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Determinants of infant mortality in India: A cross sectional state-level analysis

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Abstract
Infant Mortality Rate (IMR) is widely regarded as a key indicator of a country's health status and socioeconomic development. This study examines the determinants of IMR across Indian states, focusing on maternal anaemia, maternal undernutrition (low BMI), female literacy rate, per capita State Gross Domestic Product (GSDP), and hospital availability. Using state-level data from the Handbook of Statistics on Indian States (2020) and population projections from the Registrar General of India (2021) [26], a log-linear regression model is estimated for 27 states, incorporating a state-specific dummy variable to capture unobserved regional heterogeneity. The results reveal that maternal anaemia and low BMI significantly increase IMR, while female literacy rate and per capita State GSDP exert strong and statistically significant negative effects, underscoring the protective role of women's education and income-related socioeconomic development. In contrast, hospital availability per 10,000 population shows a positive and significant association with IMR, suggesting a reactive pattern of healthcare infrastructure expansion in high-mortality states rather than a purely preventive effect. Overall, the findings highlight that sustained reductions in infant mortality in India require integrated strategies that improve maternal nutrition and female education, raise income levels, and enhance the quality and effectiveness of healthcare services, rather than relying solely on the expansion of physical health infrastructure.

Keywords: Infant mortality rate, maternal anaemia, female literacy, state GSDP, healthcare infrastructure

Introductions
Infant Mortality Rate (IMR) serves as a key indicator of a nation's health and overall socioeconomic development. In India, despite notable improvements in public health infrastructure, substantial inter-state disparities in IMR persist, largely reflecting differences in maternal health, education, income levels, and access to effective healthcare services. Maternal anaemia and maternal undernutrition, commonly measured through low body mass index (BMI), are critical biological risk factors that elevate the likelihood of low birth weight, preterm births, and neonatal mortality (BMJ Global Health, 2025; BMC Pregnancy & Childbirth, 2023) [24]. Socioeconomic conditions, particularly female literacy, play a central role in shaping infant survival by improving women's awareness of reproductive health, enhancing healthcare-seeking behaviour, strengthening autonomy in household decision-making, and promoting better hygiene and childcare practices (Journal of Family Medicine & Primary Care, 2019). In addition, per capita State Gross Domestic Product (GSDP) serves as an important indicator of economic development and fiscal capacity, influencing household living standards as well as a state's ability to finance and deliver public health services (Economic & Political Weekly, 2020). However, evidence suggests that greater hospital availability alone does not necessarily translate into lower IMR when healthcare quality, distribution, and equitable access remain inadequate (Health Policy and Planning, 2019) [25]. Recognising the role of unobserved regional characteristics, this study incorporates a state-specific dummy variable to capture structural and contextual heterogeneity across states. Against this backdrop, the study empirically examines how maternal health, female education, economic development, and healthcare infrastructure jointly determine variations in IMR across Indian states, offering policy-relevant insights for targeted interventions aimed at reducing infant mortality and advancing health equity.

Literature review

This study investigates the determinants of infant mortality across Indian states using a log- linear specification that jointly considers maternal health, human capital, public health investment, healthcare infrastructure, and state-specific heterogeneity. The results reinforce a central insight from health economics and population health research which states that the biological vulnerability and social determinants exert stronger and more systematic effects on infant mortality than infrastructure expansion alone, particularly in cross-sectional state-level settings.

Maternal Anaemia and Infant Mortality

The positive and highly significant coefficient on maternal anaemia confirms its role as a critical proximate determinant of infant mortality. This finding aligns closely with cohort-based Indian evidence. Nair *et al.* (2016) [15], using data from Assam, demonstrate that moderate and severe anaemia substantially increase the risk of low birth weight, small-for-gestational-age births, postpartum haemorrhage, and perinatal mortality, even after adjusting for confounders. These results support the interpretation that anaemia affects infant survival through direct physiological pathways, particularly impaired oxygen delivery and placental insufficiency.

Regional synthesis further strengthens this conclusion. A South Asia focused meta-analysis by Rahman *et al.* (2020) [14] reports significantly higher odds of preterm birth, low birth weight, and perinatal mortality among anaemic mothers, while an India-specific scoping review by Benavente *et al.* (2025) [13] documents consistently adverse birth outcomes across diverse settings. The robustness of the anaemia coefficient in the present model suggests that maternal anaemia is not merely a proxy for poverty or weak health systems, but a biologically embedded driver of infant mortality, underscoring the importance of nutrition and haemoglobin focused maternal interventions.

