DOI http://dx.doi.org/10.20947/S0102-3098a0320

ORIGINAL ARTICLE

Under-five mortality and associated factors in India: an analysis at the district level

Emerson Augusto Baptista*
Subhojit Shaw**
Sampurna Kundu***

Under-five mortality refers to the death of a child before reaching the age of five. It is a critical indicator of child health and overall development within a country. In this study, we use data from the 2015-16 National Family Health Survey (NFHS) to estimate under-five mortality at the district level in India, considering a range of socioeconomic and demographic variables. We examined the association between these variables and under-five mortality using a Bayesian hierarchical model for 677 districts, employing the Integrated Nested Laplace Approximation (INLA) approach. Our findings indicate that excess under-five mortality is more prevalent in the northern and northeastern states of India. In addition, Hindu children and those born to literate mothers are less likely to die before reaching their fifth birthday. In contrast, higher risks of under-five mortality were observed among children from socially disadvantaged groups, those who were not exclusively breastfed, and those born in non-institutional settings. The results of this study underscore the urgent need for targeted strategies to reduce under-five mortality in India. Multiple factors – including biophysical conditions, sociodemographic disparities, and limited access to healthcare – must be addressed, not only through strengthening health infrastructure but also by promoting maternal education and reducing socioeconomic inequalities. Prioritizing the implementation of effective health policies and programs is essential for India to achieve the Sustainable Development Goal (SDG) target for under-five mortality and to safeguard the health of its youngest population across regions and demographic groups.

Keywords: Under-five mortality. Associated factors. India. Bayesian hierarchical model. Integrated Nested Laplace Approximation (INLA).

* El Colegio de México, Mexico City, Mexico (ebaptista@colmex.mx; https://orcid.org/0000-0001-7582-2736).
** International Institute for Population Sciences, Mumbai, India (subhojitshaw93@gmail.com; https://orcid.org/0000-0003-2612-3175).
*** University of Exeter, Exeter, United Kingdom (S.Kundu@exeter.ac.uk; https://orcid.org/0000-0002-6386-9040).

Introduction

Child mortality is a crucial indicator of a nation's healthcare system, sanitation, nutrition, and general socioeconomic conditions. High infant death rates frequently indicate a lack of healthcare resources, insufficient access to healthcare, and socioeconomic inequalities (Shaw; Sahoo, 2020; Chauhan *et al.*, 2023).

Over the past four decades of the 20th century, substantial global progress in child survival has been made, with mortality decreasing particularly in advanced economies (Ahmad *et al.*, 2000). The increase in life expectancy in these industrialized nations has been attributed to a good vital registration system, as well as to developments in medicine and the public health system (Kim; Saada, 2013). On the other hand, in low-income and lower-middle-income countries (World Bank, 2025), most deaths occur at home, in remote locations, and without the assistance of healthcare professionals (Dahab; Sakellariou, 2020). Consequently, key sources of knowledge regarding the causes of death were missed.

The 21st century continues to witness significant declines in child mortality in almost all countries worldwide, regardless of the initial socioeconomic status and development strategies (Case; Deaton, 2017). The United Nations Millennium Development Goal 4 (MDG 4, 1990-2015) (WHO, 2018) aimed to reduce child mortality, younger than five years, by two-thirds between 1990 and 2015, but many countries, especially in South Asia and sub-Saharan Africa, were substantially slower to reach the target (Bryce *et al.*, 2013). From 2015 onward, these targets were incorporated into the Sustainable Development Goals (SDG 3.2), which now guide global child survival efforts.

In 2015, the global average under-five mortality rate was 43.2 deaths per 1,000 live births. South Asia accounts for 3/10 of all 6.1 million global under-5 deaths, and India, the most populous country in this region, contributed to the highest number of deaths (1.1 million) among all countries in 2015 (WHO, 2023). Despite a reduction greater than 50% compared to 2000 (2.5 million), the current under-five mortality rates are still alarmingly high compared to those of other countries with similar socioeconomic conditions.

Over the past few decades, India has achieved considerable strides in lowering the infant and under-5 death rates. However, due to its enormous population and socioeconomic inequalities, it still faces difficulties. In India, the under-five mortality rate in 2015 was 43.57 per 1,000 live births. These figures represent a decline from 126.53 in 1990 and an improvement over the previous two decades (WHO, 2023). Efforts are still being made to accelerate the process of reducing child mortality with interventions to save lives and attain the SDG objective by 2030. Under-5 mortality rate in 2019-2021 was 42 per 1,000 live births according to the National Family Health Survey (NFHS-4) (IIPS, 2022). However, the SDG deadline is less than ten years away. Over and above, the state-level excessive variance is a major challenge. For example, the under-five mortality rate in the southern states of Kerala is as low as 5.2 per 1,000 live births, while the greatest under-5 mortality rate is 60 per 1,000 live births in the state of Uttar Pradesh in central India, demonstrating intermittent improvement and spatial inequality (Wahl *et al.*, 2023).

India's achievement in lowering under-5 mortality is crucial for reaching global health goals, notably those set in the Sustainable Development Goals (SDGs). Because India accounts for nearly one-fifth of the world's births, its progress has a disproportionate impact on global child mortality levels. High mortality rates indicate serious difficulties in protecting the rights and welfare of the youngest members of society. Thus, in this study, we use data from the 2015-16 National Family Health Survey (NFHS) to estimate under-five mortality at the district level in India, considering a range of socioeconomic and demographic variables. We examined the association between them and under-five mortality using a Bayesian hierarchical model for 677 districts based on the Integrated Nested Laplace Approximation (INLA) (Rue *et al.*, 2009). Estimates at the local level are particularly important when direct survey-based estimates are not reliable for all domains (such as districts) due to small sample sizes. The Bayesian hierarchical approach allows us to borrow strength across neighboring districts through spatially structured priors, producing smoothed and stable estimates even in areas with limited data. This is especially useful in the context of Indian districts, which vary widely in population size and survey sample density.

Material and data

Data source

This study utilizes two primary data sources: the National Family Health Survey (NFHS) and WorldPop (WorldPop, 2020).

The NFHS in India is conducted by the International Institute for Population Sciences (IIPS), under the guidance of the Ministry of Health and Family Welfare. The fourth round (NFHS-4) was implemented between January 20, 2015, and December 4, 2016. The survey employs a two-stage stratified sampling design, where primary sampling units (PSUs)[1] are selected using probability proportional to size (PPS), and households are selected systematically. Although the survey is representative at the state level, it does not guarantee adequate sample sizes for all districts, particularly in sparsely populated or hard-to-reach areas. In other words, NFHS was not designed to produce reliable direct estimates at the district level. Many districts have small sample sizes, resulting in high uncertainty in direct estimates of under-five mortality. This limitation motivates the use of model-based small area estimation techniques to improve the reliability of the estimates and allow for spatial comparisons.

