.

Geospatial assessment of infant mortality and key covariates using quantile mapping

Regional IMRs were calculated as the number of deaths among infants under 12 months of age per 1000 live births based on the survey-weighted characteristics of the study population (online supplemental table S3). To assess geographic disparities, regions were classified into quantiles based on their IMR values, ensuring an even distribution across the observed range. These quantile categories were then mapped to visualise spatial variation and identify regions with comparatively high or low IMR across survey years. Similar quantile maps were also generated for key covariates to illustrate their geographic distribution and support comparative spatial interpretation.

Kernel density estimation for spatial risk patterns of infant mortality

To examine the spatial distribution of infant mortality risk, kernel density estimation (KDE) was used to generate a spatial relative risk surface by comparing the smoothed intensity of infant deaths to that of all live births (population at risk). Point locations were analysed within an observation window defined by the Ghana national boundary. Geographic coordinates (WGS84; EPSG:4326) were projected to WGS84/UTM Zone 30N (EPSG:32630) to enable distance-based smoothing in metres. Intensity surfaces were estimated using an isotropic Gaussian kernel with a fixed bandwidth (σ=45 000). Sensitivity analyses using alternative bandwidths produced similar spatial patterns. Edge correction was applied to account for kernel truncation near boundaries. The resulting risk surface was visualised using a colour gradient to aid in the interpretation of spatial variations in risk.

Spatial autocorrelation

Spatial autocorrelation was assessed using the Global Moran's I statistic, employing a queen contiguity-based neighbourhood structure with administrative regions as the unit of analysis. Infant mortality showed a Global Moran's I of 0.196 (p=0.002), indicating significant positive spatial autocorrelation. Facility-based delivery demonstrated a similar pattern, with a positive and statistically significant Global Moran's I of 0.203 (p=0.029). Moran's scatterplots were employed to visually depict these spatial relationships, highlighting clusters characterised by high–high (HH) and low–low (LL) associations among neighbouring regions (online supplemental figure S4). We assessed local spatial autocorrelation using Moran's I and generated Local Indicators of Spatial Autocorrelation (LISA) cluster maps to identify statistically significant hotspots and cold spots of infant mortality and facility-based delivery. Statistical significance for local Moran's I was evaluated using a permutation approach (999 permutations) to obtain pseudo p values for each region, and p values were adjusted for multiple comparisons using the Benjamini-Hochberg false discovery rate procedure (q=0.05). Regions were classified into five categories: HH, high–low, low–high, LL and 'not significant', reflecting patterns of spatial clustering.

Shared frailty Cox proportional hazard model

We employed a shared frailty Cox proportional hazards model to account for unobserved spatial heterogeneity in infant mortality. Spatial analyses, including Global Moran's I and Local Indicators of Spatial Association (LISA), demonstrated statistically significant spatial clustering, indicating that infant deaths were not randomly distributed across Ghana. These findings provided empirical justification for incorporating a geographic-level random effect in the survival model. Spatial dependence was accommodated by specifying region as a shared frailty term in the Cox proportional hazards model (online supplemental equation 1), while stratifying the baseline hazard by survey year (2008, 2014 and 2022). Stratification by survey year allowed the baseline hazard to vary across survey waves, accounting for period effects and differences in underlying mortality risk over time. This approach enhances the accuracy and robustness of effect estimates, with all individuals within the same region sharing a common frailty term to allow intra-region correlation while adjusting for measured covariates. The proportional hazards assumption was evaluated using scaled Schoenfeld residuals from the survey-weighted Cox model. Diagnostic tests revealed no evidence of violation, with the global test and all individual covariate tests yielding non-significant results (p>0.05). Model refinement to enhance parsimony was informed by the Akaike Information Criterion, with all key demographic and health service variables of substantive relevance retained irrespective of statistical selection criteria. As a sensitivity analysis, we re-estimated our model using a complete-case dataset to assess the robustness of the findings. Although the complete-case analysis produced estimates that were largely consistent in direction with those from the primary multiply imputed models, the CIs were generally wider, indicating reduced statistical precision.

RESULTS

Spatial distribution of neonatal mortality and infant mortality

Geospatial quantile analysis of neonatal and infant mortality across Ghana revealed persistent regional stratification with marked heterogeneity across survey periods (figure 1). In the 2008 GDHS, neonatal mortality was highest in Central, Upper East and Ashanti regions, with moderately elevated rates in Brong Ahafo and Western regions. Northern and Volta regions showed intermediate levels, whereas Greater Accra, Eastern and Upper West exhibited the lowest mortality. By 2014, the spatial pattern reflected both continuity and regional reconfiguration. Upper East and Ashanti remained in the highest quantile, while Volta newly emerged among the highest-mortality regions, whereas Northern, Greater Accra and Eastern were in the lowest strata. The GDHS 2022 assessment, using the expanded 16-region administrative boundaries, revealed a widened distribution of high neonatal mortality across Savannah, Oti, Volta and Western regions, while Ashanti, Bono East, Eastern and Central occupied intermediate-mortality strata. The pooled multi-year analysis indicated that Ashanti, Volta and Central sustained the highest neonatal mortality burden, Upper East and Western North exhibited intermediate-elevated mortality, and Greater Accra, Eastern and Northern consistently demonstrated favourable mortality profiles.

