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Dynamic Fertility Preferences in Nigeria: A Bayesian Spatio-Temporal Analysis of DHS Data, 2003–2024

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Abstract

Background: Fertility preferences are an important indicator of reproductive intentions and demographic change, but national averages can obscure substantial geographic and life-course differences. This study examined how women's preferences for additional children have changed across Nigeria and whether these changes vary by age, individual characteristics, and geographic location between 2003 and 2024.

Methods: Data were obtained from five nationally representative Nigeria Demographic and Health Survey rounds conducted in 2003, 2008, 2013, 2018, and 2024. The analysis included married or cohabiting women aged 15–49 years. Fertility preference was defined as a binary outcome indicating whether a woman desired another child. A Bayesian hierarchical binomial model was fitted using Integrated Nested Laplace Approximation. The model incorporated nonlinear age effects, survey-year effects, individual and household characteristics, and spatial variation across states using the Besag–York–Mollié 2 model. Posterior estimates and 95% credible intervals were used to assess associations and changes over time.

Results: Fertility preference declined substantially at the national level by 2024, although considerable variation remained across states. The posterior odds of desiring another child were lower in 2024 than in 2003, while differences between some intervening survey years were less pronounced. Women with more living children had lower odds of desiring another child. Higher educational attainment and greater participation in household decision-making were also associated with lower fertility preference, whereas Muslim women had higher odds of desiring another child. Fertility preference varied systematically across the reproductive life course, with a nonlinear age pattern. Spatial estimates showed persistent geographic clustering but also substantial changes in the relative level of fertility preference across states between survey rounds, indicating that the fertility transition has not occurred uniformly across Nigeria. Sensitivity analyses showed that the main substantive and spatial findings were broadly robust to alternative prior specifications.

Conclusions: Nigeria has experienced a substantial decline in fertility preference over the study period, but the transition remains geographically uneven and varies across the reproductive life course. These findings suggest that national fertility trends can mask

important subnational differences and support geographically targeted reproductive health planning, continued investment in female education and women's empowerment, and improved access to family-planning services.

Keywords: Fertility preference; Bayesian hierarchical modelling; fertility transition; reproductive life course; spatial heterogeneity; Nigeria DHS

1 Background

Fertility preferences—the desire to have additional children or to stop childbearing—are central to understanding demographic transition, reproductive behaviour, and future population dynamics. Unlike realised fertility, which reflects both reproductive intentions and constraints, fertility preferences provide a more direct measure of desired family size and reproductive aspirations. As such, they are widely recognised as an important predictor of future fertility behaviour and an essential component of reproductive health planning [1, 2]. In sub-Saharan Africa, where fertility transitions remain incomplete and highly heterogeneous, understanding fertility preferences is particularly important for anticipating future demographic change and designing context-specific reproductive health policies.

Nigeria represents one of the most demographically complex settings in sub-Saharan Africa. Despite gradual declines in total fertility rates over recent decades, fertility levels remain among the highest globally, with substantial regional variation in reproductive behaviour and family size preferences [3, 4]. Northern regions consistently exhibit higher fertility desires and earlier childbearing patterns compared with southern regions, reflecting persistent socio-cultural, religious, and economic disparities [5, 6]. These differences suggest that fertility preferences are shaped not only by individual characteristics but also by broader contextual processes embedded within geographic and social environments.

Previous studies have identified several socio-demographic determinants of fertility preferences in Nigeria and other African countries. Female education remains one of the strongest predictors of lower desired fertility, operating through delayed marriage, increased labour force participation, enhanced reproductive autonomy, and greater exposure to alternative family norms [1, 7]. Women's decision-making autonomy and household bargaining power

have also been linked to reduced fertility desires and increased contraceptive uptake [8, 9]. Religious affiliation, place of residence, household wealth, and partner characteristics further contribute to variation in fertility intentions and reproductive outcomes across populations [5, 10].

Beyond individual-level determinants, recent demographic research has increasingly recognised the importance of spatial processes in shaping fertility behaviour. Fertility outcomes often exhibit strong geographic clustering because neighbouring regions tend to share similar socio-cultural norms, economic conditions, health systems, and diffusion processes. In Nigeria, studies by Gayawan and collaborators, among others, have demonstrated substantial spatial heterogeneity in fertility outcomes, contraceptive behaviour, and reproductive health indicators using Bayesian spatial models and Demographic and Health Survey (DHS) data [11, 12, 13]. Similar spatial fertility patterns have also been documented in other African settings, highlighting the importance of accounting for geographic dependence when analysing reproductive behaviour [14, 15].