For this study, the sample includes 259,627 children under five years of age, with all relevant variables aggregated at the district level to meet the study's objectives.

[1] In NFHS, primary sampling units (PSUs) are census enumeration blocks in urban areas and villages in rural areas, not districts.

The second data source, WorldPop, is a spatial database that provides high-resolution estimates of population distribution. The dataset is harmonized with official population figures from the United Nations Population Division (UNPD), Department of Economic and Social Affairs, and is available at a spatial resolution of 30 arc-seconds (approximately 1 km at the equator) (WorldPop, 2020).

Based on WorldPop data, the estimated total number of live births was approximately 26 million. These estimates were derived exclusively from WorldPop, which integrates national survey data (NFHS, 2015) with remote sensing imagery. Although WorldPop generates high-resolution estimates that are aligned with UN totals, some limitations persist, including the potential underestimation of populations in rapidly expanding peri-urban areas and the reliance on modeled fertility rates. Such uncertainties should be considered when interpreting the results. Furthermore, because the birth estimates are specific to 2015, more recent NFHS data were not used in order to maintain consistency with the reference year.

Measures

Dependent variable

The dependent variable in this study is under-five mortality, defined as the probability of dying between birth and before reaching five years of age. We used data on birth dates, survival status, and the age and date of death of children to apply direct estimation techniques for mortality rates. Our approach aligns with the method implemented through the "syncmrates" function in the Stata package, commonly used in DHS reports (Rutstein; Rojas, 2006). Specifically, we adopted the synthetic cohort probability approach based on full birth history data provided by women aged 15-49 years.

This method integrates age-specific death probabilities from actual cohort experiences into broader age segments to construct a synthetic cohort life table. It is period-specific and makes full use of the most recent data, providing a reliable measure of mortality (Bora; Saikia, 2018).

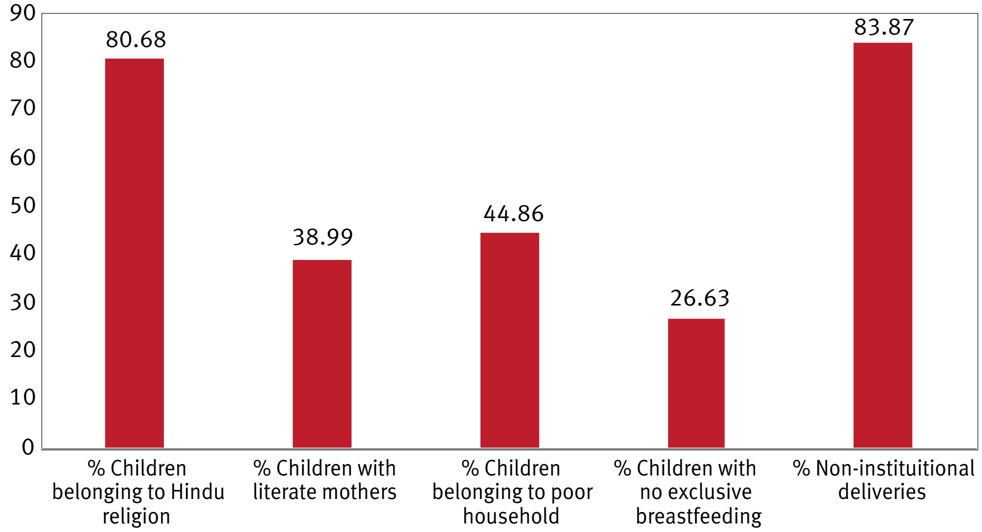
Covariates

The main covariates included in the study are religion, maternal literacy, household economic status, exclusive breastfeeding, and institutional delivery. The selection of these covariates is grounded in the extensive literature on under-five mortality in India and reflects key socioeconomic, cultural, and health-service pathways affecting child survival. Children born to literate mothers, those exclusively breastfed, and those delivered in institutional settings are expected to experience lower mortality risk, due to improved health knowledge, early-life nutrition, and access to skilled care. In contrast, household economic deprivation is expected to be associated with higher mortality, reflecting constraints in living conditions, nutrition, and timely access to healthcare. Religious affiliation is included as a contextual proxy for social and cultural heterogeneity linked to disparities in health behaviors and access to services, with the expected direction varying across settings. Overall, these variables capture both structural disadvantage and proximate determinants commonly associated with under-five mortality. All covariates were dichotomized (coded as 0 or 1) and aggregated at the district level using NFHS data. We acknowledge that this approach assumes district-level representativeness of survey-based predictors, an assumption that may not hold uniformly across all districts and is discussed as a study limitation.

Religion was categorized as Hindu or non-Hindu, the latter including Muslims, Christians, Buddhists, Parsis, Jains, and other religious groups. The education level or literacy of women was divided into two categories: no schooling and educated. Wealth quintile of households were grouped as poor (poorest and poorer) and non-poor (middle, richer and richest) (Mishra *et al.*, 2022). Children who were exclusively breastfed for at least six months were identified as exclusively breastfed. The place of delivery was categorized as institutional if the delivery took place in any public or private medical institutions.

The categories shown in Figure 1 – child belonging to the Hindu religion (80.7%), born to literate mothers (39%), belonging to the poor wealth index (44.9%), not exclusively breastfed (26.6%), and delivered in non-institutional settings (83.9%) – were coded as 1, and 0 otherwise.

FIGURE 1
Percentage of the study variables
India – 2015-2016



Source: Authors' based on NFHS-4 (2015-2016).

Methods

Standardized Mortality Ratio (SMR)

To provide a baseline comparison of mortality risk across Indian districts, we computed the Standardized Mortality Ratio (SMR), a commonly used indirect age-adjustment method. The SMR is defined as the ratio of observed to expected deaths and allows for standardized comparisons despite differing population structures (Court; Cheng, 1995). The SMR is defined in Eq. (1).

$$SMR_i = \frac{y_i}{E_i} \qquad (1)$$

$$E_i = r_s * n_i$$

Where y_i is the observed number of under-five deaths in district i (i = 1, 2, ..., 676, 677); and E_i is the expected number of deaths in district i calculated by applying the standard population mortality rate (r_s) to the population of district i (n_i). An SMR greater than 1 indicates excess mortality in the district. While informative, SMRs are limited in that they ignore spatial dependencies and are unstable in areas with small populations or rare events, potentially leading to misleading conclusions (Blangiardo *et al.*, 2013; Lawson *et al.*, 2000).

Bayesian hierarchical regression model

To overcome the limitations of SMR and enhance estimation accuracy, we implemented a Bayesian hierarchical spatial model using the Besag-York-Mollié (BYM) specification. This approach enables us to incorporate spatial structure and quantify area-level relative risk while smoothing local variability.