Infant mortality patterns displayed both convergence and divergence with neonatal mortality. The GDHS 2008 showed Upper East, Ashanti and Central concentrated in the highest-mortality quantile, with Northern and Upper West in intermediate strata, and Greater Accra, Eastern and Brong Ahafo recording the lowest mortality. The 2014 distribution identified Upper East, Volta and Ashanti in the highest-mortality quantile, differing from the 2008 neonatal pattern. By 2022, infant mortality was most elevated in Oti, Volta, Western and Central regions, indicating an expanded geographic concentration relative to earlier periods. The pooled analysis placed Upper East and Upper West in the highest-mortality strata, Northern and Ashanti in intermediate-elevated categories, Volta and Western in intermediate-lower, and Greater Accra, Brong Ahafo and Eastern as the most favourable mortality zones.

Comparative geospatial examination of neonatal and infant mortality revealed partially overlapping but distinct spatial structures. Infant mortality demonstrated greater temporal and spatial variability, particularly in Volta and Northern regions, while neonatal mortality showed more stable regional stratification. Across survey years, Upper East, Ashanti and Central Regions demonstrated similar mortality patterns, with relatively high infant and neonatal death rates. Greater Accra and Eastern maintained persistently favourable mortality profiles across both outcomes and all survey years, serving as consistent low-mortality anchors in the national landscape.

Spatial distribution of key covariates

Health insurance registration and birth weight outcomes demonstrated contrasting geographic patterns across Ghana (figure 1). NHIS registration showed heterogeneous distribution, with the highest enrolment in Upper West, Brong Ahafo and Eastern regions, intermediate in Ashanti and Upper East and lower in Northern, Greater Accra, and Central regions. Over time, the highest-registration regions shifted: in 2008, Upper East, Greater Accra and Eastern; in 2014, Upper West, Ashanti and Brong Ahafo; and in 2022, Western North, Eastern, Upper East, and Bono East. Underweight births were concentrated in central and northern zones, with Northern and Upper East consistently showing elevated prevalence, intermediate burden in Ashanti and Brong Ahafo, and lower prevalence in Upper West, Volta and Greater Accra, indicating persistent socioeconomic and nutritional gradients.

Maternal health service utilisation exhibited marked geographic stratification, with advantages concentrated in urban and southern regions and disadvantages in northern zones (figure 2). First-trimester ANC initiation was highest in Greater Accra, Ashanti and Western regions, intermediate in Upper East and Brong Ahafo, and lowest in Northern, Eastern and Oti zones. Completion of four or more ANC visits showed similar patterns, with the highest completion in Greater Accra, Ashanti and Central regions, intermediate in Brong Ahafo and Upper West, and lowest in Northern and Upper East regions. Facility-based delivery was highest in Greater Accra, Ashanti, and Brong Ahafo, intermediate in Western and Eastern zones, and lowest in Northern, Upper East and Upper West regions. Postnatal care was concentrated in Greater Accra, Volta and Brong Ahafo, intermediate in Western and Ashanti, and lower in Northern, Central and Eastern regions. Aggregated multi-year analysis revealed Greater Accra consistently occupied the highest quantiles across all maternal health indicators, while the Northern region remained persistently lower, reflecting

