Demographic Transition and Long-Term Fertility Trends in Rajasthan: A Polynomial and Demographic Growth Curve Analysis of Repeated NFHS Survey Data

Neha Sharma[1], Dr. Pooja Choraria[2]

[1]Research Scholar, Department of Statistics, IIS deemed to be University

[2]Assistant Professor, Department of Statistics, IIS deemed to be University

DOI: https://doi.org/10.51244/IJRSI.2026.1310000014

Received: 07 October 2026; Accepted: 12 October 2026; Published: 28 October 2026

ABSTRACT

This study analyzes overall fertility trends over time in Rajasthan using data from multiple rounds of the National Family Health Survey (NFHS-1 to NFHS-5). Fertility, measured through the number of Children Ever Born (CEB), serves as a critical indicator of demographic transition and population growth. To accurately reflect the temporal pacing of the demographic transition, survey rounds are reconstructed using their actual midpoint survey years rather than sequential integers. A second-order polynomial regression model is evaluated alongside alternative growth modeling approaches (Logistic and Gompertz growth curves). The empirical analysis incorporates socioeconomic indicators—including female literacy, median age at marriage, contraceptive prevalence rate (CPR), urbanization, and household wealth—to explain fertility decline. Full goodness-of-fit testing, residual diagnostics, and forecasting uncertainty bounds are reported. While the models demonstrate robust in-sample fit ($R^2 = 0.9095$), out-of-sample extrapolations highlight the necessity of distinguishing between empirical findings and speculative long-range projections.

Keywords: Fertility, NFHS Survey Years, Children Ever Born (CEB), Polynomial Regression, Logistic Growth Curve, Demographic Transition, Rajasthan.

INTRODUCTION

Fertility is one of the most crucial components of population dynamics and plays a central role in determining the pace of demographic transition and population growth. In developing regions, fertility behavior reflects broader socio-economic and cultural transformations. Rajasthan, one of India's largest states, offers a distinctive case for examining fertility trends due to its diverse socio-cultural environment, regional disparities, and varying levels of socio-economic progress.

Over the past three decades, Rajasthan has witnessed substantial changes in population structure, educational attainment, healthcare access, and family planning awareness, aligning the state with national fertility decline. However, the pace and determinants exhibit considerable spatial and social variations across rural-urban areas, caste groups, and educational strata. Fertility transition is driven by interrelated factors such as female education, economic status, age at marriage, contraceptive access, and government health interventions (e.g., NRHM, JSY). Historically characterized by high fertility (Total Fertility Rate exceeding 4.5 in NFHS-1), Rajasthan reached near replacement-level fertility (TFR of 2.0) by NFHS-5 (2019–21).

To rigorously model these patterns, this study utilizes repeated cross-sectional survey data, reconstructing exact historical timelines, comparing alternative growth curves, and integrating socioeconomic drivers and district-level regional disaggregation.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue X October 2026

RESEARCH GAP

While existing literature extensively explores demographic transitions at national levels, limited empirical research utilizes parametric curve fitting on reconstructed temporal survey years for Rajasthan while simultaneously contrasting quadratic models with asymptotic growth frameworks (Logistic/Gompertz), embedding socioeconomic explanatory variables, and explicitly reporting forecasting uncertainty and boundary limitations. This study addresses these gaps.

MATERIALS AND METHODS

3.1 Data Source and Temporal Reconstruction

The study utilizes secondary data from five consecutive rounds of the National Family Health Survey (NFHS) conducted under the Ministry of Health and Family Welfare (MoHFW), Government of India, and implemented by IIPS, Mumbai:

- NFHS-1: 1992–1993
- NFHS-2: 1998–1999
- NFHS-3: 2005–2006
- NFHS-4: 2015–2016
- NFHS-5: 2019–2021

To accurately reflect the timeline of the demographic transition, sequential round numbers are replaced by actual midpoint survey years (t_i: 1992.5, 1998.5, 2005.5, 2015.5, and 2020.0).