However, despite these advances, several important methodological and substantive gaps remain in the literature. First, much of the existing research focuses primarily on realised fertility outcomes, fertility rates, or contraceptive behaviour, with comparatively limited attention to fertility preferences themselves. Yet fertility preferences represent an earlier stage in the reproductive decision-making process and may provide more direct insight into future fertility trajectories and demographic transition dynamics [1, 2]. Second, although many studies incorporate spatial dependence, most rely on cross-sectional analyses conducted at a single point in time [13, 16]. Such approaches capture geographic variation but provide limited understanding of how fertility preferences evolve across time and reproductive life-course stages.

Third, existing studies rarely integrate spatial dependence, temporal evolution, and non-linear demographic processes within a unified modelling framework. In particular, relatively little attention has been given to modelling fertility preferences simultaneously across survey time, geographic space, and reproductive life-course characteristics such as age and marital duration. Repeated cross-sectional surveys such as the DHS provide an opportunity to investigate these dimensions jointly; however, analyses often rely on descriptive comparisons

or conventional regression approaches that may not adequately represent nonlinear demographic trajectories or residual geographic dependence [15, 9]. Consequently, there remains limited evidence on how fertility preferences vary simultaneously across time, space, and women's reproductive life course, and on whether the resulting spatial patterns are robust to alternative statistical assumptions.

Another important limitation is that fertility preferences are frequently treated as relatively static outcomes, despite their potential to change systematically with reproductive ageing, marital exposure, accumulated childbearing, and changing socioeconomic circumstances. Nonlinear relationships with age and marital duration may be obscured when these variables are represented using simple linear terms or conventional categorical groupings. At the same time, geographic differences may persist after accounting for observed individual- and household-level characteristics. A modelling framework that accommodates nonlinear life-course trajectories together with structured spatial heterogeneity is therefore needed to distinguish demographic patterns associated with individual characteristics from persistent geographic variation.

From a methodological perspective, Bayesian hierarchical models provide a flexible framework for jointly addressing these sources of heterogeneity. The reparameterised Besag–York–Mollié (BYM2) model allows spatial variation to be decomposed into structured and unstructured components while accounting for geographic dependence [17]. When combined with nonlinear random-effect specifications, such as second-order random walks for age and marital duration, and survey-year effects, the framework can capture flexible reproductive trajectories while retaining coherent probabilistic inference. This approach is particularly appropriate for repeated DHS data in which individual-level characteristics are observed within geographically structured populations and across multiple survey periods.

An additional concern in complex Bayesian hierarchical models is the potential sensitivity of posterior estimates to prior assumptions, particularly for latent spatial and nonlinear components. Prior sensitivity is therefore an important component of model validation rather than merely a technical consideration. Assessing alternative levels of shrinkage for spatial effects, alternative priors for fixed effects, and alternative specifications for the BYM2 mixing parameter provides a means of determining whether the substantive conclusions are

driven by particular prior choices.

This study develops a Bayesian hierarchical spatio-temporal framework for analysing fertility preferences in Nigeria using DHS data spanning 2003–2024. The analysis integrates individual- and household-level determinants with survey-year effects, nonlinear reproductive life-course trajectories, and structured and unstructured spatial heterogeneity. Specifically, nonlinear effects of age and marital duration are incorporated alongside geographic random effects to characterise how fertility preferences vary across reproductive life-course stages and Nigerian states. The robustness of the resulting inferences is further evaluated through systematic sensitivity analysis under alternative prior specifications.

By jointly modelling these dimensions, the study moves beyond describing temporal or spatial differences in fertility preferences to characterising fertility preference as a multi-dimensional demographic process. The framework enables assessment of temporal change, geographic persistence, nonlinear reproductive trajectories, and the robustness of these patterns to prior uncertainty. The resulting evidence provides a more integrated understanding of the heterogeneous fertility transition occurring across Nigeria and offers a statistical basis for identifying populations and geographic settings where reproductive preferences may require differentiated policy responses.

These findings have important implications for geographically targeted reproductive health interventions, fertility transition policy, and broader demographic planning in Nigeria and similar high-fertility settings in sub-Saharan Africa.

