Journal of Population Health Dynamics

https://jphdjournal.com | DOI: To be assigned | ISSN: To be supplied

Volume 1, Issue 1, page 34-43 | October 2026

RESEARCH ARTICLE

Early Childhood Mortality in Southern India: Trends, Differentials, and Determinants

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Abstract

Background: Southern India has achieved substantial reductions in early childhood mortality, but socioeconomic and demographic inequalities in child survival persist. This study examines trends, differentials, and determinants of neonatal, infant, and under-five mortality in Southern India using five rounds of the National Family Health Survey (NFHS), 1992–2021.
Methods: Southern India includes five States (Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Telangana) and three Union Territories (Andaman & Nicobar Islands, Lakshadweep, and Puducherry). Life-table methods were used to estimate neonatal mortality rate (NNMR), infant mortality rate (IMR), and under-five mortality rate (U5MR) across NFHS-1 to NFHS-5. NFHS-5 data were further analysed to examine mortality differentials by socio-demographic characteristics. To determine the factors associated with early childhood mortality, Cox proportional hazards regression analysis models were fitted separately for neonatal, infant, and under-five mortality.
Results: Mortality declined substantially in Southern India between NFHS-1 and NFHS-5, with NNMR decreasing from 42.7 to 14.4, IMR from 62.6 to 22.1, and U5MR from 79.3 to 26.4 per 1,000 live births. Mortality remained higher in rural than urban areas and varied considerably across states. Descriptive analysis showed higher mortality among children from poorer households, those born to less-educated mothers, multiple births, and socially disadvantaged groups. In multivariable Cox proportional hazards models, multiple births were associated with markedly higher hazards of neonatal (aHR=8.73; 95% CI: 5.42–14.06; $p<0.001$), infant (aHR=6.60; 95% CI: 4.33–10.06; $p<0.001$), and under-five mortality (aHR=6.52; 95% CI: 4.35–9.75; $p<0.001$). Conversely, the richest households had substantially lower hazards of neonatal (aHR=0.29; 95% CI: 0.13–0.65; $p=0.003$), infant (aHR=0.25; 95% CI: 0.13–0.48; $p<0.001$), and under-five mortality (aHR=0.23; 95% CI: 0.12–0.42; $p<0.001$). Higher maternal education, female sex, institutional delivery, and second birth order were also associated with lower mortality hazards across one or more mortality outcomes, while maternal age ≥35 years was associated with lower infant and under-five mortality hazards.
Conclusions: Southern India has made substantial progress in child survival, but persistent socioeconomic inequalities and the high mortality rate among multiple births remain important challenges. Further progress requires equity-oriented maternal, neonatal, and child-health interventions targeting disadvantaged households and high-risk pregnancies.

Keywords: NNMR, IMR, U5MR, early childhood mortality, life-table technique, Cox proportional-hazards ratio, Southern India

Key Points

- Five rounds of NFHS data were analysed to examine long-term trends and patterns in neonatal, infant, and under-five mortality across Southern India.
- The study highlights the progress in childhood survival alongside persistent socioeconomic and demographic inequalities in mortality.
- Multivariable Cox proportional-hazards models identified important maternal, child-related, and household socioeconomic factors associated with childhood mortality.
- The findings underscore the importance of improving maternal and newborn healthcare and addressing socioeconomic inequalities to achieve further reductions in childhood mortality.

1 Introduction

Early childhood mortality, encompassing neonatal, infant, and under-five mortality, remains an important indicator of population health, social development, and health-system performance. Although India has achieved substantial reductions in child mortality over the past three decades, progress has varied considerably across regions and population groups[1]. The Sustainable Development Goals (SDGs), particularly Target 3.2, call for an end to preventable deaths of newborns and children under-five by 2030, making continued reductions in early childhood mortality an important public health priority[2].

India has made considerable progress in child survival, with the under-five mortality rate declining sharply since 1990. Recent estimates indicate that India's under-five

mortality rate declined to about 27 deaths per 1,000 live births by 2024, while neonatal and infant mortality have also reached historically low levels [2, 3]. However, the pattern of mortality reduction has changed as overall mortality has declined. Recent evidence shows that neonatal deaths now constitute a large proportion of under-five deaths, with early-neonatal mortality remaining the dominant component of child mortality in India [1]. This increasing concentration of mortality in the earliest period of life indicates that further progress will depend increasingly on improving maternal, newborn, and immediate postnatal care.

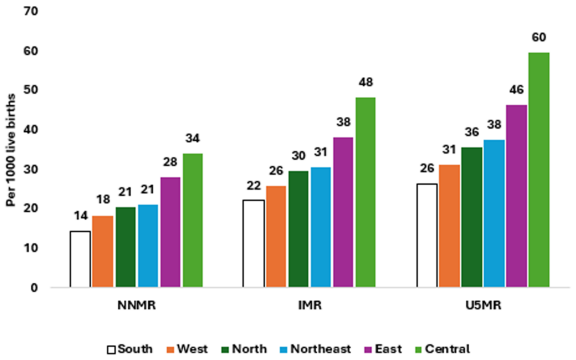


Figure 1. Neonatal, Infant, and Under-five Mortality Rates

Note: The regions of India have been categorised as per the NFHS-5 national report as follows: **North:** Chandigarh, Delhi, Haryana, Himachal Pradesh, Jammu & Kashmir, Ladakh, Punjab, Rajasthan, and Uttarakhand. **Central:** Chhattisgarh, Madhya Pradesh, and Uttar Pradesh. **East:** Bihar, Jharkhand, Odisha, and West Bengal. **Northeast:** Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura. **West:** Dadra & Nagar Haveli and Daman & Diu, Goa, Gujarat, and Maharashtra. **South:** Andaman & Nicobar Islands, Andhra Pradesh, Karnataka, Kerala, Puducherry, Tamil Nadu, and Telangana. NNMR = neonatal mortality rate; IMR = infant mortality rate; U5MR = under-five mortality rate.

Source: Authors' calculation based on NFHS-5 dataset.