Maternal undernutrition, proxied by low BMI, also exhibits a positive and statistically significant association with infant mortality. This finding is consistent with evidence that chronic energy deficiency compromises fatal growth and neonatal resilience. Ambreen *et al.* (2024) show that underweight women face significantly higher risks of delivering low-birth- weight and SGA infants, a pattern widely observed across South Asia.

Importantly, the simultaneous significance of anaemia and low BMI in the regression indicates that these variables capture distinct but complementary dimensions of maternal health. While anaemia reflects micronutrient deficiency, low BMI captures long-term macronutrient deprivation. This reinforces earlier arguments that infant mortality is shaped by multiple nutritional pathways rather than a single indicator. Indian evidence reviewed by Benavente *et al.* (2025) [13] similarly highlights that undernourished mothers are more likely to give birth to biologically vulnerable infants, contributing to persistent mortality differentials across regions.

Female Literacy and Infant Mortality

The strong and statistically significant negative coefficient on female literacy highlights education as a key structural determinant of infant survival. This result is consistent with demographic and public-health evidence from India. Using NFHS data, Moradhvaj and Samir (2023) [23] demonstrate that maternal education significantly reduces under-five mortality and explains a substantial share of rural-urban mortality differentials once compositional factors are controlled.

Ecological analyses further show that female literacy outperforms income and infrastructure variables in explaining inter-state variation in infant mortality (Mukherjee *et al.*, 2019) [18]. The persistence of the literacy effect in the present model, even after controlling for maternal health, public spending, and hospital availability, suggests that female education operates through behavioural, informational, and institutional channels including improved care- seeking, hygiene practices, and utilisation of maternal-child health services rather than merely reflecting economic status.

Public Health Expenditure and Infant Mortality

The negative and significant coefficient on per capita public health expenditure indicates that higher state-level investment contributes to lower infant mortality. This finding is consistent with cross-country evidence showing that health expenditure and workforce capacity are more closely aligned with improved population health outcomes than infrastructure alone (Kittipittayakorn, 2025) [17].

Indian studies similarly suggest that public health spending reduces infant mortality by expanding access to antenatal care, institutional delivery, and neonatal services, though the magnitude of impact depends on governance quality and effective allocation. The present result supports an enabling interpretation which indicates that the public spending lowers infant mortality insofar as it strengthens service delivery and preventive care, rather than through expenditure increases per se.

Hospital Availability and Infant Mortality

A key result of the analysis is the positive and statistically significant association between hospital availability per 10,000 population and infant mortality. This finding does not imply that hospitals worsen outcomes; rather, it reflects a reactive pattern of infrastructure expansion. States with persistently high infant mortality are more likely to invest in hospital capacity, generating a positive association in cross-sectional data.

This interpretation is well supported in the literature. Mukherjee and Sudha (2019) [18] argue that hospital expansion often follows disease burden rather than preventing it. Cross-country evidence by Kittipittayakorn (2025) [17] similarly finds that while health expenditure and workforce density reduce infant mortality, hospital beds may show weak or even positive associations due to inefficiencies or concentration in high-burden regions. Micro-level studies further demonstrate that facility functionality matters more than mere availability: Sabde *et al.* (2018) [1] document widespread bypassing of weak public facilities, while Tekeba *et al.* (2024) [19] show that early discharge after delivery limits postnatal monitoring. Together, these findings support the interpretation that infrastructure without quality and continuity of care has limited mortality-reducing potential.

State-Specific Structural Heterogeneity

The inclusion of a state-specific dummy variable captures unobserved regional characteristics influencing infant mortality beyond measured covariates. The significance of this control suggests that factors such as historical

deprivation, demographic composition, and governance capacity play an important role in shaping IMR across states. Evidence from Indian regional studies indicates strong path dependence in health outcomes, with certain states persistently underperforming despite improvements in individual indicators.

Accounting for such heterogeneity improves model specification and reduces omitted- variable bias, strengthening confidence in the estimated effects of maternal health, literacy, expenditure, and infrastructure variables.