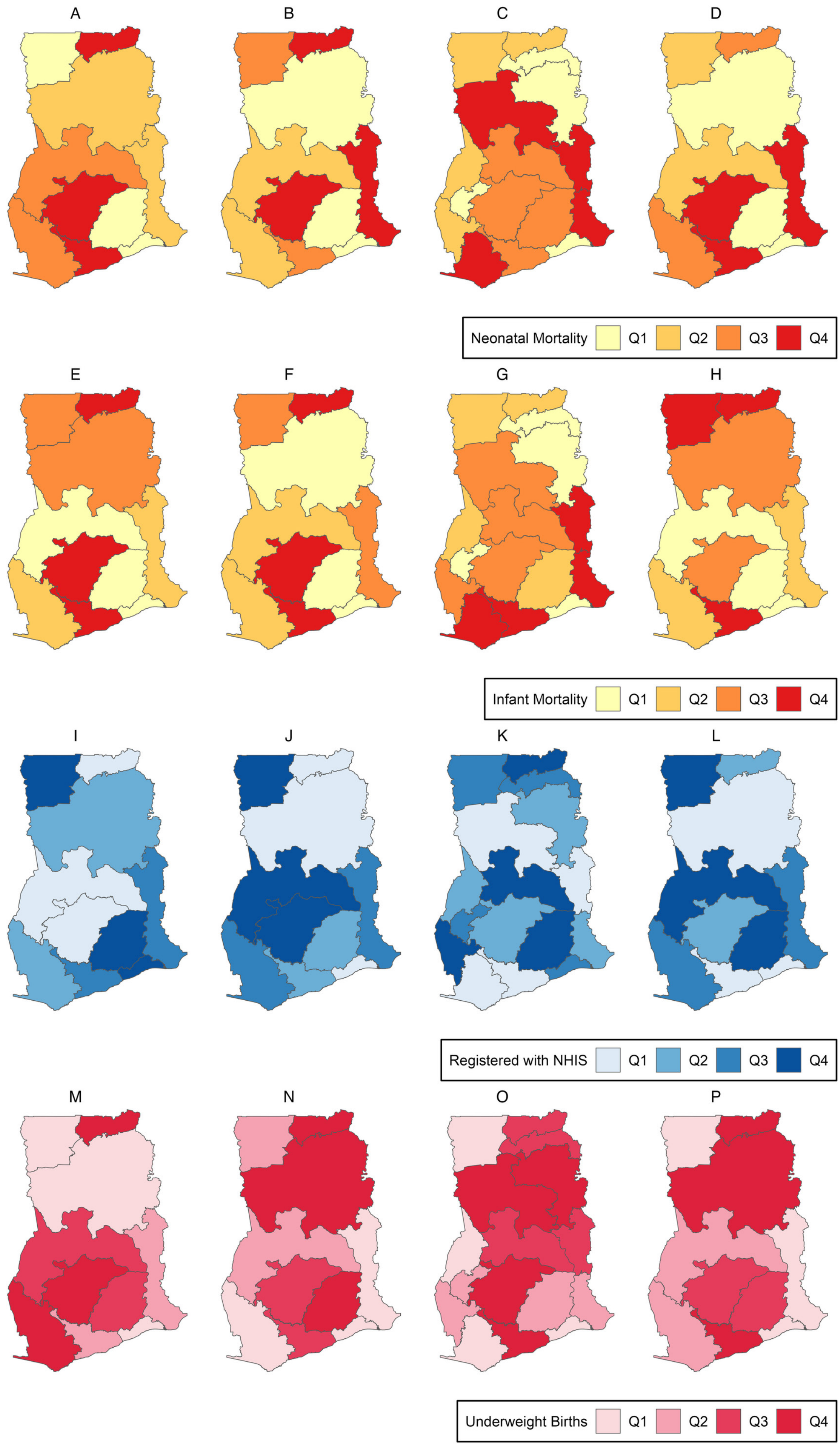

Figure 1 Quantile maps of neonatal mortality ((A) GDHS 2008, (B) GDHS 2014, (C) GDHS 2022, (D) pooled data), infant mortality ((E) GDHS 2008, (F) GDHS 2014, (G) GDHS 2022, (H) pooled data), registered with NHIS ((I) GDHS 2008, (J) GDHS 2014, (K) GDHS 2022, (L) pooled data), underweight births ((M) GDHS 2008, (N) GDHS 2014, (O) GDHS 2022, (P) pooled data). GDHS, Ghana Demographic and Health Survey; NHIS, National Health Insurance Scheme.