Southern India, comprising five States (Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Telangana) and three Union Territories (UTs) (Andaman & Nicobar Islands, Lakshadweep, and Puducherry), provides an important setting for examining the changing mortality profile. It is evident from **Figure 1** that multiple rounds of the National Family Health Survey (NFHS) consistently show that Southern states generally have lower child mortality than many northern and central states [4]. Nevertheless, lower regional mortality does not imply the elimination of inequalities. Recent evidence demonstrates substantial differences in mortality levels and the pace of decline across Indian States and UTs, including within relatively low-mortality regions [1]. Evidence comparing northern and southern India also indicates that maternal education, birth interval, maternal age, antenatal care, birth characteristics, and household conditions remain associated with early childhood mortality in Southern India [5]. Thus, Southern India can be characterized as a relatively low-mortality but heterogeneous setting in which understanding the determinants of the remaining mortality burden is increasingly important.

The determinants of early childhood mortality operate through interconnected socioeconomic, demographic, biological, environmental, and health-system pathways. The analytical framework proposed by Mosley and Chen [6] provides a useful basis for understanding these relationships by distinguishing between socioeconomic determinants and the proximate determinants, through which, they affect child survival. These proximate determinants include maternal factors, environmental contamination, nutrient deficiency, injury, and personal illness control. In the Indian context, maternal education, household economic conditions, social disadvantage, reproductive behaviour, birth characteristics, place of residence, and healthcare utilisation may influence child survival through these pathways [5]. Their importance may be particularly evident in relatively low-mortality settings, where further improvements increasingly depend on addressing residual inequalities and the quality and timeliness of care rather than coverage alone.

Neonatal survival is particularly sensitive to conditions surrounding pregnancy and childbirth [7]. Prematurity, low birth weight, intrapartum complications, and infections remain major contributors to neonatal mortality [2]. Although national programmes such as the National Health Mission (NHM), Janani Suraksha Yojana (JSY), Janani Shishu Suraksha Karyakram (JSSK), and other maternal and child health initiatives have contributed to expanding access to maternal and newborn services, persistent gaps in the continuity and quality of care remain [8, 9, 10]. Thus, further improvements in child survival require not only sustained coverage but also greater attention to the quality, completeness, and timeliness of care across the maternal-newborn continuum [7, 11, 12, 13].

Despite extensive research on childhood mortality in India, important gaps remain in understanding mortality within relatively low-mortality regions. National-level studies have established substantial declines in neonatal, infant, and under-five mortality over the past three decades, but they also demonstrate persistent variation across states and age-specific mortality components [1] . Comparative studies of northern and southern India have highlighted regional differences and associated risk factors, but provide limited evidence on the combined patterns of trends, differentials, and determinants across the southern states and Union Territories as a distinct analytical region [5]. Similarly, state- and district-level studies provide important localised insights into childhood mortality but have limited regional generalizability. The present study addresses these gaps by examining neonatal, infant, and under-five mortality together across Southern India using five rounds of the NFHS for trend assessment and the most recent, the fifth round of NFHS for analysing socioeconomic and demographic differentials and determinants. By treating Southern India as a distinct analytical setting, the study moves beyond documenting aggregate mortality decline to examine residual inequalities and factors associated with child survival in a region that has achieved comparatively low mortality but continues to exhibit within-region heterogeneity [1, 5].

2 Methods

2.1 Sample design and data source

The present study used data from all five rounds of the NFHS data, an Indian version of the Demographic & Health Survey (DHS), conducted in India between 1992 and 2021. NFHS-1, NFHS-2, NFHS-3, NFHS-4, and NFHS-5 were conducted during 1992–1993, 1998–1999, 2005–2006, 2015–2016, and 2019–2021, respectively. The NFHS is a nationally representative cross-sectional household survey conducted with the support of the Ministry of Health and Family Welfare (MoHFW), coordinated by the International Institute for Population Sciences (IIPS), Mumbai, and executed through collaboration among various survey organizations and Population Research Centres. A two-stage stratified sample is utilized in the NFHS survey. The probability proportional to size (PPS) sampling method was used to select the primary sample units (PSUs), which were villages in rural areas and Census Enumeration Blocks (CEBs) in urban areas. Detailed information about the sampling, data collection, and survey instruments can be found in the NFHS India Report [4, 14, 15, 16, 17].

For the present study, the analysis was restricted to Southern India, comprising five States (Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Telangana) and three UTs (Andaman & Nicobar Islands, Lakshadweep, and Puducherry). State classifications were retained as provided in each NFHS dataset [4], without retrospective recoding or harmonisation of state boundaries across survey rounds. For instance, Andhra Pradesh was treated as a single state in NFHS 1-3, whereas Andhra Pradesh and Telangana were represented separately in NFHS 4 & 5. Therefore, state-specific estimates for Andhra Pradesh in the earlier rounds refer to the undivided state and are not directly equivalent to estimates for present-day Andhra Pradesh. For Lakshadweep, mortality estimates were based on 278 births; as no neonatal, infant, or under-five deaths were observed, the corresponding mortality rates were reported as 0.0%, this should be interpreted cautiously. Moreover, the first three rounds of NFHS surveys didn't provide data on any of the UTs, including southern India.

2.2 Data collection

The data collection for the NFHS survey utilized a comprehensive questionnaire encompassing thematic categories including socio-demographic information, lifestyle characteristics, access to healthcare services, and fertility history. Detailed information was collected on fertility, birth histories, mortality, and maternal and child health characteristics from ever-married eligible women aged 15-49 years. Questions were carefully crafted to ensure clarity and relevance across diverse populations. The questionnaire, crafted in 18 regional languages, was rigorously tested and pretested, then deployed via computer-assisted personal interviewing. To guarantee data quality, field staff underwent multiple training sessions before the final survey implementation [4].

2.3 Study Population

The analysis of mortality rates used birth histories from the five years preceding each survey. Analyses of socioeconomic and demographic differentials and determinants were based on NFHS-5 data [4]. **Table 1** presents the number of neonatal, infant, and under-five deaths and live births included in the five survey rounds. Across the five rounds, the Southern India sample comprised 80,304 live births, 1,714 neonatal deaths, 2,426 infant deaths, and 2,698 under-five deaths. The increase in the number of observations in NFHS-4 & NFHS-5 primarily reflects the substantially larger survey sample and should not be interpreted as an increase in mortality [4, 14, 15, 16, 17].