Under this framework, the observed count of under-five deaths in district i, y_i, is assumed to follow a Poisson distribution (Eq. 2):

$$y_i \sim Poisson(E_i\, \Theta_i) \qquad (2)$$

Where E_i is the expected number of deaths and θ_i is the relative risk in district i. The logarithm of the relative risk is modeled as (Eq. 3):

$$log\,(\Theta_i) = \beta_0 + u_i + v_i \qquad (3)$$

Here, β_0 is the overall intercept; u_i represents spatially structured random effects following an intrinsic conditional autoregressive distribution (iCAR), $u \sim ICAR\,(W,\sigma_u^2)$ (Besag *et al.*, 1991); and υ_i denotes spatially unstructured random effect, modelled using an exchangeable prior, $v_i \sim Normal\,(0,\sigma_u^2)$.

To investigate potential determinants of under-five mortality, we extended the model to include covariates (Eq. 4):

$$log\,(\theta_i) = \beta_0 + \beta_1\, x_{1i} + \beta_2\, x_{2i} + \beta_3\, x_{3i} + \beta_4\, x_{4i} + \beta_5\, x_{5i} + u_i + \upsilon_i \qquad (4)$$

The covariates x_1 through x_5 represent the percentage of Hindu children, literate mothers, children from socially deprived groups, children not exclusively breastfed, and children born outside of institutional settings, respectively. All variables were derived from NFHS-4 survey data. The coefficients β_s quantify the change in relative risk associated with a one-unit increase in each predictor. The spatial structure was defined using a Moore adjacency (queen contiguity) specification, whereby districts that share either a boundary or a vertex are considered neighbors. While this first-order specification captures local dependence, it may not adequately represent longer-range spatial interactions, which constitutes a limitation of our model.

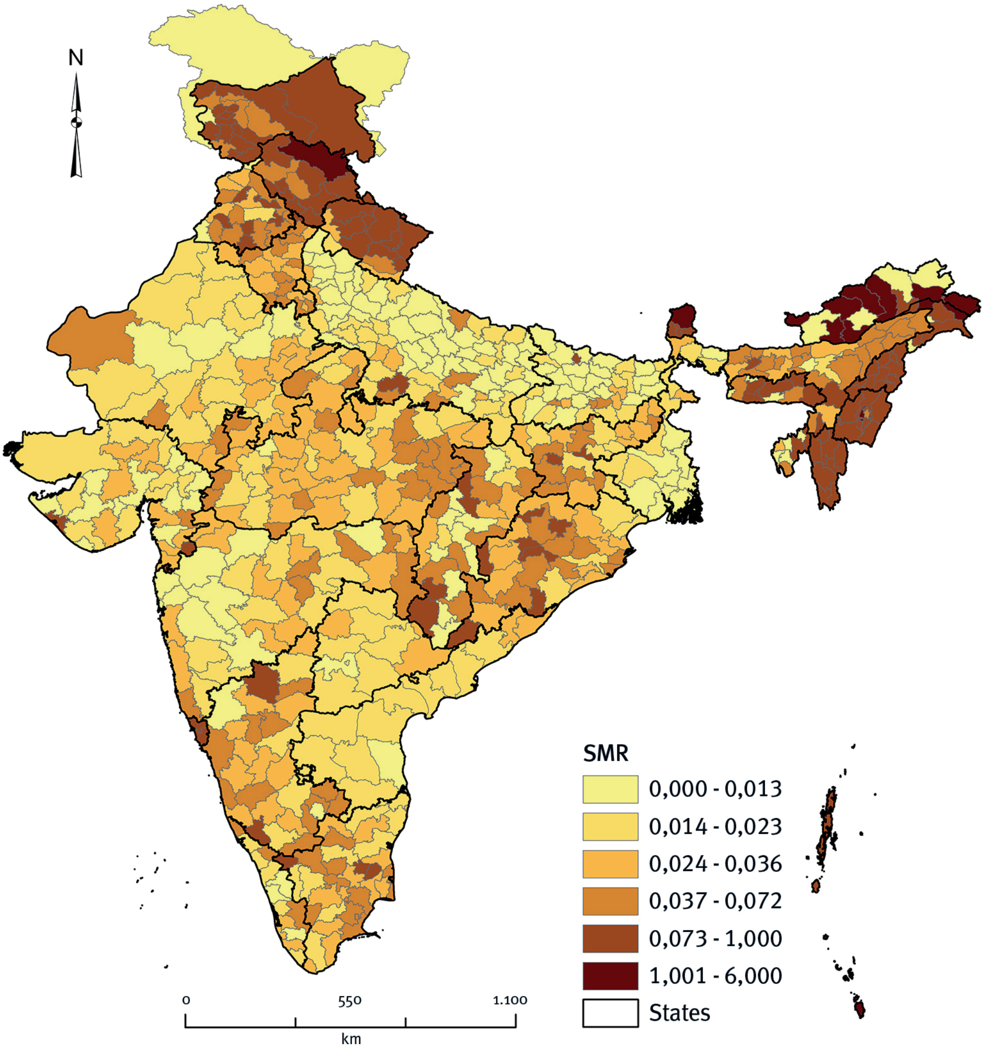
While the covariates are based on survey-derived district-level aggregates and may carry measurement error, these were treated as fixed effects in our analysis. Acknowledging this limitation, future work could incorporate measurement error modeling to further refine the estimates. All Bayesian computations were performed using the Integrated Nested Laplace Approximation (INLA) within the R-INLA package.

Results

Standardized Mortality Ratio (SMR)

Figure 2 shows the spatial distribution of SMR for 677 districts in India. Overall, excess mortality (>1) was more widespread in the northern and northeastern states of India. These regions are characterized by lower socioeconomic development, such as lack of education among mothers, poor economic status, absence of exclusive breastfeeding, no institutional deliveries (that might be due to challenging terrain), and limited access to healthcare facilities. The northeastern districts of East Kameng, West Siang, and Papum Pare, all in the Arunachal Pradesh and neighboring regions, have the highest under-five mortality rates. In contrast, the lowest SMR are recorded in the districts of Thane and Pune, in Maharashtra state and Allahabad, in Uttar Pradesh state.

FIGURE 2
Standardized Mortality Ratio (SMR) of under-five mortality, districts
India – 2015-2016



Source: Authors' estimates based on NFHS-4 (2015-2016) and WorldPop (2015).