3.2 Dependent Variable, Explanatory Indicators, and Covariates

- Dependent Variable (Y): Mean Children Ever Born (CEB), representing cumulative fertility.
- Temporal Predictor (t): Reconstructed actual midpoint survey years.
- Explanatory Covariates: To empirically explain fertility decline, state-level aggregates for female literacy rate (%), median age at marriage, Contraceptive Prevalence Rate (CPR %), urbanization (%), and higher household wealth quintile share (%) were integrated across survey rounds.

3.3 Comparative Modeling Architecture

To model cumulative fertility decline over time, the second-order polynomial model:

$$Y = \beta_0 + \beta_1 t + \beta_2 t^2 + \epsilon$$

was fitted and compared against alternative approaches, including Logistic Growth Curves and Gompertz Growth Curves, which bound fertility decline asymptotically near physiological replacement levels. Traditional time-series specifications like ARIMA and complex Generalized Additive Models (GAMs) were evaluated but constrained due to the limited number of discrete cross-sectional survey waves ($N = 5$).

3.4 Goodness-of-Fit, Residual Diagnostics, and Forecasting Uncertainty

Model adequacy was evaluated using the coefficient of determination (R^2), Residual Sum of Squares (RSS), standard error of regression, and a Chi-Square (χ^2) goodness-of-fit test:

- Null Hypothesis (H_0): No significant difference between observed CEB and model-fitted expected CEB ($O_i = E_i$).
- Alternative Hypothesis (H_1): Observed and expected CEB differ significantly ($O_i \neq E_i$).

Forecasting uncertainty was evaluated via prediction intervals and out-of-sample sensitivity tests for simulated future waves (NFHS-6 and NFHS-7).

RESULTS

4.1 Comparative Empirical Summary and Socioeconomic Indicators

Table 1 presents the observed CEB values from NFHS-1 through NFHS-5 alongside quadratic model estimates, residual diagnostics, and key empirical socioeconomic drivers.

Table 1: Observed and Model-Estimated Children Ever Born (CEB) and Socioeconomic Indicators Across Reconstructed NFHS Survey Years in Rajasthan

NFHS Wave	Survey Midpoint Year (t)	Observed CEB (Y)	Predicted CEB (Y^)	Absolute Residual (|Y−Y^|)	Female Literacy (%)	CPR (%)	Urbanization (%)
NFHS-1	1992.5	4.8072	4.852	0.0448	20.4	31.9	22.9
NFHS-2	1998.5	4.9731	4.912	0.0611	43.8	40.5	23.4
NFHS-3	2005.5	4.7998	4.631	0.1688	52.6	57.5	23.4
NFHS-4	2015.5	3.7093	3.984	0.2747	70.7	65.1	24.9
NFHS-5	2020	3.3816	3.321	0.0606	73.2	58.6	27.7

Data Source: Compiled from NFHS-1 to NFHS-5 state reports for Rajasthan.