2.4 Study variables

2.4.1 Outcome variables

We computed the following three mortality outcomes: neonatal, infant, and under-five mortality. A neonatal death was defined as a death occurring within the first 28 completed days of life; an infant death as a death occurring before completion of the first year of life; and an under-five death as a death occurring before completion of five years of age. The corresponding mortality indicators were expressed per 1,000 live births: the neonatal mortality rate (NNMR), infant mortality rate (IMR), and under-five mortality rate (U5MR). The NNMR, IMR, and U5MR are the probabilities that a child exposed to a specific period dies before reaching one month (28 days), one year, and five years, respectively.

2.4.2 Explanatory variables

The present analysis is guided by earlier literature [5] on the selection of explanatory variables, which were based on theoretical relevance to the child survival framework [6]. These are as follows: *Maternal characteristics*: maternal education (no schooling, primary, secondary, and >secondary); mother's age at survey (<20 years, 20–34 years, and 35+ years); and currently working (not-working, and working). *Paternal characteristics*: father's education (< secondary, >secondary, and DK [Don't know]); and occupation (salaried employee, agricultural, manual labor, and others). *Child characteristics*: sex of child (male or female); type of delivery (vaginal or caesarean); and type of birth (singleton or multiple); place of delivery (home delivery or institutional delivery); birth order (1st, 2nd, and >=3). *Household characteristics*: place of residence (urban or rural); religion (Hindu, Muslim, and others); caste (scheduled caste [SC], scheduled tribe [ST], other backward class [OBC], and general caste); and wealth index (poorest, poorer, middle, richer, and richest).

2.5 Statistical analysis

Trends in neonatal, infant, and under-five mortality rates were estimated across NFHS-1 to NFHS-5 to assess changes in childhood mortality over time. Descriptive statistics were used to examine the distribution of births and mortality events, followed by life-table analysis to estimate mortality rates and their temporal changes across the five NFHS surveys. Mortality indicators were further examined according to selected maternal, paternal, child, and household characteristics to assess socioeconomic and demographic differentials using the NFHS-5 survey. Finally, Cox proportional hazards regression analysis was conducted to identify determining factors associated with childhood mortality. It is noteworthy that the analysis was based on the NFHS Birth Records file. During data examination, substantial missing information was observed for maternal working status, father's education, and father's occupation in this file. These variables were consequently excluded from the final multivariable Cox regression models to avoid further reduction in the complete-case analytical sample and the number of ob-

Table 1. Distribution of neonatal, infant, and under-five deaths and live births in the five years preceding the survey, Southern India, NFHS-1 to NFHS-5, 1992–2021.

Rounds of NFHS and Year	Neonatal Deaths	Infant deaths	Under-five deaths	Live births
NFHS-1 (1992-93)	372	529	599	9,488
NFHS-2 (1998-99)	262	359	415	7,714
NFHS-3 (2005-06)	180	252	272	7,343
NFHS-4 (2015-16)	454	625	696	26,223
NFHS-5 (2019-21)	446	661	716	29,536
Total (NFHS-1 to NFHS-5, 1992-2021)	**1,714**	**2,426**	**2,698**	**80,304**

Note: The mortality events and live births refer to the five years preceding each survey.
Source: Authors' calculation based on NFHS-1 to NFHS-5, 1992-2021.

served mortality events.

2.5.1 Life-table analysis

Neonatal, infant, and under-five mortality rates were estimated using a weighted abridged life-table procedure based on the age-specific mortality framework suggested in the official DHS guide [18] and applied in previous analyses of NFHS birth-history data [19, 20]. Children born during the five years preceding each survey were considered for mortality estimation. The analysis used the standard childhood age intervals of 0, 1–2, 3–5, 6–11, 12–23, 24–35, 36–47, and 48–59 months. For each age interval, deaths and observed exposure were aggregated using the NFHS sampling weights. The age-specific mortality rate was calculated as the weighted number of deaths (d_x) divided by the corresponding weighted exposure (e_x) in the interval, as $m_x = d_x/e_x$. Age-specific probabilities of death (q_x) were subsequently derived from these mortality rates using the abridged life-table transformation, and the corresponding probabilities of survival were calculated ($p_x = 1\text{-}q_x$). Cumulative survival probabilities were then obtained by multiplying the interval-specific survival probabilities sequentially. Neonatal mortality was estimated from mortality during the first month (28 days) of life (NNMR = (1-s1)*1000), infant mortality from cumulative mortality through 11 months (IMR = (1-s12)*1000), and under-five mortality from cumulative mortality through 59 months (U5MR = (1-s60)*1000). Where (s1), (s12), and (s60) denote cumulative survival probabilities to 1, 12, and 60 months, respectively. Estimates were expressed per 1,000 live births. Children who were alive at the time of the interview contributed observed exposure up to their age at interview, whereas children who died contributed exposure up to their recorded age at death. Thus, follow-up for surviving children was truncated at the survey date, reflecting their observed period of exposure to mortality risk. All mortality estimates incorporated the NFHS sampling weights (v005/1000000) to account for the complex survey design. The calculations were implemented using a user-defined Stata program, rather than a built-in life-table command (**Supplementary material S1**).

The NFHS birth-history variables, including date of interview, date of birth, survival status, age at death, and sampling weight, were used. Missing essential birth-history information was explicitly handled in the life-table program by excluding observations with missing date of birth (b3) or survival status (b5), and, among deceased children, observations with missing age at death (b7). Although the present study life-table STATA program was designed to exclude such observations, no observations were excluded because these variables were complete in the NFHS-5 dataset. Any DHS/NFHS imputation or preprocessing undertaken before in the dataset is separate from the missing-data handling performed by the present Stata program [18]. Accordingly, mortality estimates were based on the processed NFHS standard recode variables.

2.5.2 Cox proportional hazards regression analysis

Further, determinants of mortality were examined using NFHS-5 data. Multicollinearity diagnostics were performed, and all variance inflation factor (VIF) values were found to be low (mean VIF = 2.23), indicating no evidence of collinearity. To determine factors associated with early childhood mortality, multivariable Cox proportional hazards with right censoring regression models were fitted using the '*stset*','*stsum*', and '*svy: stcox*' Stata command (**Supplementary material S2**). The time-to-event approach was used to account for differential exposure to the risk of death and right censoring among children who remained alive at the end of the respective risk period. Because childhood mortality is an event occurring over age/time, and the NFHS birth histories provide information on age at death and survival, a time-to-event approach was considered more appropriate for estimating associations with mortality while accounting for differential exposure time and right censoring.