Spatial model for under-five mortality

Table 1 presents the posterior estimates of the fixed effects (β_0, β_1, β_2, β_3, β_4, β_5) from the BYM model fitted using R-INLA. A one–percentage-point increase in the proportion of Hindu child population (β_1) is associated with a very small reduction in the risk of under-five mortality (approximately 0.2%). Similarly, a higher percentage of literate mothers (β_2) is associated with a reduction of approximately 2.2% in mortality risk per percentage-point increase; however, the corresponding 95% credible interval includes zero, indicating that this effect is not statistically robust after accounting for spatial dependence. In contrast, social disadvantage shows a strong and consistent association with mortality outcomes: a one–percentage-point increase in the proportion of children belonging to Scheduled Castes and Scheduled Tribes (β_3) is associated with an increase of approximately 1.6% in the risk of under-five mortality. Finally, higher proportions of children not exclusively breastfed (β_4) and non-institutional deliveries (β_5) are associated with small increases in mortality risk (approximately 0.6% and 0.4%, respectively).

TABLE 1
Posterior estimates (mean, SD, and 95% credible interval) of fixed effects in the BYM model for under-five deaths, districts
India – 2015-2016

Fixed effects	Mean	SD	2.5%	97.5%
β_1	-4.414	0.306	-5.015	-3.813
β_2	-0.002	0.002	-0.005	0.002
β_3	-0.022	0.026	-0.073	0.028
β_4	0.016	0.002	0.012	0.019
β_5	0.006	0.004	-0.003	0.014
β_6	0.004	0.003	-0.002	0.009

Source: Authors' estimates based on NFHS-4 (2015-2016) and WorldPop (2015).

Figures 3 and 4 show the spatial distribution of the posterior mean of the specific relative risks, $\varsigma_{it} = exp\,(u_i + \upsilon_i)$, and their posterior probability of exceeding 1, respectively. They should be interpreted as the residual RR for each district after the risk factors x_1, x_2, x_3, x_4 and x_5 are considered.

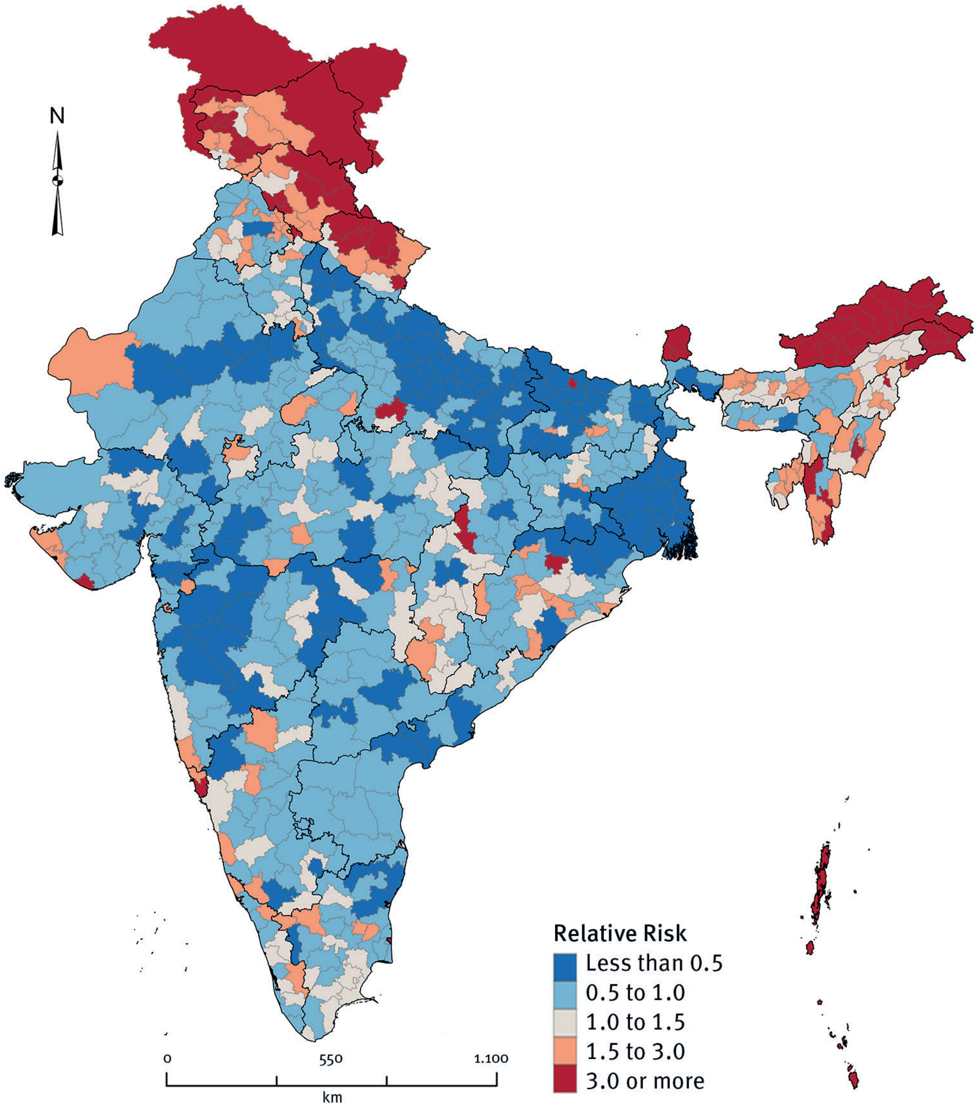
The posterior mean of the district-level relative risk of under-five mortality after covariate adjustment (Figure 3) reveals pronounced spatial heterogeneity across India. Districts with RR > 1 indicate a higher-than-expected risk of under-five mortality after accounting for sociodemographic characteristics, maternal literacy, infant feeding practices, delivery conditions, and spatial dependence, whereas districts with RR < 1 exhibit a lower-than-expected risk.

Even after adjustment, clusters of elevated relative risk (RR ≥ 1.5, and in some cases ≥ 3.0) persist, particularly in parts of northern India – including districts in Jammu and Kashmir, Himachal Pradesh, and Uttarakhand – as well as in northeastern areas such as Arunachal Pradesh and the Andaman and Nicobar Islands. These spatial concentrations suggest the presence of unobserved or residual contextual factors not fully captured by the covariates included in the model.

In contrast, large contiguous areas of central, western, and southern India display consistently lower relative risks (RR < 1), with several districts exhibiting substantially reduced risks (RR < 0.5). These patterns indicate that, after controlling for key socioeconomic and health-related determinants, under-five mortality risk remains systematically lower in these regions.

Overall, the adjusted posterior mean map highlights persistent spatial inequalities in under-five mortality across Indian districts, underscoring the importance of geographically targeted interventions and the potential role of contextual factors beyond individual- and household-level characteristics.