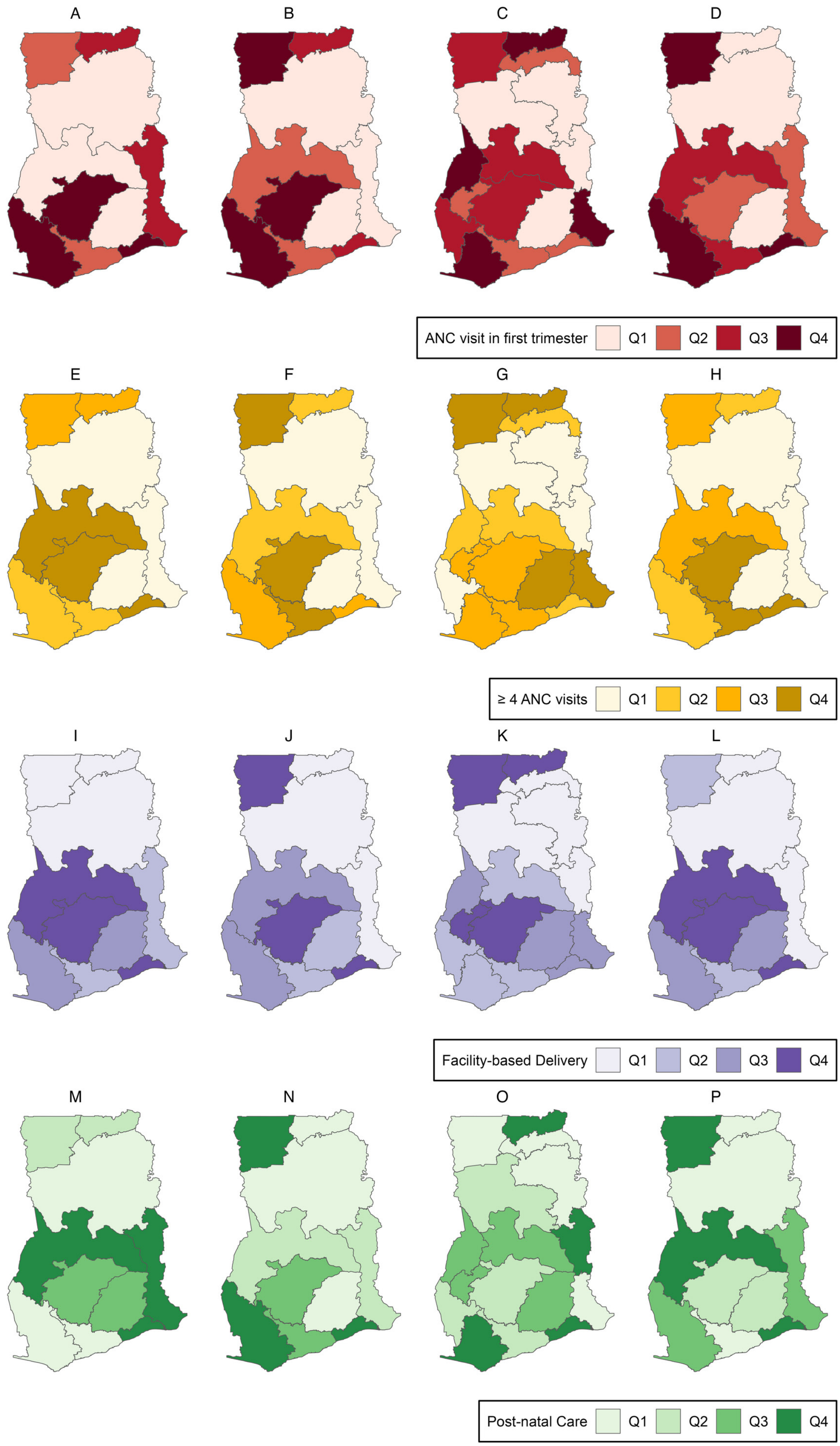

Figure 2 Quantile maps of ANC visit in the first trimester ((A) GDHS 2008, (B) GDHS 2014, (C) GDHS 2022, (D) pooled data), ≥4 ANC visits ((E) GDHS 2008, (F) GDHS 2014, (G) GDHS 2022, (H) pooled data), facility-based delivery ((I) GDHS 2008, (J) GDHS 2014, (K) GDHS 2022, (L) pooled data), postnatal care ((M) GDHS 2008, (N) GDHS 2014, (O) GDHS 2022, (P) pooled data). ANC, antenatal care; GDHS, Ghana Demographic and Health Survey.

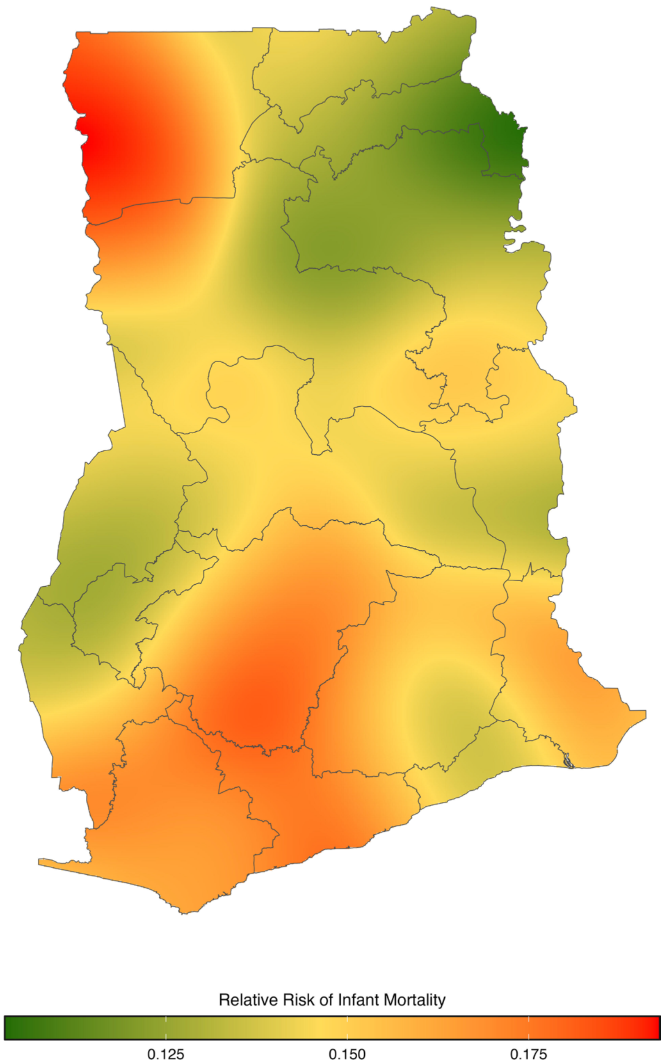

Figure 3 Spatial risk of infant mortality in Ghana (pooled data).