Neonatal mortality was analysed over the first 28 days of life, infant mortality over the first 12 months, and under-five mortality over the first 60 months. Children who survived beyond the corresponding age limit were right-censored at the end of the risk period, while children who died within the specified period were treated as events. Three variables with extensive missingness (mothers' working status, fathers' education, and Occupation in NFHS birth records) were excluded from the multivariable models when their inclusion resulted in substantial loss of observations or mortality events. Moreover, observations with missing values for variables included in a particular multivariable model were excluded from that model using a complete-case approach. Consequently, the effective analytical sample and number of observed deaths varied slightly across the three mortality outcomes. The neonatal model included 429 (96.2%) of 446 identified neonatal deaths, the infant model included 639 (96.7%) of 661 identified infant deaths, and the under-five model included 693 (96.8%) of 716 identified under-five deaths. The models examined the associations between selected maternal, child, and household characteristics. The associations were expressed as adjusted hazard ratios (aHRs) with 95% confidence intervals (CIs). A variable was considered to be statistically significant if the P-value was less than 0.05.

Moreover, the proportional-hazards assumption was assessed using Schoenfeld residual-based tests, examining

both global and covariate-specific tests. The diagnostic results were used to identify potential departures from the proportional-hazards assumption in each mortality model.

Because the NFHS employs a complex multistage sampling design, all analyses incorporated the survey sampling weights (v005/1000000) and, where applicable, the clustering and stratification variables to obtain appropriate estimates and variance measures. Model fit was assessed using the survey-adjusted Wald F statistic. The Cox proportional hazards regression models were statistically significant overall, with Wald F statistics of 10.50 (neonatal), 10.92 (infant), and 12.37 (under-five mortality), respectively (all $p < 0.001$). All statistical analyses were performed using Stata version 17 (StataCorp, College Station, TX, USA).

2.6 Ethical Considerations

The study used secondary data from the NFHS. The ethical approval for the NFHS survey was obtained from the Institutional Review Board (IRB) of the International Institute of Population Sciences (IIPS), Mumbai, India. Written and informed consent was obtained from each respondent before participating in the survey; additionally, written informed consent was obtained from the parent/guardian of each respondent under 18 years of age. No separate ethical approval was required for this secondary data analysis, since the NFHS dataset is an anonymous, publicly available dataset with no identifiable information about the study participants.

3 Results

3.1 Trend in Early Childhood Mortality in Southern India

To estimate mortality, live births and deaths occurring during 0-4 years preceding the survey were considered, and mortality rates were estimated using a weighted abridged life-table procedure based on the age-specific mortality framework suggested in the official DHS guide [18].

Figure 2 shows a substantial and consistent decline in neonatal, infant, and under-five mortality in Southern India from NFHS-1 to NFHS-5, with rates remaining considerably lower than the corresponding all-India levels throughout the period. Mortality was consistently higher in rural than urban areas, although the urban–rural gap narrowed over time, particularly for neonatal mortality.

Table 2 demonstrates a marked decline in neonatal, infant, and under-five mortality across the States of Southern India from NFHS-1 to NFHS-5. Among the major States, Kerala recorded the lowest mortality levels across surveys. Whereas, undivided Andhra Pradesh showed higher rates in the earlier rounds. Overall, mortality declined substantially across all major states, with Southern India maintaining considerably lower mortality rates than the national average throughout the period. Lakshadweep recorded 0 neonatal, infant, and under-five deaths among 278 births, resulting in observed mortality rates of 0.0%; however, these estimates should be interpreted with caution, given the relatively small denominator and absence of observed mortality events.

Note: *Andhra Pradesh is presented as the undivided state in NFHS-1 to NFHS-3, whereas Andhra Pradesh and Telangana are presented separately in NFHS-4 and NFHS-5, consistent with the state classifications in the respective NFHS datasets. Earlier Andhra Pradesh estimates, therefore, include the area that subsequently became Telangana. **Lakshadweep had 278 births with no observed neonatal, infant, or under-five deaths; therefore, the corresponding mortality rates were 0.0%. ˆfirst three rounds of NFHS surveys didn't provide data on any of the UTs, including Southern India. UTs = Union territories; NNMR = neonatal mortality rate; IMR = infant mortality rate; U5MR = under-five mortality rate.

Source: Authors' calculation based on NFHS-1 to NFHS-5, 1992-2021.

3.2 Differentials in Early Childhood Mortality

Table 3 presents substantial differentials in neonatal, infant, and under-five mortality across socioeconomic, demographic, maternal, paternal, child, and household characteristics in Southern India based on NFHS-5. Overall, Southern India recorded considerably lower mortality than the national average, with NNMR, IMR, and U5MR of 14.4, 22.1, and 26.4 per 1,000 live births, respectively, compared with 25.0, 35.4, and 43.1 for India as a whole. Mortality showed a clear socioeconomic gradient, declining consistently with increasing maternal education and household wealth. NNMR, IMR, and U5MR were highest among children of mothers with no education (27.9, 41.8, and 56.3) and lowest among those whose mothers had education beyond secondary level (7.7, 11.4, and 12.1). A similarly pronounced gradient was observed across wealth groups, with U5MR declining from 58.7 among the poorest households to only 6.0 among the richest.

Maternal age was also associated with mortality, with children born to mothers younger than 20 years experiencing substantially higher NNMR (29.0), IMR (48.7), and U5MR (69.9) than those born to mothers aged 20–34 years (14.2, 21.9, and 26.2, respectively). Interestingly, the NNMR was higher among children of non-working mothers compared to working mothers. However, though with less difference, this is just the opposite in the case of IMR and U5MR. Paternal characteristics showed similar socioeconomic differentials: children of fathers with less than secondary education and those whose fathers were engaged in agricultural or manual occupations generally experienced higher mortality than children of more educated or salaried fathers (**Table 3**).

Note: # some variables had missing cases; * unweighted numbers; ˆ weighted rates; NNMR = neonatal mortality rate; IMR = infant mortality rate; U5MR = under-five mortality rate; SC = Scheduled Caste; ST = Scheduled Tribe; OBC = Other Backward Classes; DK = don't know.

Source: Authors' calculation based on NFHS-5 dataset.

Table 2: Trends in Neonatal, Infant, and Under-five mortality rates across the States/UTs of Southern India, NFHS 1-5 (1992-2021).