Overall, the results are consistent with existing literature in showing that maternal anaemia and undernutrition act as proximate biological risks, female literacy and public health expenditure function as upstream protective determinants, and hospital availability affects infant mortality only when accompanied by quality and effective service delivery. The findings imply that policies focused solely on expanding hospital capacity are unlikely to achieve sustained reductions in infant mortality unless complemented by targeted investments in maternal nutrition, female education, and the functional strength of public health systems.

Objective of the Study: The primary objective of this study is to examine the key determinants of infant mortality across Indian states by analysing the relative influence of maternal health conditions, female educational attainment, public health investment, and healthcare infrastructure availability, while also accounting for state-specific structural heterogeneity. Specifically, the study assesses how maternal anaemia, female literacy rate, hospital availability per 10,000 population, and per capita public health expenditure shape variations in the Infant Mortality Rate (IMR) across states in India.

To achieve this objective, the study employs a log-linear regression framework that enables the estimation of the elasticity of IMR with respect to key explanatory variables. This approach facilitates a comparative assessment of the relative importance of maternal, social, and health-system factors in determining infant survival outcomes. The inclusion of a state-specific dummy variable allows the model to account for unobserved regional characteristics, including historical deprivation, governance capacity, and demographic composition, which may systematically influence infant mortality beyond observable covariates.

Using recent and reliable secondary data drawn from the Handbook of Statistics on Indian States (2020), NFHS-5 (2019-21), population projections from the Registrar General of India (2021) [26], and the Population Census of 2011, the study seeks to generate evidence-based insights that can inform targeted and region-sensitive policy interventions. By integrating maternal health, female education, public health expenditure, and healthcare infrastructure within a unified empirical framework, the analysis aims to contribute to policy discussions on reducing infant mortality and strengthening health equity across Indian states.

Hypothesis

1. Does maternal anaemia significantly increase infant mortality across Indian states?
2. Does higher female literacy reduce infant mortality by improving maternal knowledge and health-seeking behaviour?
3. Does greater public health expenditure contribute to lower infant mortality through improved maternal and child health services?
4. Is hospital availability associated with infant mortality in a way that reflects healthcare demand rather than direct mortality reduction?
5. Do structurally disadvantaged states exhibit persistently higher infant mortality even after accounting for maternal health, literacy, and health-system factors?

Data and Source: This study is based on secondary data compiled from multiple authoritative and nationally representative sources to ensure reliability, comparability, and policy relevance. State-level indicators on infant mortality, healthcare infrastructure, and public health expenditure are primarily drawn from the Handbook of Statistics on Indian States (2020), published by the Reserve Bank of India, which provides systematically compiled and officially validated state- wise statistics.

Information on maternal health and female literacy is obtained from the National Family Health Survey (NFHS-5, 2019-21), a large-scale, nationally representative household survey conducted under the stewardship of the Ministry of Health and Family Welfare. NFHS-5 offers robust and standardized measures of maternal anaemia, female literacy, and related health indicators, allowing for meaningful inter-state comparisons. Population projections used to standardize health infrastructure indicators are sourced from the Registrar General of India (2021) [26], while baseline demographic structures are taken from the Population Census of India (2011).

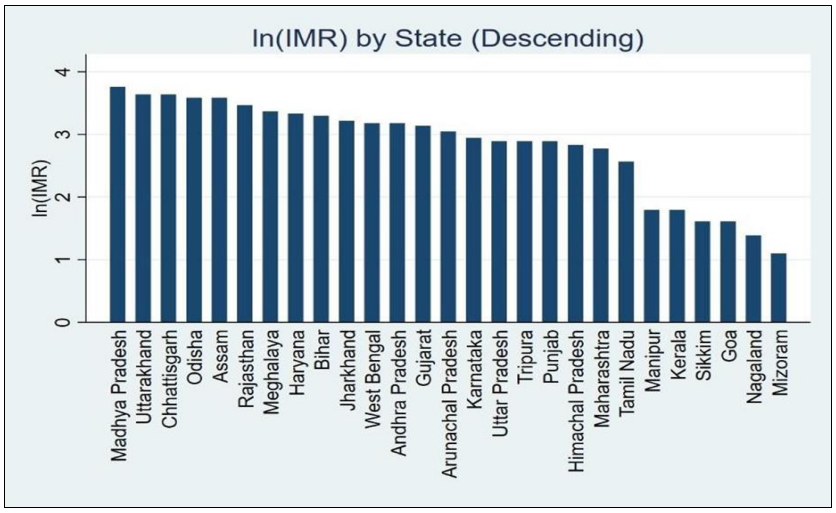
The integration of these datasets enables the construction of a comprehensive state-level analytical framework that captures biological, social, economic, and health-system dimensions of infant mortality. By combining survey-based health indicators with administrative and macroeconomic data, the study enhances empirical validity and reduces reliance on any single data source. This multi-source approach strengthens the credibility of the findings and supports the development of targeted, region-sensitive policy insights aimed at reducing infant mortality and advancing health equity across Indian states.