2 Methods

2.1 Data

This study utilised repeated cross-sectional data from five rounds of the Nigeria Demographic and Health Survey (NDHS) conducted in 2003, 2008, 2013, 2018, and 2024. The NDHS is a nationally representative survey implemented by the National Population Commission (NPC) in collaboration with ICF under the global Demographic and Health Survey (DHS) programme. The survey collects detailed information on fertility, reproductive health, family planning, maternal and child health, and socio-demographic characteristics of women aged

15–49 years.

The NDHS adopts a stratified two-stage cluster sampling design. In the first stage, enumeration areas are selected using probability proportional to size within each state and the Federal Capital Territory (FCT). In the second stage, households are systematically sampled within selected clusters. Sampling weights are provided to account for unequal probabilities of selection and non-response. The present study pooled individual-level data across all survey waves to examine the spatial and temporal dynamics of fertility preferences in Nigeria over a 21-year period. The analysis focused on currently married or cohabiting women aged 15–49 years.

The outcome variable was fertility preference, defined as whether a woman desired another child. Women who were undecided, infecund, sterilised, or had missing responses were excluded to ensure consistency in the interpretation of fertility intentions. Explanatory variables included educational attainment, place of residence, religion, women's participation in household decision-making, partner employment status, and modern contraceptive use. Additional individual- and household-level covariates included media exposure, contact with family-planning services, household wealth, and partner's educational attainment. Age and age at first union were included as continuous variables to capture nonlinear reproductive life-course patterns. Table 1 presents the weighted descriptive characteristics of the study population across survey years.

Because state coding schemes differed across DHS survey waves, state identifiers were harmonised before analysis. Earlier DHS rounds used codes ranging from 10–370, whereas the 2003 and 2024 surveys used codes ranging from 1–37. All state identifiers were standardised to a unified 1–37 coding structure corresponding to the 36 Nigerian states and the Federal Capital Territory.

To account for unequal probabilities of selection and to place respondents on a common weighting scale in the pooled analysis, the original DHS sampling weights were normalised by their mean. For respondent i, the normalised sampling weight was defined as

$$w_i = \frac{v005_i}{\overline{v005}} = \frac{v005_i}{\dfrac{1}{n}\displaystyle\sum_{j=1}^{n} v005_j},$$

where $v005_i$ denotes the original DHS sampling weight for respondent i, $\overline{v005}$ is the mean DHS sampling weight across the analysis population, and n is the number of women in the analysis population. This transformation preserves the relative weighting of respondents while placing the weights on a common scale with mean one.

State-level administrative boundary shapefiles for Nigeria were obtained from publicly available geospatial sources. Spatial adjacency relationships were constructed using queen contiguity criteria, whereby states sharing a common boundary or vertex were considered neighbours. Let $s \sim r$ denote neighbouring states. The resulting adjacency matrix formed the basis for modelling spatial dependence within a Bayesian hierarchical framework.

Conceptually, fertility preferences were viewed as dynamic demographic processes evolving across geographic space, survey time, and women's reproductive life course. Rather than treating fertility intentions as static outcomes, the analysis conceptualised reproductive decision-making as a process shaped by reproductive ageing, age at entry into union, socioeconomic circumstances, household context, and socio-cultural heterogeneity. The modelling framework therefore integrated spatial dependence, temporal variation across survey waves, nonlinear life-course trajectories, and contextual variability within a unified Bayesian hierarchical structure.

2.2 Bayesian Hierarchical Model

Let Y_{ist} denote the fertility preference outcome for woman i residing in state s during survey year t. Conditional on the latent probability p_{ist}, the outcome was assumed to follow a Bernoulli distribution:

$$Y_{ist} \sim \text{Bernoulli}(p_{ist}),$$

with

$$\text{logit}(p_{ist}) = \eta_{ist}.$$

The linear predictor was specified as

$$\begin{aligned}\eta_{ist} = \beta_0 + \mathbf{x}_{ist}^{\top}\boldsymbol{\beta} + f_{\text{age}}(a_{ist}) + \delta_{\text{age},s}(a_{ist}) + \delta_{\text{MD},s}(d_{ist}) \\ + \beta_{2008} I(t = 2008) + \beta_{2013} I(t = 2013) + \beta_{2018} I(t = 2018) + \beta_{2024} I(t = 2024) \\ + u_{c[i]} + v_{q[i]} + \gamma_s.\end{aligned}$$

Here, β_0 denotes the intercept, $\mathbf{x}_{ist}$ represents the vector of observed individual- and household-level covariates, and $\boldsymbol{\beta}$ denotes the corresponding regression coefficients. The function $f_{\text{age}}(a_{ist})$ represents the national nonlinear association between woman's current age and fertility preference, while $\delta_{\text{age},s}(a_{ist})$ represents the state-specific departure from the national age trajectory. Similarly, $\delta_{\text{MD},s}(d_{ist})$ represents the corresponding state-specific departure.