States/UTs	NNMR					IMR					U5MR				
	NFHS1	NFHS2	NFHS3	NFHS4	NFHS5	NFHS1	NFHS2	NFHS3	NFHS4	NFHS5	NFHS1	NFHS2	NFHS3	NFHS4	NFHS5
Andhra Pradesh*	47.1	44.5	40.4	23.9	20.2	71.9	64.6	53.0	35.0	31.2	92.9	98.0	65.8	39.0	39.8
Karnataka	45.7	37.4	28.6	18.9	15.9	64.2	51.9	43.5	27.5	25.5	84.8	67.7	51.2	36.1	29.8
Kerala	15.7	13.3	11.6	4.4	3.4	23.6	15.0	14.7	5.6	4.5	29.7	16.3	16.7	9.7	4.7
Tamil Nadu	46.7	34.4	20.0	14.2	12.7	67.2	47.7	32.1	20.1	18.3	80.1	67.4	45.9	42.8	22.3
Telangana*	-	-	-	19.9	17.2	-	-	-	27.6	26.7	-	-	-	30.8	29.3
Union territoriesˆ															
Andaman & Nicobar	-	-	-	7.3	12.3	-	-	-	9.9	20.9	-	-	-	9.9	20.9
Lakshadweep**	-	-	-	23.2	0.0	-	-	-	27.1	0.0	-	-	-	27.1	0.0
Puducherry	-	-	-	5.8	2.3	-	-	-	17.1	2.9	-	-	-	18.4	4.4
South India Total	42.7	36.1	28.8	17.1	14.4	62.6	50.7	40.8	24.5	22.1	79.3	72.5	51.2	35.3	26.4
All India Total	48.7	43.6	39.1	29.5	25.0	77.9	67.9	57.2	40.8	35.4	113.7	99.2	74.9	51.3	43.1

Table 3: Unweighted cases and weighted mortality rates for neonatal, infant, and under-five children by background characteristics in Southern India, NFHS-5 (2019-21).

Background Characteristics#	Neonatal deaths*	NNMRˆ	Infant deaths*	IMRˆ	U5 deaths*	U5MRˆ	Live births*
Mother's factors							
Mother's education							
No education	80	27.9	115	41.8	128	56.3	2,726
Primary	40	23.0	60	30.1	64	32.2	1,871
Secondary	265	14.9	396	23.7	428	28.1	17,286
> Secondary	61	7.7	90	11.4	96	12.1	7,653
Mother's age							
<20 years	18	29.0	25	48.7	26	69.9	661
20-34 years	399	14.2	594	21.9	646	26.2	26,639
35+ years	29	12.9	42	16.5	44	20.0	2,236
Mother currently working							
Not working	50	17.4	65	21.2	70	24.1	3,384
Working	22	14.6	30	23.6	32	25.0	1,150
Father's factors							
Father's education							
<Secondary	18	26.6	25	34.3	30	39.2	871
>Secondary	54	14.5	70	18.8	72	20.9	3,652
Father's occupation							
Salaried employee	19	14.3	20	14.5	20	14.5	1,538
Agricultural	25	16.5	42	31.6	46	34.0	1,434
Manual labor	24	19.8	28	22.3	31	28.3	1,339
Others	4	16.8	5	20.1	5	20.1	220
Child's factors							
Sex of child							
Male	255	16.2	376	24.7	404	28.5	15,354
Female	191	12.5	285	19.2	312	24.2	14,182
Type of delivery							
Vaginal delivery	294	17.3	435	25.5	474	30.8	16,490
Caesarean delivery	146	10.3	218	17.2	233	20.2	12,779
Multiple birth							
Single	399	12.7	603	20.1	657	24.1	28,950
Multiple	47	95.3	58	113.9	59	135.7	586
Place of delivery							
Home delivery	32	68.4	41	78.0	44	83.8	592
Institutional delivery	414	13.4	620	21.1	672	25.4	28,944
Birth order							
1st order	217	15.4	313	23.9	336	27.4	13,045
2nd order	137	10.9	208	16.0	226	20.6	11,808
3rd & above order	92	21.1	140	32.8	154	38.9	4,683
HH factors							
Place of residence							
Urban	110	10.8	172	17.7	181	21.3	9,895
Rural	336	16.8	489	25.0	535	29.7	19,641
Religion							
Hindu	388	15.9	573	23.9	625	29.1	23,849
Muslim	37	6.8	57	12.9	59	13.5	4,071
Others	21	12.1	31	18.7	32	19.9	1,616
Caste							
SC	127	18.8	184	27.5	200	34.4	6,634
ST	52	25.5	83	42.2	91	48.0	2,450
OBC	234	12.8	340	19.7	368	23.4	17,109
General	23	8.6	37	13.0	40	14.8	2,500
DK	5	17.0	9	40.8	9	40.8	181
Wealth index							
Poorest	39	29.5	65	43.5	73	58.7	1,629
Poorer	109	23.8	147	32.3	164	44.4	5,079
Middle	141	15.1	214	25.1	229	28.3	8,698
Richer	128	14.4	191	22.8	204	25.1	8,797
Richest	29	3.8	44	5.4	46	6.0	5,333
South India Total	**446**	**14.4**	**661**	**22.1**	**716**	**26.4**	**29,536**
All India Total	**5,743**	**25.0**	**8,038**	**35.4**	**8,828**	**43.1**	**235,155**

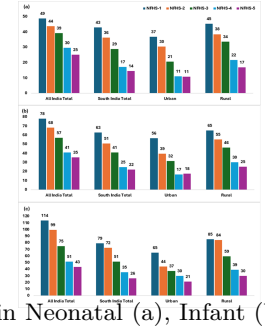


Figure 2. Trend in Neonatal (a), Infant (b), and Under-five (c) Mortality Rate in Southern India by place of residence, NFHS 1-5, 1992-2021.

Note: The urban and rural represent mortality rates in southern India.

Source: Authors' calculation based on NFHS-1 to NFHS-5, 1992-2021.

3.3 Results of Cox Proportional Hazards regression Analysis

Table 4 presents the results from the Cox proportional hazards regression with right-censoring model analysis. To investigate which factors best explain and are associated with neonatal, infant, and under-five child deaths, a separate Cox proportional hazards regression with right-censoring models was fitted for each mortality indicator using NFHS-5 data.

Table 4: Adjusted Cox proportional hazards ratio for neonatal, infant, and under-five mortality by background characteristics among children in Southern India, NFHS-5 (2019-21).