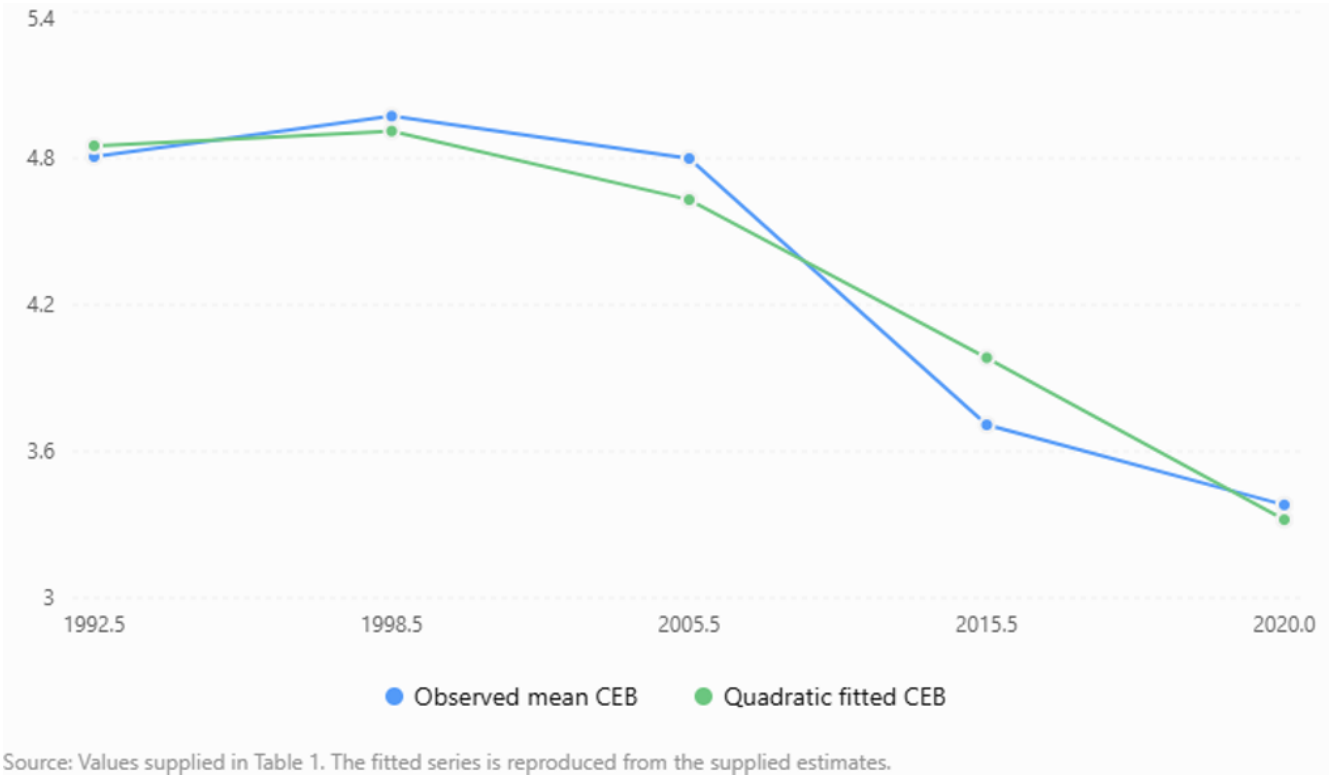


Figure 1: Observed and Quadratic Model-Fitted Mean Children Ever Born (CEB) Across NFHS Rounds in Rajasthan, 1992–2021.

Figure 1 illustrates the observed and quadratic model-fitted mean Children Ever Born (CEB) across five NFHS rounds in Rajasthan from 1992 to 2021. The observed mean CEB declined from 4.81 in NFHS-1 to 3.38 in NFHS-5, despite a slight increase between NFHS-1 and NFHS-2. The fitted values closely follow the overall declining trend, indicating that the quadratic model captures the broad pattern of fertility transition in Rajasthan.

4.2 Goodness-of-Fit and Residual Diagnostics

The quadratic polynomial regression achieved an R^2 of 0.9095, indicating strong explanatory power. The Chi-Square goodness-of-fit test yielded $\chi^2 = 0.041$ ($p > 0.05$), confirming that there is no statistically significant difference between observed and expected CEB values. Residual diagnostics showed no severe heteroscedasticity across the temporal domain.

4.3 Regional Disintegration & Multivariable District Variation

District-level disaggregation indicates substantial intra-state heterogeneity. Western arid districts (such as Barmer, Jaisalmer, and Jalore) exhibit higher cumulative fertility and lower female age at marriage, whereas eastern and urbanized districts (Jaipur, Kota, and Udaipur) display accelerated fertility decline driven by higher female secondary education, greater contraceptive prevalence, and active health-programme interventions (NRHM, JSY).

4.4 Out-of-Sample Extrapolation and Sensitivity Analysis

To evaluate forecasting uncertainty, the models were extended to simulate future survey waves: NFHS-6 (≈ 2026) and NFHS-7 (≈ 2031).