FIGURE 3
Posterior mean of district-level relative risk (RR) of under-five deaths after covariate adjustment
India – 2015-2016

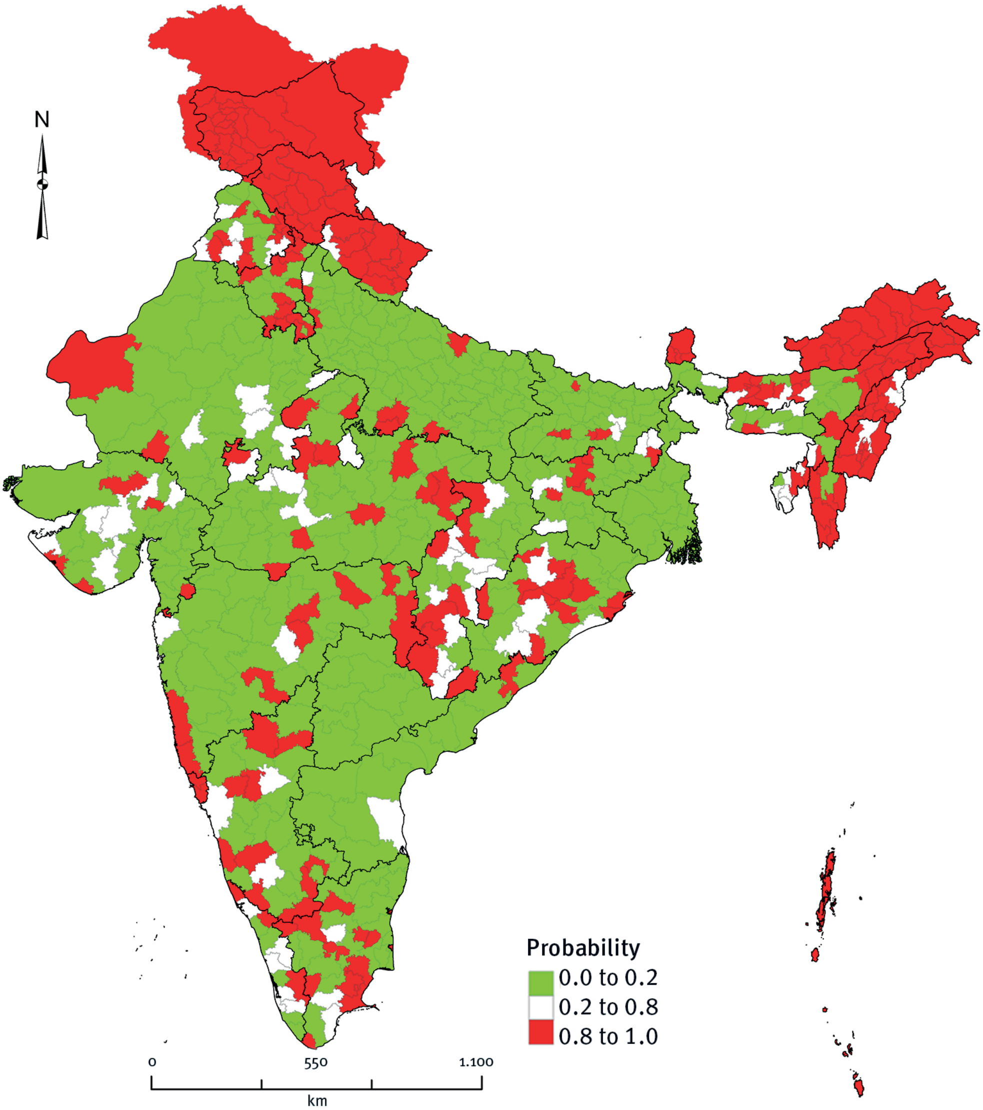


Source: Authors' estimates based on NFHS-4 (2015-2016) and WorldPop (2015).

Figure 4 displays the posterior probability that the district-level relative risk of under-five mortality exceeds one, $p(\varsigma_{it} > 1|y)$, after adjusting for covariates and spatial dependence.

This map highlights the degree of statistical certainty associated with elevated mortality risks across districts. Districts shown in red indicate high posterior probabilities ([$Pr(RR > 1|y)] \geq 0.8$), providing strong evidence of excess under-five mortality risk, whereas districts shown in green correspond to low probabilities ([$Pr(RR > 1|y)] \leq 0.2$), suggesting strong evidence of lower-than-expected risk. Districts in the intermediate category reflect greater uncertainty, where the data do not strongly support either elevated or reduced risk.

FIGURE 4
Posterior probability that district RR exceeds 1 [$Pr(RR > 1|y)$]
India – 2015-2016



Source: Authors' estimates based on NFHS-4 (2015-2016) and WorldPop (2015).

High posterior probabilities of excess risk are concentrated in northern India, particularly across districts in Jammu and Kashmir, Himachal Pradesh, and Uttarakhand, as well as in several districts of the northeastern states and the Andaman and Nicobar Islands. These areas exhibit a high degree of certainty that under-five mortality risk remains elevated even after accounting for observed covariates. In contrast, large parts of central, western, and southern India display low posterior probabilities, indicating strong evidence of reduced mortality risk relative to the national average. Overall, the probability map underscores pronounced spatial heterogeneity in the certainty of excess under-five mortality risk and reinforces the presence of persistent geographic inequalities beyond measured sociodemographic and health-related factors.

Discussion

The district-level estimation of under-five mortality in India provides new insights into the determinants of child survival. Hindu children and children of literate mothers are less likely to die before completing their 5th birthday. Previous studies from India have shown that literate mothers have a greater influence on child health through pathways of women's autonomy, psychosocial behavior, and health care utilization, which pay a significant role in reducing child mortality (Singh-Manoux *et al.*, 2008; Khan; Das, 2020). Conversely, the present study has shown that children from poor-deprived groups and children without exclusive breastfeeding and non-institutional delivery have shown higher risk of under-5 mortality rate. Research has shown that post-natal care, inaccessibility of prenatal, intrapartum, and postnatal care including skilled attendance, institutional delivery, and full immunization, play a crucial role in altering child health (Black *et al.*, 2013; Altman *et al.*, 2017; Singh *et al.*, 2022). Previous research has estimated that exclusive breastfeeding can reduce under-5 mortality rate, saving 800,000 lives every year in low- and middle-income countries (Black *et al.*, 2013; Sankar *et al.*, 2015). Both the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) recommend exclusive breastfeeding for the first 6 months of life (Sankar *et al.*, 2015). Although India has improved the status of exclusive breastfeeding practices from 66.7% (2015-2016) to 70.4% (2019-2021), certain populations still do not practice the WHO-recommended duration (Reddy *et al.*, 2023). Hence, targeted interventions must be adopted for various social strata.