Background characteristics	Neonatal mortality		Infant mortality		Under-five mortality	
	aHR [95% CI]	p	aHR [95% CI]	p	aHR [95% CI]	p
Mother's factors						
Mother's education						
No education	Reference		Reference		Reference	
Primary	0.95 [0.55, 1.63]	0.842	0.83 [0.53, 1.28]	0.398	0.74 [0.49, 1.12]	0.154
Secondary	0.84 [0.54, 1.30]	0.425	0.82 [0.58, 1.17]	0.270	0.79 [0.57, 1.08]	0.143
> Secondary	0.57 [0.33, 1.00]	0.050	0.53 [0.34, 0.84]	0.007	0.50 [0.33, 0.77]	0.002
Mother's age						
<20 years	Reference		Reference		Reference	
20-34 years	0.70 [0.36, 1.36]	0.296	0.62 [0.37, 1.04]	0.072	0.61 [0.37, 1.01]	0.052
35+ years	0.69 [0.31, 1.55]	0.369	0.50 [0.26, 0.97]	0.039	0.49 [0.26, 0.93]	0.028
Child's factors						
Sex of child						
Male	Reference		Reference		Reference	
Female	0.75 [0.58, 0.96]	0.020	0.76 [0.62, 0.93]	0.008	0.78 [0.64, 0.95]	0.014
Type of delivery						
Vaginal delivery	Reference		Reference		Reference	
Caesarean delivery	0.70 [0.53, 0.93]	0.015	0.79 [0.63, 1.00]	0.046	0.80 [0.64, 1.00]	0.049
Multiple birth						
Single	Reference		Reference		Reference	
Multiple	8.73 [5.42, 14.06]	<0.001	6.60 [4.33, 10.06]	<0.001	6.52 [4.35, 9.75]	<0.001
Place of delivery						
Home delivery	Reference		Reference		Reference	
Institutional delivery	0.33 [0.21, 0.51]	<0.001	0.43 [0.28, 0.65]	<0.001	0.47 [0.31, 0.70]	<0.001
Birth order						
1st order	Reference		Reference		Reference	
2nd order	0.65 [0.50, 0.85]	0.001	0.63 [0.51, 0.78]	<0.001	0.64 [0.52, 0.79]	<0.001
3rd & above order	0.87 [0.59, 1.27]	0.462	0.97 [0.71, 1.32]	0.838	0.98 [0.73, 1.31]	0.866
HH factors						
Place of residence						
Urban	Reference		Reference		Reference	
Rural	0.97 [0.69, 1.37]	0.878	0.89 [0.69, 1.16]	0.394	0.89 [0.69, 1.15]	0.382
Religion						
Hindu	Reference		Reference		Reference	
Muslim	0.55 [0.35, 0.86]	0.008	0.68 [0.46, 1.00]	0.049	0.66 [0.45, 0.96]	0.029
Others	0.86 [0.49, 1.49]	0.584	0.92 [0.57, 1.47]	0.726	0.87 [0.55, 1.39]	0.564
Caste						
SC	Reference		Reference		Reference	
ST	1.13 [0.71, 1.81]	0.612	1.35 [0.95, 1.93]	0.097	1.29 [0.91, 1.81]	0.149
OBC	0.86 [0.64, 1.16]	0.317	0.90 [0.71, 1.14]	0.362	0.87 [0.69, 1.11]	0.261
General	0.73 [0.40, 1.31]	0.292	0.71 [0.44, 1.17]	0.180	0.71 [0.44, 1.13]	0.150
DK	1.06 [0.37, 3.09]	0.910	1.59 [0.72, 3.51]	0.255	1.42 [0.64, 3.15]	0.395
Wealth index						
Poorest	Reference		Reference		Reference	
Poorer	1.03 [0.60, 1.77]	0.917	0.94 [0.62, 1.44]	0.784	0.92 [0.64, 1.34]	0.674
Middle	0.76 [0.43, 1.34]	0.347	0.84 [0.54, 1.32]	0.446	0.77 [0.51, 1.15]	0.202
Richer	0.86 [0.46, 1.63]	0.651	0.86 [0.53, 1.40]	0.547	0.78 [0.50, 1.20]	0.257
Richest	0.29 [0.13, 0.65]	0.003	0.25 [0.13, 0.48]	<0.001	0.23 [0.12, 0.42]	<0.001
Initial observations	29,373		29,373		29,373	
Initial deaths/events	446		661		716	
Cox analytical N	28,457		28,457		28,457	
Events retained	429		639		693	
Event retention rate	96.2%		96.7%		96.8%	
Wald F	10.50		10.92		12.37	
Model P values	<0.001		<0.001		<0.001	

Note: Reference categories are indicated in the table. Models were estimated using Cox proportional hazards regression. Estimates account for the NFHS complex survey design, including sampling weights, clustering of observations within 5,226 primary sampling units (PSUs), stratification across 498 strata, and 4,728 design degrees of freedom. Wald F statistics are survey-adjusted. aHR = Adjusted Hazard Ratio; CI = Confidence interval; SC = Scheduled Caste; ST = Scheduled Tribe; OBC = Other Backward Classes; DK = don't know.
Source: Authors' calculation based on NFHS-5 dataset.

In the multivariable model, several factors were associated with mortality across the three age-specific outcomes. Higher maternal education was associated with lower mortality. Compared with mothers with no education, children of mothers with education beyond secondary school had lower hazards of neonatal death (aHR=0.57; 95% CI: 0.33–1.00; p=0.050), infant death (aHR=0.53; 95% CI: 0.34–0.84; p=0.007), and under-five death (aHR=0.50; 95% CI: 0.33–0.77; p=0.002). Maternal age of 35 years or older was associated with lower hazards of infant mortality (aHR=0.50; 95% CI: 0.26–0.97; p=0.030) and under-five mortality (aHR=0.49; 95% CI: 0.26–0.93; p=0.028), although the corresponding association for neonatal mortality was not statistically significant (**Table 4**).