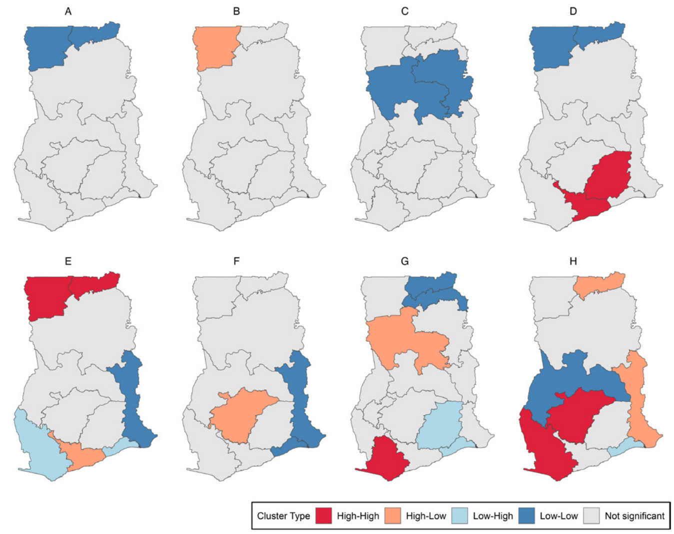

Figure 4 Local Indicators of Spatial Association cluster maps of facility-based delivery ((A) Ghana Demographic and Health Survey (GDHS) 2008, (B) GDHS 2014, (C) GDHS 2022, (D) pooled data) and infant mortality ((E) GDHS 2008, (F) GDHS 2014, (G) GDHS 2022, (H) pooled data) in Ghana.

entrenched geographic inequities. These spatially heterogeneous patterns in maternal health service utilisation and birth outcomes provide a critical context for interpreting persistent geographic disparities in infant mortality.

Relative risk of infant mortality in Ghana

KDE of the relative risk of infant mortality reveals substantial spatial heterogeneity across Ghana's regions (figure 3). The map displays a gradient in risk intensity, with higher relative risks (red tones) predominantly clustered in the Upper West and parts of the Northern region. There exists considerable risk within the central belt, towards the coastal regions. Elevated risks are also evident toward the southeastern and southwestern borders, encompassing Volta, Western and Central regions. Conversely, the lowest relative risks (green tones) are concentrated in the eastern and northeastern parts of the country, particularly within Greater Accra, Eastern and parts of the North East regions. These areas consistently demonstrate a protective spatial effect, suggesting more favourable survival outcomes for infants.

Spatial clustering of facility-based delivery and infant mortality in Ghana

LISA cluster analysis (figure 4) revealed notable spatial heterogeneity in both facility-based delivery and infant mortality across survey rounds in Ghana. LISA revealed distinct and evolving spatial patterns in both facility-based delivery and infant mortality across Ghana. Facility-based delivery exhibited persistent geographic disparities, with significant LL clusters consistently concentrated in the northern belt, particularly in the Upper East and Upper West regions in 2008 and again in the pooled analysis, indicating areas of persistently low service utilisation. In contrast, high-high clusters, representing areas of high coverage surrounded by similarly high-performing regions, emerged in the Eastern and Central regions in the pooled dataset, reflecting spatially contiguous improvements in the south-central zone. The 2022 analysis, based on the new 16-region boundaries, showed the persistence of low-low clustering in the Savannah and Northern regions, reinforcing the pattern of limited access to facility-based delivery in the north, while most other regions remained spatially random. These findings suggest that despite overall national progress, the spatial inequality in maternal service utilisation remains geographically entrenched, with northern regions consistently lagging behind.

The spatial distribution of infant mortality demonstrated a complementary yet more complex pattern. Across survey years, HH clusters of elevated infant mortality were initially observed in the Upper East and Upper West regions, highlighting areas of persistently high mortality risk. Over time, additional hotspots emerged in parts of the south-west, particularly the Western region in 2022, and in both Ashanti and Western in the pooled analysis, suggesting a shifting concentration of mortality