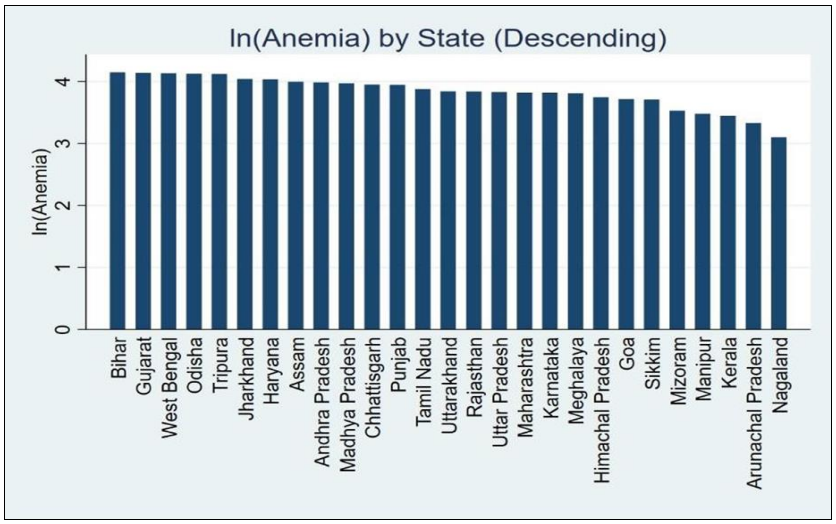
Methodology and Model Specification

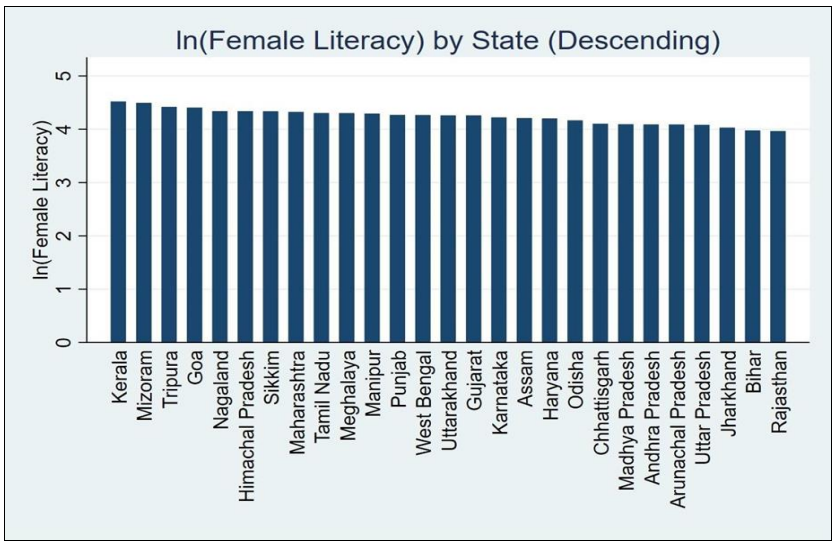
$\ln(IMR_i) = \beta_0 + \beta_1 \ln(Anemic_i) + \beta_2 \ln(SW\_FLR_i) + \beta_3 HospitalAvailability_i + \beta_4 PublicHealthExp_i + \beta_5 D\_Jharkhand_i + u_i$ Where