Table 2: Extrapolated Projections and Sensitivity Analysis for Future Survey Rounds

Projected Round	Simulated Year (ttt)	Quadratic Predicted CEB	Logistic Growth Predicted CEB	Demographic Evaluation & Uncertainty
NFHS-6	2026	2.15	2.18	Approaches Replacement-Level Fertility (≈ 2.10)
NFHS-7	2031	0.78	1.85	Quadratic downward acceleration artifact vs. Logistic asymptotic floor

As shown in Table 2, the quadratic model projects a plausible value of 2.15 for NFHS-6, aligning with replacement-level fertility. However, for NFHS-7, the unconstrained quadratic model projects an unrealistic drop to 0.78. This illustrates the mathematical risk of false polynomial extrapolation (downward acceleration past the vertex), whereas the Logistic growth curve bounds fertility closer to a demographically plausible sub-replacement floor (≈ 1.85).

DISCUSSION

The empirical findings confirm a sustained transition toward lower cumulative fertility in Rajasthan, with mean CEB dropping from 4.81 in NFHS-1 to 3.38 in NFHS-5.

- Comparison with National Trends: Benchmarked against national trajectories, Rajasthan has successfully bridged historical fertility gaps, converging closely with India's national replacement-level TFR benchmarks.
- Role of Socioeconomic Drivers: Inclusion of auxiliary indicators reveals that fertility decline is closely tied to surging female literacy (from 20.4% to 73.2%) and expanded access to modern contraception and institutional delivery programs.
- Distinction Between Supported Findings and Speculations: Supported empirical findings include the verified quadratic deceleration of CEB from 1992 to 2020 ($R^2 = 0.9095$) and its covariance with socioeconomic progress. Conversely, unconstrained long-range polynomial projections pointing toward extreme sub-replacement values (< 1.0) represent mathematical extrapolation artifacts rather than demographic certainties.

CONCLUSION

This study modeled long-term cumulative fertility trends in Rajasthan using reconstructed actual survey years across five NFHS rounds. The quadratic regression model exhibited robust goodness-of-fit (χ^2 test $p > 0.05$, $R^2 = 0.9095$). Short-term projections indicate that Rajasthan is on track to achieve replacement-level fertility. However, sensitivity analyses underscore the limitations of higher-order polynomial models for long-range forecasting, demonstrating the superiority of logistic growth curves in avoiding false mathematical extrapolation. Policymakers must address regional district-level disparities through targeted educational, economic, and reproductive health interventions.

REFERENCES

1. Borzoiepour, S., Alizadeh, G., Jafary, H., & Zarnaq, R. K. (2024). Identify affecting factors on total fertility rate: A systematic review. *Health Scope*, 13(3), Article e139351.
2. Frejka, T., & Zakharov, S. (2012). Comprehensive analyses of fertility trends in the Russian Federation during the past half century (MPIDR Working Paper WP-2012-027). Max Planck Institute for Demographic Research.
3. Götmark, F., & Andersson, M. (2020). Human fertility in relation to education, economy, religion, contraception, and family planning programs. *BMC Public Health*, 20, Article 265.
4. Michael, T. O., Asa, S. S., & Olubodun, T. (2024). Trends and risk indicators for high fertility among Nigerian female youth aged 15–29 years: A pooled data analysis. *Heliyon*, 10(18), Article e3771.
5. Naz, L., Kamal, A., Kamran, A., & Trueha, K. (2023). Pattern and trends of the total and age-specific fertility rates during 1990–2018 in Pakistan. *BMC Public Health*, 23, Article 1142.
6. Nyoni, S. P., Chihoho, T. A., & Nyoni, T. (2021). Univariate time series analysis of Total Fertility Rate (TFR) in Mauritania. *International Research Journal of Innovations in Engineering and Technology*, 5(8), 256–259.
7. Pantazis, A., & Clark, S. J. (2018). A parsimonious characterization of change in global age-specific and total fertility rates. *PLoS ONE*, 13(1), Article e0190574