While a large body of research has examined infant and under-five mortality in India using national, state-level, or region-specific analyses, many studies rely on descriptive rates or regression approaches that do not explicitly account for spatial dependence. This study advances the literature by providing a nationwide, district-level spatial analysis of under-five mortality that jointly models observed deaths and residual geographic risk. By applying a Bayesian spatial framework, we identify districts where excess mortality persists even after accounting for key socioeconomic characteristics and maternal and child health practices. This approach complements existing evidence by highlighting place-based vulnerabilities that are not fully explained by commonly used determinants, thereby extending prior regional and descriptive studies on child mortality in India.

This study reveals substantial spatial heterogeneity in under-five mortality across Indian districts even after adjusting for key sociodemographic, maternal, and healthcare-related covariates and accounting for spatial dependence. The adjusted posterior mean and probability maps indicate that elevated mortality risks persist in several districts – particularly in northern India, selected northeastern areas, and the Andaman and Nicobar Islands – suggesting the influence of unobserved contextual factors beyond those captured by the model. These findings are consistent with previous research highlighting the role of poverty, limited healthcare access, and suboptimal infant feeding practices in shaping child health outcomes in India (Kumar *et al.*, 2012; Puri *et al.*, 2020). Environmental issues such as poor water and sanitation, overcrowded living conditions, and cultural and behavioral factors like traditional practices and gender bias also contribute to under-five mortality (Panda *et al.*, 2020). Examples include Uttar Pradesh and Bihar, which have high under-five mortality rates due to high population density and malnutrition (Kumar *et al.*, 2012).

In addition to socio-demographic factors, biophysical factors impact under-5 mortality rate in India. Millions of child deaths in India have been attributed to biophysical factors such as pneumonia, preterm birth, low birth weight, diarrhea, neonatal infections, birth asphyxia, and other birth-related complications (Darmstadt *et al.*, 2005). Pneumonia, a serious respiratory illness, is one of the main causes and is often exacerbated by substandard housing and limited access to treatment (Mulholland, 2003). Low birth weight and preterm delivery also play major roles; premature babies are more vulnerable to various health issues and have undeveloped organs that may struggle to function properly outside the womb (Behrman *et al.*, 2007). Diarrhea, often caused by contaminated water and inadequate sanitation, is a leading cause of dehydration and mortality in young children (Mokomane *et al.*, 2018). Newborns, with their immature immune systems, are particularly vulnerable to infections such as sepsis and meningitis (Bundy *et al.*, 2024). Birth asphyxia, a condition where an infant does not receive enough oxygen before, during, or immediately following birth, also contributes significantly to high mortality rates (Golubnitschaja *et al.*, 2011). These biophysical factors, along with other birth-related complications, underscore the necessity for comprehensive medical measures to improve child survival.

Other studies have also highlighted social stigma and taboos, as sex differences in infant and child mortality have been observed in India due to social son preference, which negatively affects the survival of girls (Jha *et al.*, 2006; Mitra, 2014). Additionally, evidence indicates an association between child mortality and markers of socioeconomic status, affecting deprived social groups (Scheduled Caste), poor and uneducated people, and those living in rural households (Deshpande, 2001; Mohindra *et al.*, 2006; Subramanian *et al.*, 2006; Singh-Manoux *et al.*, 2008). In other words, there are significant spatial disparities alongside socioeconomic and demographic differences (Singh *et al.*, 2011). To reduce under-five mortality rates, efforts should focus on improving healthcare infrastructure, enhancing maternal education, ensuring better public health program implementation, and addressing socioeconomic inequalities. Tackling these issues can lead to significant progress in reducing under-five mortality rates in these regions.

However, there are some limitations to this study. First, due to the cross-sectional nature of the survey, spatial causality cannot be established. Second, we could not capture the maternal migration status during the survey. Third, there may be several unobserved factors that could not be included in the models. All these aspects must be addressed in future investigations.

Conclusion

The findings of this study contribute to the literature on under-five mortality in India by providing a nationwide, district-level spatial assessment that goes beyond descriptive and regional analyses. By jointly examining socioeconomic, maternal, and health-service factors within a spatial framework, the study highlights how structural disadvantages and place-based vulnerabilities shape persistent geographic inequalities in child mortality. These results emphasize the urgent need for targeted and context-specific approaches to reduce under-five mortality in India. Addressing biophysical risks, socio-demographic inequalities, and limited access to healthcare is essential not only to strengthen health systems but also to promote maternal education and reduce socioeconomic disparities. Through effective implementation of health policies and programs, India can accelerate progress toward achieving the SDG target of reducing under-five mortality and protecting the health of its youngest population across regions and social groups.

References

AHMAD, O. B.; LOPEZ, A. D.; INOUE, M. The decline in child mortality: a reappraisal. **Bulletin of the World Health Organization**, v. 78, n. 10, p. 1175-1191, 2000.

ALTMAN, R.; SIDNEY, K.; COSTA, A. de; VORA, K.; SALAZAR, M. Is institutional delivery protective against neonatal mortality among poor or tribal women? A cohort study from Gujarat, India. **Maternal and Child Health Journal**, v. 21, n. 5, p. 1065-1072, 2017.

BEHRMAN, R. E.; BUTLER, A. S. Mortality and acute complications in preterm infants. *In*: BEHRMAN, R. E.; BUTLER, A. S. (Ed.). **Preterm birth**: causes, consequences, and prevention. Washington, DC: National Academies Press, 2007.

BESAG, J.; YORK, J.; MOLLIÉ, A. Bayesian image restoration, with two applications in spatial statistics. **Annals of the Institute of Statistical Mathematics**, v. 43, n. 1, p. 1-20, 1991.

BLACK, R. E. *et al*. Maternal and child undernutrition and overweight in low-income and middle-income countries. **The Lancet**, v. 382, n. 9890, p. 427-451, 2013.

BLANGIARDO, M.; CAMELETTI, M.; BAIO, G.; RUE, H. Spatial and spatio-temporal models with R-INLA. **Spatial and Spatio-Temporal Epidemiology**, v. 4, p. 33-49, 2013.

BORA, J. K.; SAIKIA, N. Neonatal and under-five mortality rate in Indian districts with reference to Sustainable Development Goal 3: an analysis of the National Family Health Survey of India (NFHS), 2015-2016. **PLOS One**, v. 13, n. 7, e0201125, 2018.

BRYCE, J.; BLACK, R. E.; VICTORA, C. G. Millennium Development Goals 4 and 5: progress and challenges. **BMC Medicine**, v. 11, n. 1, p. 225, 2013.

BUNDY, L. M.; RAJNIK, M.; NOOR, A. Neonatal meningitis. **StatPearls**. Treasure Island: StatPearls Publishing, 2024. Available from: http://www.ncbi.nlm.nih.gov/books/NBK532264/

CASE, A.; DEATON, A. Mortality and morbidity in the 21st century. **Brookings Papers on Economic Activity**, v. 2017, p. 397-476, 2017.