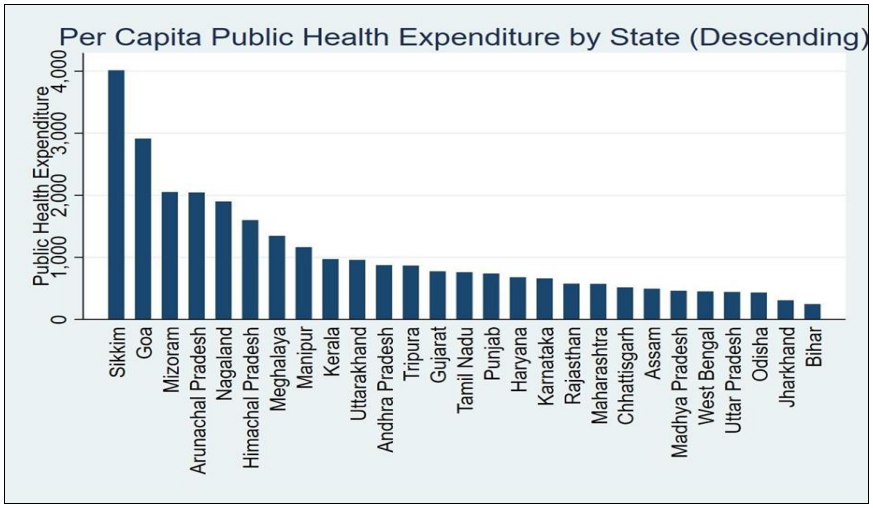
- ln (IMRi)= Natural logarithm of Infant Mortality Rate in state *i*
- Anemici = Percentage of anaemic pregnant women in state *i*
- SW_FLRi= Percentage of women with schooling (female literacy indicator) in state *i* HospitalAvailabilityi= Hospitals per 10,000 population in state *i* PublicHealthExpi= State-wise per capita public health expenditure
- DJharkhand,i= Dummy variable (1 = Jharkhand, 0 = otherwise)
- ui= Error term
- indexes Indian states

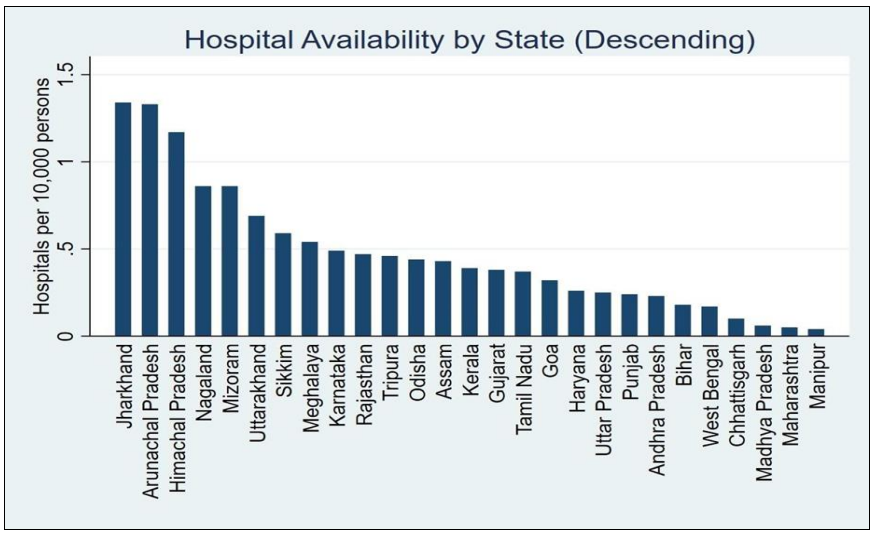
The relationship between infant mortality and key socio-economic and health system determinants across Indian states is examined using the log-linear regression model where the dependent variable is the natural logarithm of the infant mortality rate in state i. The explanatory variables include the prevalence of anaemia among women as a proxy for maternal nutritional status, the proportion of women with schooling capturing female educational attainment, hospital availability per 10,000 population representing health infrastructure, and state-wise per capita public health expenditure reflecting government investment in health services. A state-specific dummy variable for Jharkhand is included to account for persistent structural and developmental disadvantages unique to the state. The error term captures unobserved state-level factors influencing infant mortality. The model is estimated using Ordinary Least Squares (OLS) on cross-sectional state-level data, and logarithmic transformation of selected variables allows coefficient interpretation in elasticity terms while mitigating heteroskedasticity concerns.