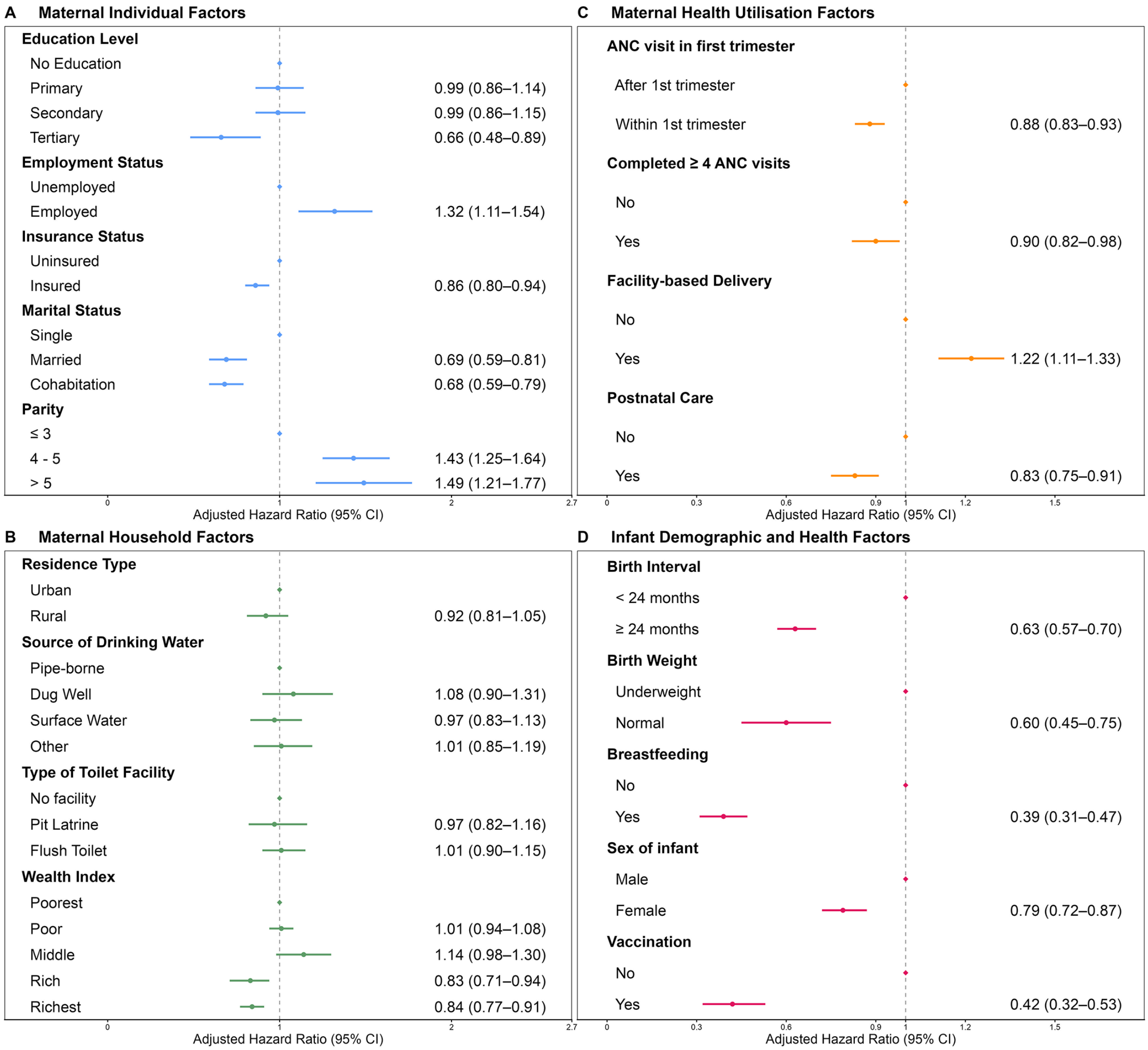

Figure 5 Adjusted HRs for infant mortality from shared frailty Cox proportional hazard model. ANC, antenatal care.

risk towards certain southern regions. Conversely, LL clusters, indicative of lower mortality surrounded by similar areas, were observed in Greater Accra and Volta in earlier survey rounds, reflecting areas of relative advantage. Transitional high-low and low-high outlier clusters in Savannah (GDHS 2022), Volta (pooled data) and Greater Accra (GHDS 2008, 2022 and pooled data) further indicated spatial disparities in infant mortality across adjacent regions.

Determinants of infant mortality in Ghana

Figure 5 presents the adjusted HRs (aHRs) for infant mortality derived from a shared frailty Cox proportional hazards model, which accounts for regional-level clustering. The frailty term was statistically significant ($p<0.001$), with an intraclass correlation coefficient of 22.3%, indicating that over one-fifth of the unexplained variation in infant mortality was attributable to unobserved regional differences (online supplemental table S4). Sensitivity analysis using complete-case data showed the same directionality of effects but with reduced precision, likely due to the loss of statistical power (online supplemental table S5) Supplementary Document). The analysis demonstrates a strong and progressive increase in the hazard of infant mortality with advancing maternal age. While mothers aged 20–24 showed a higher hazard relative to those aged 15–19, this association was not statistically significant (aHR=1.46; 95% CI 0.96 to 2.22). However, from age 25 onwards, the association becomes statistically significant and increases steadily, reaching its peak among mothers aged 45–49 (aHR=5.01; 95% CI 3.19 to 7.88).

Regarding maternal social determinants, being married (aHR=0.69; 95% CI 0.59 to 0.81) or cohabiting (aHR=0.68; 95% CI 0.59 to 0.79) was associated with a significantly reduced hazard of infant mortality compared with single mothers. Conversely, maternal employment was associated with an increased hazard (aHR=1.32; 95% CI 1.11 to 1.54). Educational attainment exerted differential effects; tertiary education was associated with reduced hazard (aHR=0.66; 95% CI 0.48 to 0.89), while primary and secondary education showed no statistically significant associations. Household wealth was also associated with a lower hazard, particularly among the rich (aHR=0.83; 95% CI 0.71 to 0.94) and richest (aHR=0.84; 95% CI 0.77 to 0.91) groups. Health insurance coverage was associated with a 14% reduction in the hazard of infant mortality (aHR=0.86; 95% CI 0.80 to 0.94). Higher parity was a predictor of increased hazard of mortality, with ratios of 1.43 (95% CI 1.25 to 1.64) for mothers with 4–5 children and 1.49 (95% CI 1.21 to 1.77) for those with more than five children.