Marked differences were also evident by child and birth characteristics. Male children had higher neonatal, infant, and under-five mortality than female children. Mortality was higher among children delivered vaginally than by caesarean section, although these descriptive differences should not be interpreted as causal because the mode of delivery may be influenced by underlying maternal and pregnancy-related risk factors. Multiple births showed an exceptionally high mortality burden, with NNMR, IMR, and U5MR reaching 95.3, 113.9, and 135.7 per 1,000 live births, respectively. Home delivery was also associated with substantially higher mortality than institutional delivery, particularly for neonatal mortality (68.4 vs. 13.4). Mortality was lowest among second-order births, whereas third or higher-order births showed elevated mortality compared with first- and second-order births (**Table 3**).

Household and social characteristics further demonstrated important inequalities. Rural children experienced higher NNMR, IMR, and U5MR than urban children (16.8, 25.0, and 29.7 versus 10.8, 17.7, and 21.3, respectively). Mortality was particularly high among ST children, followed by SC children, whereas children belonging to the General category had considerably lower mortality. The observed patterns indicate that childhood mortality in Southern India remains closely associated with socioeconomic disadvantage, maternal and paternal characteristics, birth circumstances, and household conditions. These descriptive findings highlight the importance of addressing inequalities in education, economic status, maternal age, access to institutional delivery, and care for high-risk births, while the independent contribution of these factors should be assessed through multivariable analysis (**Table 3**).

Female children experienced lower hazards of neonatal (aHR=0.75; 95% CI: 0.58–0.96, p=0.020), infant (aHR=0.76; 95% CI: 0.62–0.93; p=0.008), and under-five

mortality (aHR=0.78; 95% CI: 0.64–0.95; p=0.014) than male children. Caesarean delivery was associated with modestly lower hazards of infant (aHR=0.79; 95% CI: 0.63–1.00; p=0.046) and under-five mortality (aHR=0.80; 95% CI: 0.64–1.00; p=0.049), while the association with neonatal mortality was also protective (aHR=0.70; 95% CI: 0.53–0.93; p=0.015). Multiple births showed a substantially higher hazard of mortality across all three outcomes: approximately ninefold for neonatal mortality (aHR=8.73; 95% CI: 5.42–14.06; p<0.001), more than sixfold for infant mortality (aHR=6.60; 95% CI: 4.33–10.06; p<0.001), and under-five mortality (aHR=6.52; 95% CI: 4.35–9.75; p<0.001). Institutional delivery was associated with lower hazards of neonatal (aHR=0.33; 95% CI: 0.21–0.51; p<0.001), infant (aHR=0.43; 95% CI: 0.28–0.65; p<0.001), and under-five mortality (aHR=0.47; 95% CI: 0.31–0.70; p<0.001) (**Table 4**).

Second birth order was associated with lower hazards of infant mortality (aHR=0.63; 95% CI: 0.51–0.78; p<0.001) and under-five mortality (aHR=0.64; 95% CI: 0.52–0.79; p<0.001), and was also associated with lower neonatal mortality (aHR=0.65; 95% CI: 0.50–0.85; p=0.001) Children from the richest households had substantially lower hazards of mortality than those from the poorest households for neonatal (aHR=0.29; 95% CI: 0.13–0.65; p=0.003), infant (aHR=0.25; 95% CI: 0.13–0.48; p<0.001), and under-five mortality (aHR=0.23; 95% CI: 0.12–0.42; p<0.001). Muslim children had lower estimated hazards than Hindu children for neonatal, infant, and under-five mortality, although the strength of evidence varied across the three models (**Table 4**).

For neonatal mortality, the global proportional-hazards test was not statistically significant (χ^2 = 32.75, df = 22, p = 0.0656), although covariate-specific departures were observed for maternal education, multiple birth, and household wealth. The infant mortality diagnostic showed an identical pattern of results and is being verified. For under-five mortality, the global test did not indicate a significant departure from the proportional-hazards assumption (χ^2 = 24.47, df = 22, p = 0.3233). Nevertheless, individual departures were observed for multiple birth and selected household wealth categories.

4 Discussion

The findings demonstrate that Southern India has achieved substantial progress in child survival, with mortality levels in NFHS-5 considerably below the national averages. Nevertheless, the descriptive results indicate that mortality remains unequally distributed across socioeconomic, maternal, reproductive, and household characteristics. This pattern is consistent with recent evidence from India showing that, despite large reductions in childhood mortality over successive NFHS rounds, children from poorer households and those born to less-educated mothers continue to experience disproportionately higher mortality rates [5, 7, 21, 22].

The Cox proportional hazards analysis, which accounted for right censoring and differences in time at risk, identified several consistent socioeconomic, maternal, reproductive, and child-level correlates of mortality. Household wealth emerged as one of the most consistent determinants across all three mortality outcomes. Compared with children from the poorest households, those from the richest households had substantially lower hazards of neonatal, infant, and under-five mortality (aHR=0.29, 0.25, and 0.23, respectively). This persistent wealth gradient is consistent with evidence from India, showing that socioeconomic inequality remains an important feature of child survival despite long-term reductions in mortality [1, 5, 21, 22, 23]. Economic advantage may therefore operate through multiple interconnected pathways rather than through a single mechanism. The persistence of the wealth gradient in Southern India is particularly important because it indicates that relatively favourable regional mortality levels do not necessarily imply equitable survival.

Maternal education showed a similarly important association. Children of mothers with education beyond secondary school experienced lower hazards of infant and under-five mortality and a lower, although borderline, hazard of neonatal mortality compared with children of mothers with no education. This finding agrees with evidence from NFHS-based studies demonstrating the continuing importance of maternal education for child survival in India [24, 25]. Education may influence survival through health knowledge, reproductive behaviour, healthcare utilisation, and the capacity to recognise and respond to childhood illness.

Multiple births showed the strongest association among the child-level characteristics examined. Compared with singleton births, multiple births were associated with markedly higher hazards of neonatal, infant, and under-five mortality (aHR=8.73, 6.60, and 6.52, respectively). The particularly strong neonatal association is biologically plausible because multiple gestations are more frequently accompanied by prematurity, low birth weight, fetal growth restriction, and neonatal complications. Previous Indian evidence similarly identifies multiple births as a major risk factor for infant and child mortality [7, 21, 22, 23, 25, 26]. The persistence of this association beyond the neonatal period indicates that the vulnerability associated with multiple births may extend throughout early childhood. These findings reinforce the importance of identifying multiple pregnancies early and ensuring appropriate antenatal surveillance, skilled delivery, and postnatal follow-up.