Regression Results

Variable name	Coefficient	P-value	Significance
ln_anemic	1.4675	0.000	***
ln_sw_flr	−2.1663	0.001	***
Hospital availability per 10000 pers	0.7294	0.015	**
State wise per capita public health ex	−0.000338	0.006	***
d_jh	−1.3065	0.014	**
Constant	6.4513	0.045	**
F	18.79	0.000	
R Square	0.8173		
Adjusted R Square	0.7738		

Correlation Matrix

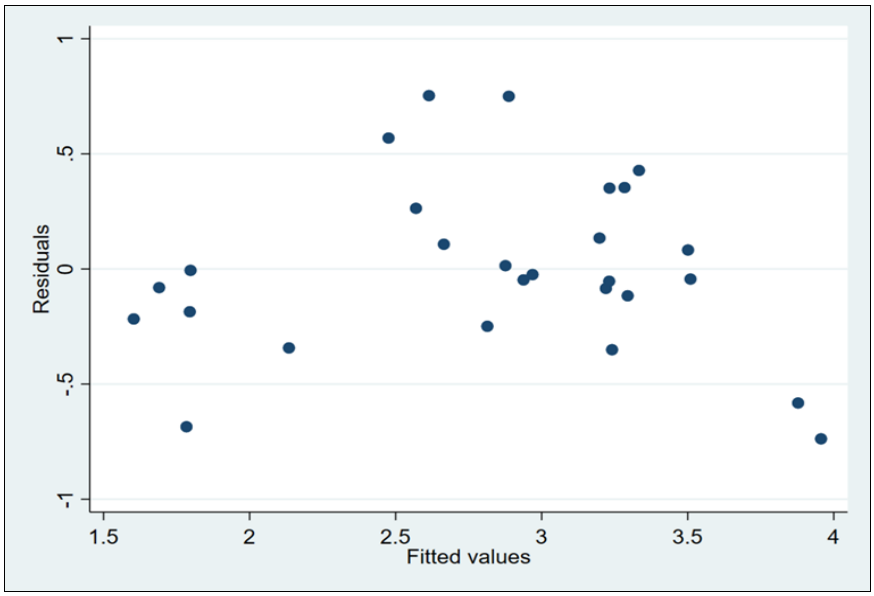
```
. correlate ln_imrin2020 ln_anemic ln_sw_flr hospitalavailabilityper10000pers statewisepercapitapublichealthex d_jh
(obs=27)

             | ln_~2020 ln_ane~c ln_s~flr hospit~s statew~x     d_jh
-------------+------------------------------------------------------
ln_imrin2020 |   1.0000
  ln_anemic  |   0.6977   1.0000
  ln_sw_flr  |  -0.6882  -0.3883   1.0000
hospitalav~s |  -0.1507  -0.3842   0.0370   1.0000
statewisep~x |  -0.6891  -0.5614   0.4757   0.3416   1.0000
       d_jh  |   0.1005   0.1574  -0.2809   0.4768  -0.1746   1.0000
```

Test Results VIF, BPG

```
. estat vif

    Variable |       VIF       1/VIF
-------------+----------------------
hospitalav~s |      1.97    0.508200
statewisep~x |      1.81    0.553758
   ln_anemic |      1.73    0.576502
        d_jh |      1.71    0.586350
   ln_sw_flr |      1.41    0.710529
-------------+----------------------
    Mean VIF |      1.72

.
```

```
. estat hettest

Breusch-Pagan/Cook-Weisberg test for heteroskedasticity
Assumption: Normal error terms
Variable: Fitted values of ln_imrin2020

H0: Constant variance

    chi2(1) =   0.12
Prob > chi2 = 0.7320

.
```

Graph of Residuals



Discussion of the Results: The regression analysis examines the determinants of Infant Mortality Rate (IMR) across 27 Indian states using an ordinary least squares framework. The model demonstrates strong overall performance, with a high joint significance (F-statistic significant at the 1 per cent level) and substantial explanatory power, accounting for over 80 per cent of inter-state variation in infant mortality. The relatively low Root Mean Square Error indicates that the model captures the underlying variation in IMR with reasonable precision. Taken together, the results suggest that maternal health risks, female human capital, public health investment, healthcare infrastructure patterns, and state-specific structural factors jointly influence infant mortality outcomes in India.

A key finding of the analysis is the positive and highly significant association between maternal anaemia and infant mortality. The estimated coefficient ($\beta \approx 1.47$, $p<0.001$) implies that a 1 per cent increase in maternal anaemia is associated with approximately a 1.5 per cent increase in IMR, holding other factors constant. This magnitude is both statistically and economically meaningful. The result reflects a well-established biological pathway, whereby reduced haemoglobin levels during pregnancy impair fatal oxygenation, increase the likelihood of low birth weight, premature delivery, and neonatal complications, and ultimately elevate the risk of infant death. The robustness of this effect suggests that maternal anaemia operates as a direct biological determinant, rather than merely capturing broader socioeconomic deprivation. Consequently, policies aimed at reducing infant mortality must prioritise maternal nutrition and anaemia prevention alongside health-system expansion.