Maternal health service utilisation was consistently associated with reduced hazards of infant mortality. Specifically, early ANC initiation within the first trimester (aHR=0.88; 95% CI 0.83 to 0.93), completion of at least four ANC visits (aHR=0.90; 95% CI 0.82 to 0.98) and receipt of postnatal care (aHR=0.83; 95% CI 0.75 to 0.91) were all predictors of infant survival. Notably, facility-based delivery was associated with a higher hazard of infant mortality compared with non-facility delivery (aHR=1.22; 95% CI 1.11 to 1.33).

At the infant level, factors associated with significantly reduced hazards included normal birth weight (aHR=0.60; 95% CI 0.45 to 0.75), breastfeeding (aHR=0.39; 95% CI 0.31 to 0.47), female sex (aHR=0.79; 95% CI 0.72 to 0.87), birth intervals of 24 months or more (aHR=0.63; 95% CI 0.57 to 0.70) and vaccination (aHR=0.42; 95% CI 0.32 to 0.53).

DISCUSSION

We conducted a comprehensive study on the geographic disparities and determinants of infant mortality in Ghana and found significant spatial patterns and survival outcomes that depict disparities across administrative regions and sociodemographic strata. Infant demographic and health factors, some maternal sociodemographic and maternal health service utilisation factors were significantly associated with infant survival outcomes. Infants with normal birth weight, breastfeeding and vaccinated infants had a better survival outcome, and these findings are consistent with previous studies.[15 25] Female infants experienced about a 21% lower mortality hazard than males, consistent with previous studies reporting higher early mortality among boys.[26 27] This survival advantage among females has been attributed to biological and developmental factors, including faster lung maturation, stronger immune responses and protective effects of oestrogen and X-linked genes.[28 29] In contrast, male infants are more vulnerable to complications such as respiratory distress and infections, which contribute to their elevated risk of death in the neonatal and infant periods.

Among maternal and household factors, marital status emerged as a strong determinant of infant survival. Infants born to married or cohabiting mothers had an estimated one-third lower hazard of death compared with those of single mothers, possibly reflecting the benefits of additional social and economic support. We also observed steep socioeconomic gradients: wealthier households experienced substantially lower infant mortality, reflecting better living conditions and greater capacity to seek timely care. Maternal education showed a similarly stratified pattern; only tertiary education demonstrated an association with lower infant mortality, whereas primary or secondary schooling did not significantly reduce mortality. This suggests that it is higher levels of education, rather than schooling alone, that translate into improved newborn care practices, health literacy and access to resources. In addition, having health insurance independently contributed to lower infant mortality, likely by reducing financial barriers to skilled care and enabling mothers to seek prompt treatment for pregnancy-related complications or infant illnesses.[30 31] Collectively, these findings underscore the critical role of socioeconomic and financial access factors in shaping infant survival. Other studies conducted in other sub-Saharan African countries similarly attributed factors associated with infant survival to high-level maternal education, high household wealth index and utilisation of maternal health services during pregnancy and at birth.[32–34]

Counterintuitively, maternal employment was associated with an increased hazard of infant mortality, a finding that contrasts with conventional expectations of the protective effects of socioeconomic participation. This finding may reflect the challenges working mothers in Ghana face in balancing income generation with infant care.[35] Many women are engaged in informal or physically demanding occupations such as farming, trading or domestic labour, where maternity protections are limited, and working conditions often restrict exclusive breastfeeding and timely healthcare-seeking. Even in formal employment, rigid work schedules, inadequate maternity leave and limited workplace accommodations create barriers to consistent caregiving and breastfeeding. While employment can improve household income, which in theory should support better nutrition and access to healthcare, these benefits may be offset by time constraints, lack of affordable childcare and persistent gendered expectations of women's unpaid domestic responsibilities.

Healthcare utilisation factors were important. Early and adequate ANC attendance and postnatal care were associated with markedly better infant survival. Initiating ANC in the first trimester and completing at least four visits both reduced mortality risk, while receipt of postnatal care was also protective. These findings align with evidence that maternal contact with health services promotes birth preparedness and early problem detection.[36] The higher hazard of infant mortality among facility-delivered births likely reflects risk selection, whereby women experiencing pregnancy or delivery complications are more likely to seek institutional care. Thus, the observed association may represent confounding by indication rather than a causal effect of facility delivery on mortality.

Spatial disparities in infant mortality were pronounced, with clear evidence that contextual and structural factors substantially shape survival outcomes in Ghana. Our findings indicate that approximately one-fifth of the unexplained variation in infant mortality was attributable to regional-level effects, underscoring the importance of broader contextual influences beyond individual and household characteristics. Spatial cluster analyses further confirmed persistent geographic concentrations of high infant mortality in particular regions. Such clustering is likely driven by variations in the availability and quality of maternal and child health services: regions with fewer health facilities, limited numbers of skilled birth attendants, weak referral systems and logistical barriers face higher risks of infant deaths.[11 21 37 38]