Institutional delivery was associated with substantially lower mortality hazards across all three outcomes, while caesarean delivery was associated with modestly lower hazards. These associations should, however, be interpreted cautiously because delivery practices are strongly related to maternal risk, socioeconomic position, pregnancy complications, and access to health services. The observed association with institutional delivery is therefore more appropriately interpreted as reflecting the broader maternal and newborn care environment rather than as evidence of a direct causal effect. Previous Indian research similarly indicates that the survival benefit associated with institutional delivery depends importantly on the quality and accessibility of maternal and newborn care [12].

The association between birth order and mortality was less straightforward. Second-order births had lower hazards of neonatal, infant, and under-five mortality than first births, whereas higher-order births did not show a statistically significant association after adjustment.

Previous Indian evidence has also demonstrated that the relationship between birth order and mortality varies across stages of infancy and childhood [27, 28]. Maternal age showed a significant association, mainly for infant and under-five mortality. Children of mothers aged 35 years or older experience lower hazards than those of mothers younger than 20 years, and these findings are in line with recent studies [4, 5].

Female children had lower hazards of neonatal, infant, and under-five mortality than male children in the adjusted models. This finding is consistent with previous Indian evidence showing substantial sex differences in neonatal mortality, although the direction and magnitude of sex differentials can vary across the post-neonatal and childhood periods and by socioeconomic context [29]. The consistency observed in the present analysis nevertheless indicates that child sex remained associated with survival after adjustment for the socioeconomic and demographic characteristics included in the models.

Several characteristics that showed differences in descriptive analyses, including rural residence and some social-group categories, were not independently associated with mortality after adjustment. Some recent studies similarly demonstrate that rural–urban and social-group differentials in child mortality are closely intertwined with socioeconomic and maternal characteristics [20, 30]. The absence of an independent association should therefore not be interpreted as evidence that social or geographic disadvantage is irrelevant to child survival.

5 Limitations

This study has several limitations. First, the retrospective nature of NFHS birth-history data may introduce recall or reporting errors in dates of birth, survival status, and age at death. Second, the Cox proportional hazards analyses used right-censored survival data, and censoring may limit the interpretation of mortality risks among children who were alive at the end of follow-up. Third, maternal occupation, paternal education, and paternal occupation were excluded from the final Cox proportional hazards regression models because of substantial missing information in the NFHS Birth Records file for data completeness and model-specification considerations; their exclusion should not be interpreted as evidence that these characteristics are unimportant determinants of child survival. The final models retained 429 (96.2%) of 446 neonatal deaths, 639 (96.7%) of 661 infant deaths, and 693 (96.8%) of 716 under-five deaths. Fourth, mortality estimates for small geographic or population subgroups may be unstable, particularly where few or no deaths were observed. Fifth, household-level characteristics were measured at the time of the NFHS interview and may not fully represent household conditions at the time of birth or death. Sixth, residual confounding from unmeasured socioeconomic, environmental, healthcare-access, and biological factors cannot be excluded. Seventh, changes in state boundaries across survey periods may affect the comparability of geographic estimates. Finally, given the observational nature of the data, the observed associations should not be interpreted as causal relationships.

An additional limitation of this study is that the birth interval was not incorporated into the analysis. Although birth order was considered, it does not fully capture the influence of the spacing between successive births on child survival. Short preceding birth intervals may adversely affect maternal nutritional recovery, newborn health, and the availability of parental care and household resources. Consequently, the potential influence of birth spacing on neonatal, infant, and under-five mortality could not be assessed in the present study.

6 Conclusion

The analysis of NFHS-1 to NFHS-5 demonstrates a considerable decline in neonatal, infant, and under-five mortality in Southern India between 1993 and 2021, with mortality levels substantially lower than the national averages. However, the findings suggest that the remaining burden of childhood mortality in Southern India is increasingly characterised by inequality rather than uniformly high mortality. Household wealth and multiple birth were the most consistent correlates across all three mortality periods, while higher maternal education, institutional delivery, female sex, and second birth order were associated with lower hazards for one or more outcomes. Although several descriptive differentials, such as maternal education, rural residence, caste, maternal age, and place and type of delivery, were attenuated after adjustment, their observed gradients highlight the importance of addressing the broader socioeconomic and healthcare conditions underlying child survival. These findings support a dual approach: continued strengthening of high-quality maternal, newborn, and child healthcare, alongside measures that address the socioeconomic conditions underlying unequal survival. Particular attention is warranted for economically disadvantaged households and multiple pregnancies, while sustained investment in maternal education, antenatal care, skilled delivery, and postnatal and neonatal services remains important.

Declarations

Funding

This research received no specific funding or financial support from any public, commercial, or not-for-profit funding agency.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Considerations

The study used secondary data from the NFHS. The ethical approval for the NFHS survey was obtained from the Institutional Review Board (IRB) of the International Institute of Population Sciences (IIPS), Mumbai, India. Written and informed consent was obtained from each respondent before participating in the survey; additionally, written informed consent was obtained from the parent/guardian of each respondent under 18 years of age. No separate ethical approval was required for this secondary data analysis, since the NFHS dataset is an anonymous, publicly available dataset with no identifiable information about the study participants.

Consent for publication

Not applicable. The study does not contain any individual person's identifiable information.

The data are not published or considered for publication in any other journal

The author confirms that this manuscript has not been published previously and is not currently under

consideration for publication in any other journal.

Data Availability

This study is based on five rounds of India's National Family and Health Survey (NFHS), collected between 1992 and 2021, and publicly available for download on request for research and study purposes. Data can be requested through the Demographic and Health Surveys Program's data distribution system: https://dhsprogram.com/.

Authors' contribution

***Jyoti S. Hallad*:** Conceptualisation, Methodology, Supervision, Writing – review and editing.

***Javeed A. Golandaj*:** Conceptualisation, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review and editing.

Acknowledgements

An earlier version of the manuscript was presented at the Southern Regional Conference of the Indian Association for the Study of Population (IASP). The authors gratefully acknowledge the IASP for providing the opportunity and for the valuable academic feedback received. The authors also acknowledge the DHS and the IIPS for providing access to the NFHS data used in this study. The authors are grateful to the anonymous reviewers for their constructive comments and suggestions, which have significantly improved the manuscript.

How to cite this paper

Hallad JS, Golandaj JA. Early childhood mortality in Southern India: trends, differentials, and determinants. *Journal of Population Health Dynamic* . 2026;1(1):34-43.

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