Female literacy emerges as one of the strongest protective determinants of infant mortality. The coefficient on female literacy is negative and statistically significant ($\beta \approx -2.17$, $p = 0.001$), indicating that a 1 per cent increase in female literacy is associated with roughly a 2.2 per cent reduction in IMR, ceteris paribus. This sizeable effect underscores the role of female human capital as a structural driver of child survival. Higher literacy among women enhances health awareness, care-seeking behaviour, hygiene practices, and utilisation of maternal and child health services. Importantly, the literacy effect remains strong even after controlling for maternal health conditions and health-system variables, confirming that female education is not merely a proxy for income or infrastructure but an independent and cumulative determinant of improved infant survival.

Hospital availability per 10,000 population shows a positive and statistically significant association with infant mortality ($\beta \approx 0.73$, $p = 0.015$). In substantive terms, an additional unit increase in hospital availability is associated with a notable increase in IMR, conditional on other variables. This result should not be interpreted as evidence that hospitals worsen infant outcomes. Instead, it reflects a pattern of reactive healthcare infrastructure expansion, where states with persistently high infant mortality invest more heavily in hospital capacity in response to higher health needs. The finding also highlights the distinction between availability and effectiveness of healthcare services. Greater facility presence does not automatically translate into lower mortality when service quality, staffing, equitable access, and postnatal continuity of care remain weak. Thus, infrastructure expansion alone may have limited mortality-reducing impact in the absence of functional improvements.

Per capita public health expenditure exhibits a negative and statistically significant relationship with infant mortality ($\beta \approx -0.00034$, $p = 0.006$). Although the coefficient is numerically small, its interpretation is meaningful in aggregate terms. For instance, an increase of 100 units in per capita public health spending is associated with an approximate

3.4 per cent reduction in IMR, holding other factors constant. This result highlights the role of public health investment as an enabling mechanism that supports antenatal care, institutional delivery, neonatal services, and preventive health programmes. However, the effect of expenditure is conditional on governance quality and efficient allocation, suggesting that spending reduces infant mortality only when it is effectively translated into service delivery.

The inclusion of a state-specific dummy variable further captures unobserved regional heterogeneity in infant mortality outcomes. The significant coefficient on the Jharkhand dummy indicates that, even after accounting for maternal health, female literacy, public health expenditure, and hospital availability, this state differs systematically from the reference category. Such differences likely reflect historical deprivation, demographic composition, geographic constraints, or institutional capacity, which are not fully captured by observable indicators. Accounting for this heterogeneity improves model specification and strengthens confidence in the estimated relationships.

The regression results present a coherent and policy-relevant narrative. Biological risks, particularly maternal anaemia, significantly elevate infant mortality, while social determinants such as female literacy and institutional factors like public health expenditure exert strong protective effects. The positive association between hospital availability and IMR underscores the limitations of infrastructure-focused strategies when not accompanied by improvements in quality, accessibility, and effectiveness of care. These findings suggest that sustained reductions in infant mortality in India require an integrated approach that combines maternal nutrition interventions, investments in female education, efficient public health spending, and strengthening of healthcare system functionality rather than relying solely on the expansion of physical infrastructure.

Conclusion: This study examined the determinants of infant mortality across Indian states by integrating maternal health conditions, female educational attainment, public health expenditure, healthcare infrastructure availability, and state-specific heterogeneity within a unified empirical framework. Using a log-linear regression model based on recent state-level data, the analysis demonstrates that variations in infant mortality are shaped more strongly by biological vulnerability and social determinants than by the expansion of physical health infrastructure alone.

The findings identify maternal anaemia as a critical proximate determinant of infant mortality. The magnitude and robustness of its effect indicate that higher anaemia prevalence significantly elevates infant deaths, even after controlling for education, public spending, and healthcare availability. This result aligns with clinical and epidemiological evidence showing that anaemia during pregnancy compromises fatal development and neonatal survival (Nair *et al.*, 2016; Rahman *et al.*, 2020) [14, 15], underscoring the continued importance of maternal nutrition interventions.