CHAUHAN, B. G.; KUMAR, P.; KUNDU, S. Inequalities and effect of non-biological factors on perinatal mortality in Uttar Pradesh. **International Journal of Social Determinants of Health and Health Services**, v. 53, n. 3, p. 303-310, 2023.

COURT, B. V.; CHENG, K. K. Pros and cons of standardised mortality ratios. **The Lancet**, v. 346, n. 8987, p. 1432, 1995.

DAHAB, R.; SAKELLARIOU, D. Barriers to accessing maternal care in low income countries in Africa: a systematic review. **International Journal of Environmental Research and Public Health**, v. 17, n. 12, p. 4292, 2020.

DARMSTADT, G. L. *et al*. Evidence-based, cost-effective interventions: how many newborn babies can we save? **The Lancet**, v. 365, n. 9463, p. 977-988, 2005.

DESHPANDE, A. Caste at birth? Redefining disparity in India. **Review of Development Economics**, v. 5, n. 1, p. 130-144, 2001.

GOLUBNITSCHAJA, O. *et al*. Birth asphyxia as the major complication in newborns: moving towards improved individual outcomes by prediction, targeted prevention and tailored medical care. **The EPMA Journal**, v. 2, n. 2, p. 197-210, 2011.

IIPS; ICF. **National Family Health Survey (NFHS-4), 2015-16**: India. Mumbai: IIPS, 2017.

IIPS; ICF. **National Family Health Survey (NFHS-5), 2019-2020**. Mumbai: IIPS, 2022. Available from: http://rchiips.org/nfhs/NFHS-5Reports/NFHS-5_INDIA_REPORT.pdf.

JHA, P. *et al*. Low male-to-female sex ratio of children born in India. **The Lancet**, v. 367, n. 9506, p. 211-218, 2006.

KHAN, J.; DAS, S. K. The burden of anthropometric failure and child mortality in India. **Scientific Reports**, v. 10, n. 1, p. 20991, 2020.

KIM, D.; SAADA, A. The social determinants of infant mortality and birth outcomes in western developed nations: a cross-country systematic review. **International Journal of Environmental Research and Public Health**, v. 10, n. 6, 2013.

KUMAR, C.; SINGH, P. K.; RAI, R. K. Under-five mortality in high focus states in India: a district level geospatial analysis. **PLOS One**, v. 7, n. 5, e37515, 2012.

LAWSON, A. B. *et al*. Disease mapping models: an empirical evaluation. **Statistics in Medicine**, v. 19, n. 17-18, p. 2217-2241, 2000.

MISHRA, P. S. *et al*. Spatial inequalities in skilled birth attendance in India: a spatial-regional model approach. **BMC Public Health**, v. 22, n. 1, p. 79, 2022.

MITRA, A. Son preference in India: implications for gender development. **Journal of Economic Issues**, v. 48, n. 4, p. 1021-1037, 2014.

MOHINDRA, K. S.; HADDAD, S.; NARAYANA, D. Women’s health in a rural community in Kerala, India: do caste and socioeconomic position matter? **Journal of Epidemiology & Community Health**, v. 60, n. 12, p. 1020-1026, 2006.

MOKOMANE, M. *et al*. The global problem of childhood diarrhoeal diseases: emerging strategies in prevention and management. **Therapeutic Advances in Infectious Disease**, v. 5, n. 1, p. 29-43, 2018.

MULHOLLAND, K. Global burden of acute respiratory infections in children: implications for interventions. **Pediatric Pulmonology**, v. 36, n. 6, p. 469-474, 2003.

PANDA, B. K.; KUMAR, G.; AWASTHI, A. District level inequality in reproductive, maternal, neonatal and child health coverage in India. **BMC Public Health**, v. 20, n. 1, p. 58, 2020.

PURI, P. *et al.* A cross-sectional study on selected child health outcomes in India: quantifying the spatial variations and identification of the parental risk factors. **Scientific Reports**, v. 10, n. 1, p. 6645, 2020.

REDDY, N. S. *et al.* Exclusive breastfeeding practices and its determinants in Indian infants: findings from the National Family Health Surveys-4 and 5. **International Breastfeeding Journal**, v. 18, n. 1, p. 69, 2023.

RUE, H.; MARTINO, S.; CHOPIN, N. Approximate Bayesian inference for latent Gaussian models by using Integrated Nested Laplace Approximations. **Journal of the Royal Statistical Society: Series B**, v. 71, n. 2, p. 319-392, 2009.

RUTSTEIN, S. O.; ROJAS, G. **Guide to DHS statistics**. Calverton: ORC Macro, 2006.

SANKAR, M. J. *et al.* Optimal breastfeeding practices and infant and child mortality: a systematic review and meta-analysis. **Acta Pediatrica**, v. 104, suppl. 467, p. 3-13, 2015.

SHAW, S.; SAHOO, H. Accessibility to primary health centre in a tribal district of Gujarat, India: application of two step floating catchment area model. **GeoJournal**, v. 85, n. 2, p. 505-514, 2020.

SINGH-MANOUX, A. *et al.* Adult education and child mortality in India: the influence of caste, household wealth, and urbanization. **Epidemiology**, v. 19, n. 2, p. 294-301, 2008.

SINGH, A. *et al.* Infant and child mortality in India in the last two decades: a geospatial analysis. **PLOS One**, v. 6, n. 11, e26856, 2011.

SINGH, L. *et al.* Association between timing and type of postnatal care provided with neonatal mortality: a large scale study from India. **PLOS One**, v. 17, n. 9, e0272734, 2022.

SUBRAMANIAN, S. V. *et al.* The mortality divide in India: the differential contributions of gender, caste, and standard of living across the life course. **American Journal of Public Health**, v. 96, n. 5, p. 818-825, 2006.

WAHL, B. *et al.* Neonatal, infant, and child mortality in India: progress and future directions. **Indian Journal of Pediatrics**, 2023.

WHO. **Millennium Development Goals (MDGs)**. Geneva: World Health Organization, 2018. Available from: https://www.who.int/news-room/fact-sheets/detail/millennium-development-goals-(mdgs)

WHO. **Under-five mortality rate (SDG 3.2.1)**. Geneva: World Health Organization, 2023. Available from: https://www.who.int/data/gho/data/indicators/indicator-details/GHO/under-five-mortality-rate-(probability-of-dying-by-age-5-per-1000-live-births)

WORLDPOP. **Global 1km population total adjusted to match the corresponding UNPD estimate**. Southampton: University of Southampton, 2020.