Our finding reveals that the two northernmost regions, Upper East and Upper West, which were previously identified as having a higher distribution of infant mortality in earlier datasets, have exhibited notable improvements when assessed with later surveys, suggesting that concerted efforts in health system strengthening and policy implementation are yielding dividends. Central to this progress has been the revitalisation of community-based primary care through the CHPS model, particularly via the Ghana Essential Health Intervention Project (GEHIP), which demonstrated a reduction in infant mortality by accelerating CHPS expansion and reinforcing community-engaged emergency referrals.[39] Building on GEHIP's success, the CHPS-Plus initiative scaled these improvements across the entire Upper East Region by reactivating community health volunteers, improving referral systems with locally organised transport and providing equipment and leadership training across health service tiers. Additionally, the introduction and expansion of Ghana's Free Maternal Health Policy under the NHIS, particularly targeted at historically underserved regions like the Upper East and Upper West, played a vital role in reducing financial barriers to accessing care. This policy led to increased usage of ANC, facility-based delivery and skilled birth services, contributing to better maternal and infant health outcomes.[40 41] By contrast, other regions, particularly those in the middle and western parts, remain lagging due to the uneven rollout of CHPS and less targeted health policy support. Despite the national maternal fee-exemption policy, many mothers still face out-of-pocket expenses, especially in the western and Ashanti regions.[42] This ongoing burden stems from delayed reimbursements to facilities, frequent shortages of essential supplies and limited coverage of services, all of which have eroded the promise of comprehensive financial protection during pregnancy and childbirth.[43]

This study has several important strengths. First, by drawing on three rounds of nationally representative GDHS data, the analysis captures trends and patterns in infant mortality across different administrative boundaries and health policy periods in Ghana. The large sample size and broad geographic coverage ensure that findings are generalisable to the national population. A further strength is the integration of both individual-level determinants and spatially explicit measures, which allowed for a more comprehensive understanding of how infant mortality varies not only by maternal and infant characteristics but also across regions. The use of multiple geospatial outputs, such as KDE surfaces, spatial quantiles and cluster maps, provides a nuanced and policy-relevant depiction of geographic disparities. Another strength lies in the study's ability to incorporate a wide range of maternal, household and infant covariates, offering an in-depth perspective on the multifaceted determinants of infant mortality.

Nonetheless, certain limitations should be acknowledged. The GDHS surveys are cross-sectional in nature, which limits the ability to establish causality between risk factors and infant mortality. The reliance on maternal recall of birth histories, sometimes over long periods, introduces the potential for reporting errors or misclassification of survival times. While the intentional displacement of cluster GPS coordinates has minimal impact on regional-level analysis, it may reduce precision in detecting fine-scale spatial clusters. In this study, some maternal health service utilisation and child health covariates contained missing data and were imputed under the missing-at-random assumption, while the outcome and several key predictors were fully observed. If missingness in these partially observed covariates was related to unmeasured factors associated with infant mortality, the corresponding effect estimates may be biased, potentially attenuating observed associations. Although complete-case sensitivity analyses yielded broadly similar patterns of association, the possibility of residual bias due to non-random missingness cannot be entirely ruled out. Furthermore, some potentially important determinants of infant mortality, including quality of health services, cultural practices and environmental exposures, were not captured in the GDHS, leaving room for residual confounding.

Based on these findings, several recommendations emerge. First, maternal and child health policies should continue to prioritise high-risk regions, particularly those where clusters of elevated mortality remain, while also sustaining progress in regions that have shown improvement. Second, interventions should extend beyond health sector responses to address social determinants such as female education, economic empowerment and equitable access to health services. Third, spatially explicit analyses such as those employed in this study should be integrated into national monitoring systems to enable policymakers to identify emerging hotspots in real time and respond with targeted programmes. Finally, future research should explore community- and facility-level factors, including health service quality and environmental risks, which were not captured in the GDHS but are likely to shape infant mortality outcomes.

CONCLUSION

This study shows that infant mortality in Ghana is unevenly distributed and marked by clear geographic clustering, with patterns of risk varying substantially across the country. Although earlier survey rounds revealed consistently high-burden areas, more recent data indicate improvements in several previously affected locations, suggesting positive effects of targeted interventions and expanded maternal and child health initiatives. Beyond spatial disparities, the findings underscore the importance of maternal sociodemographic characteristics, including age, education and employment status, in shaping infant survival. In addition, maternal health service utilisation factors, as well as infant-level characteristics, emerged as particularly strong determinants of mortality.

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Acknowledgements The authors acknowledge the Ghana Statistical Service and the DHS programme for making the data available for this study

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Funding MJH is supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (No. 2022R1A2C1091488).

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval The data for this study were obtained from the DHS Programme. Ethical clearance for the original data collection was conducted by the ICF Institutional Review Board, which ensures compliance with US Department of Health and Human Services regulations (45 CFR 46). As this research involves only the secondary analysis of anonymised, publicly available data, it did not require further local institutional review. The primary contact for ethical oversight of the dataset is the ICF Institutional Review Board Administrator(irb@icf.com), Institutional Research Integrity Office (research.development@tth.gov.gh).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. The datasets used in this study are publicly available by registering the abstract and analysis plan at https://dhsprogram.com/data/available-datasets.cfm.

Author note The reflexivity statement for this paper is linked as an online supplemental file 2.

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