Female literacy emerges as one of the strongest protective factors against infant mortality, reflecting its role as a structural determinant operating through improved health awareness, care-seeking behaviour, and utilisation of maternal and child health services. The persistence of this effect reinforces existing Indian evidence that women's education yields durable and intergenerational gains in child survival (Mukherjee *et al.*, 2019; Moradhvaj & Samir, 2023) [18, 23].

The analysis further shows that public health expenditure contributes to lower infant mortality by enabling access to essential services, although its effectiveness depends on governance and efficient allocation. In contrast, the positive association between hospital availability and infant mortality reflects a pattern of reactive infrastructure expansion in high- need states, highlighting that facility density alone is insufficient to reduce mortality without corresponding improvements in quality and functionality.

The findings suggest that sustained reductions in infant mortality in India require an integrated strategy prioritising maternal nutrition, female education, and effective public health systems, rather than an exclusive focus on infrastructure expansion.

Policy Relevance: The econometric model demonstrates that variations in infant mortality across Indian states are driven by an interaction of proximate biological risks, structural social determinants, public health financing, and health-system responsiveness, rather than by healthcare infrastructure expansion in isolation. Its policy relevance lies in offering a framework for designing targeted, multi-sectoral interventions that align closely with India's maternal and child health priorities.

The strong positive association between maternal anaemia and infant mortality underscores the urgency of reinforcing nutrition-focused maternal health policies. Anaemia in pregnancy, defined as haemoglobin concentration below 11 g/dL, is a well-established risk factor for low birth weight, prematurity, and neonatal mortality (World Health Organization, 2011) [22]. Despite sustained policy efforts such as the Anaemia Mukt Bharat programme, anaemia prevalence remains persistently high across several states (Ministry of Health and Family Welfare, 2018; NFHS-5, 2019-21). The elasticity implied by the model suggests that even modest reductions in anaemia prevalence can yield

meaningful declines in infant mortality, reinforcing the need for improved antenatal screening, adherence to iron-folic acid supplementation, dietary diversification, and strengthened programme monitoring.

The significant negative effect of female literacy highlights education as a foundational public health intervention rather than a peripheral social investment. Female literacy is recognised as a key social determinant of health, influencing health knowledge, reproductive behaviour, autonomy in decision-making, and utilisation of maternal and child health services (World Bank, 2021). The model's findings support integrated education-health policies, including sustained investments in girls' schooling, adult female literacy initiatives, and community- based health education. These priorities are consistent with the objectives of the National Education Policy 2020, which explicitly frames female education as a driver of long-term social and health outcomes (Government of India, 2020).

The negative association between per capita public health expenditure and infant mortality affirms the importance of sustained public investment in health. Public health expenditure, defined as government spending on preventive, promotive, and curative services, is a core input for achieving universal health coverage (WHO, 2010). The results indicate that higher spending facilitates access to essential maternal and neonatal services. At the same time, the findings imply that expenditure effectiveness depends critically on governance quality and allocation efficiency, consistent with evidence that mortality reduction occurs when spending improves service coverage and quality rather than merely expanding physical assets (Kittipittayakorn, 2025) [17].

The positive association between hospital availability and infant mortality carries an important cautionary message for infrastructure-led policy approaches. Rather than suggesting a detrimental effect of hospitals, this relationship reflects reactive infrastructure expansion, whereby facilities are disproportionately concentrated in high-mortality regions. This finding cautions against equating facility density with health-system performance and supports a policy shift towards improving quality of care, human resources, and postnatal continuity, as emphasised in India's National Health Policy 2017 (Government of India, 2017) [20].

Finally, the significance of the state-specific dummy variable highlights persistent regional heterogeneity in infant mortality outcomes, shaped by historical deprivation, demographic composition, and institutional capacity. This underscores the necessity of region-sensitive policy design, consistent with the NITI Aayog Health Index, which advocates differentiated strategies based on state-specific health-system constraints (NITI Aayog, 2021) [21].

The policy relevance of this model lies in demonstrating that sustained reductions in infant mortality require an integrated strategy that combines maternal nutrition interventions, female education, efficient public health financing, and improvements in healthcare quality. Policies that focus narrowly on infrastructure expansion, without addressing underlying biological and social determinants, are unlikely to deliver durable gains in infant survival or health equity across Indian states.

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