WORLD BANK. **World Bank country and lending groups**. Washington, DC, 2025. Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

About the authors

Emerson Augusto Baptista holds a PhD in Demography from the Universidade Federal de Minas Gerais (CEDEPLAR/UFMG, Brazil) and a Master's degree in Geography. He completed a postdoctoral fellowship at Brown University (USA), at the Institute at Brown for Environment and Society. He is currently Professor-Researcher at the Center for Demographic, Urban and Environmental Studies (CEDUA), El Colegio de México, and a National Researcher (Level II) in the Sistema Nacional de Investigadores (SNI) of SECIHTI.

Subhojit Shaw holds a PhD in Population Studies from the International Institute for Population Sciences and an MSc (Gold Medalist). He is currently a Consultant at the National Institute of Disaster Management (NIDM) under the NPCCHH project, funded by the National Centre for Disease Control (NCDC), Ministry of Health and Family Welfare (MoHFW), Government of India.

Sampurna Kundu is a Postdoctoral Research Fellow in Epidemiology in the Department of Psychology, Faculty of Health and Life Sciences, at the University of Exeter. She holds a PhD in Social Medicine and Community Health from Jawaharlal Nehru University, New Delhi, India, an MPhil in Biostatistics and Demography from the International Institute for Population Sciences, Mumbai, India, and an MSc in Biostatistics and Demography from the same institution.

Contact address

Emerson Augusto Baptista
El Colegio de México, Carretera Picacho Ajusco 20, Col. Ampliación Fuentes del Pedregal
C.P. 14110 Tlalpan, Mexico City, Mexico

Subhojit Shaw
International Institute for Population Sciences, Department of Development Studies,
Mumbai 10 400088, India.

Sampurna Kundu
University of Exeter, Department of Psychology, Faculty of Health and Life Sciences,
Washington Singer Laboratories, Perry Road, Exeter, Devon, EX4 4QG, United Kingdom

CRediT

Funding: Not applicable.
Conflicts of interest: The authors certify that they have no personal, commercial, academic, political or financial interest that represents a conflict of interest in relation to the manuscript.
Ethical Approval: The authors declare that the study did not include human beings or animals.
Availability of data and material: After publication, the data will be available on demand to the authors – a condition justified in the manuscript
Authors' contributions:
Emerson Augusto Baptista: conceptualization; data curation; formal analysis; investigation; methodology; software; supervision; visualization; writing – review & editing
Subhojit Shaw: conceptualization; data curation; formal analysis; investigation; writing – original draft.
Sampurna Kundu: conceptualization; data curation; formal analysis; investigation; writing – original draft.
Editors: Bernardo Lanza Queiroz, Júlia Almeida Calazans and Maria Carolina Tomás

Resumo

Mortalidade em crianças menores de cinco anos e fatores associados na Índia: uma análise em nível distrital

A mortalidade em menores de cinco anos refere-se ao óbito de uma criança antes de completar esta idade. Trata-se de um indicador fundamental para compreender a saúde infantil e o nível de desenvolvimento de um país. Neste estudo, utilizamos dados da Pesquisa Nacional de Saúde da Família (NFHS, na sigla em inglês) de 2015-2016 para estimar a mortalidade em crianças menores de cinco anos a nível distrital na Índia, considerando uma série de variáveis socioeconômicas e demográficas. Examinamos a associação entre essas variáveis e a mortalidade em crianças menores de cinco anos utilizando um modelo hierárquico bayesiano para 677 distritos, empregando a abordagem de Integrated Nested Laplace Approximation (INLA). Os resultados indicam que a mortalidade em crianças menores de cinco anos é mais elevada nos estados do norte e nordeste da Índia. Além disso, crianças hindus e aquelas cujas mães são alfabetizadas têm menor probabilidade de morrer antes de completar cinco anos. Por outro lado, riscos mais elevados de mortalidade foram observados entre crianças pertencentes a grupos socialmente desfavorecidos, que não foram amamentadas ou que nasceram fora de instituições de saúde. Os resultados deste estudo ressaltam a necessidade urgente de estratégias direcionadas para enfrentar a mortalidade em crianças menores de cinco anos na Índia. Uma série de fatores, tais como condições biofísicas, desigualdades sociodemográficas e acesso limitado aos serviços de saúde, deve ser considerada não apenas para fortalecer a infraestrutura de saúde, mas também para promover a educação materna e reduzir as desigualdades socioeconômicas. A prioridade na implementação de políticas e programas de saúde eficazes é essencial para que a Índia atinja a meta dos Objetivos de Desenvolvimento Sustentável (ODS) de reduzir a mortalidade infantil e proteger a saúde de sua população mais jovem em diferentes regiões e grupos demográficos.

Palavras-chave: Mortalidade em crianças menores de cinco anos. Fatores associados. Índia. Modelo hierárquico bayesiano. Integrated Nested Laplace Approximation (INLA).

Resumen

Mortalidad en niños menores de cinco años y factores asociados en India: un análisis a nivel distrital

La mortalidad en menores de cinco años se refiere al fallecimiento de un niño o niña antes de alcanzar dicha edad. Es un indicador fundamental para comprender la salud infantil y el nivel de desarrollo de un país. En este estudio, utilizamos datos de la Encuesta Nacional de Salud Familiar (NFHS, por sus siglas en inglés) de 2015–2016 para estimar la mortalidad en niños menores de cinco años a nivel distrital en India, considerando una serie de variables socioeconómicas y demográficas. Examinamos la asociación entre estas variables y la mortalidad en niños menores de cinco años utilizando un modelo jerárquico bayesiano para 677 distritos, empleando el enfoque de Integrated Nested Laplace Approximation (INLA). Nuestros resultados indican que el exceso de mortalidad en niños menores de cinco años es más prevalente en los estados del norte y noreste de India. Además, los niños hindúes y aquellos cuyas madres saben leer y escribir tienen menos probabilidades de morir antes de cumplir cinco años. Por otro lado, se observaron mayores riesgos de mortalidad entre niños pertenecientes a grupos socialmente desfavorecidos, que no fueron amamantados o que nacieron fuera de instituciones de salud. Los resultados de este estudio destacan la necesidad urgente de implementar estrategias específicas para enfrentar la mortalidad infantil en India. Una variedad de factores —como las condiciones biofísicas, las desigualdades sociodemográficas y el acceso limitado a los servicios de salud— deben ser considerados no solo para fortalecer la infraestructura sanitaria, sino también para promover la educación materna y reducir las desigualdades socioeconómicas. Priorizar la implementación de políticas y programas de salud eficaces es esencial para que India logre la meta de los Objetivos de Desarrollo Sostenible (ODS) relacionada con la reducción de la mortalidad infantil y la protección de la salud de su población más joven en las distintas regiones y grupos demográficos.

Palabras clave: Mortalidad en niños menores de cinco años. Factores asociados. India. Modelo jerárquico bayesiano. Integrated Nested Laplace Approximation (INLA).

Received for publication in 04/07/2025
Approved for publication in 16/01/2025