The national smooths describe the overall nonlinear association between fertility preference and the two reproductive life-course variables, whereas the state-specific terms allow these associations to vary across states. The state-specific functions were modelled hierarchically so that information could be shared across states while retaining geographic differences in the shape of the nonlinear associations. The state-level spatial effect γ_s therefore represents residual spatial heterogeneity after accounting for the observed covariates and the state-specific life-course associations.

The survey-year indicators capture differences in fertility preferences between survey waves, with 2003 serving as the reference year. The terms $u_{c[i]}$ and $v_{q[i]}$ represent PSU- and stratum-level random effects, respectively. The model did not include a separate state-by-survey-year interaction term. Temporal differences were estimated through survey-year fixed effects, while residual spatial dependence was modelled through the BYM2 spatial component.

The nonlinear national associations of age and marital duration were modelled using second-order random walk (RW2) priors. For a generic latent function $f(x)$, the RW2 prior was specified as

$$f(x) - 2f(x-1) + f(x-2) \sim \mathcal{N}(0, \tau_f^{-1}),$$

where τ_f denotes the precision parameter controlling the smoothness of the trajectory.

The national nonlinear age association was specified as

$$f_{\text{age}}(a) - 2f_{\text{age}}(a-1) + f_{\text{age}}(a-2) \sim \mathcal{N}(0, \tau_{\text{age}}^{-1}),$$

State-specific departures from the national trajectories were also modelled using RW2 priors. For state s, the age-specific deviation was specified as

$$\delta_{\text{age},s}(a) - 2\delta_{\text{age},s}(a-1) + \delta_{\text{age},s}(a-2) \sim \mathcal{N}(0, \tau_{\text{age},s}^{-1}),$$

and the marital-duration-specific deviation was specified as

$$\delta_{\text{MD},s}(d) - 2\delta_{\text{MD},s}(d-1) + \delta_{\text{MD},s}(d-2) \sim \mathcal{N}(0, \tau_{\text{MD},s}^{-1}).$$

The hierarchical state-specific formulation allows the association between fertility preference and age, as well as the association between fertility preference and marital duration, to differ across states while borrowing information across states. This provides a common national nonlinear trajectory together with state-specific departures from that trajectory, rather than assuming either a single trajectory for all states or completely independent state-specific curves.

The RW2 formulation allows the associations between fertility preference and reproductive life-course variables to vary flexibly across their respective ranges while penalising abrupt changes between adjacent values. This avoids imposing restrictive linear assumptions and permits the identification of nonlinear patterns across different stages of the reproductive life course.

The nonlinear functions were centred to improve identifiability with the model intercept and fixed effects. Posterior estimates of the national smooths were used to characterise overall nonlinear life-course patterns in fertility preferences, while the state-specific components were used to characterise geographic variation in these associations.

Spatial dependence was modelled using the reparameterised Besag–York–Mollié 2 (BYM2) specification:

$$\gamma_s = \frac{1}{\sqrt{\tau_s}} \left(\sqrt{\phi}\, u_s^* + \sqrt{1-\phi}\, v_s^* \right),$$

where u_s^* represents the scaled spatially structured effect, v_s^* denotes the unstructured state-level effect, τ_s is the overall spatial precision, and $\phi \in [0, 1]$ is the BYM2 mixing parameter. The structured component captures residual spatial dependence among neighbouring states, whereas the unstructured component captures state-specific heterogeneity not explained by the spatial structure.

The structured spatial component followed an intrinsic conditional autoregressive (ICAR) prior:

$$u_s^* \mid u_{-s} \sim \mathcal{N}\left(\frac{1}{n_s} \sum_{r \sim s} u_r^*, \frac{1}{n_s \tau_u} \right),$$

where n_s denotes the number of neighbouring states.

The posterior distribution of ϕ was used to assess the relative contribution of structured and unstructured spatial heterogeneity within the BYM2 decomposition. Larger values of ϕ indicate a greater contribution from the structured spatial component.

The normalised sampling weights defined above were incorporated into the Bayesian model through the likelihood. For posterior state-year summaries, individual posterior mean fertility-preference probabilities were aggregated using the same normalised sampling weights. For state s and survey year t, the posterior weighted mean was calculated as

$$\widehat{P}_{st} = \frac{\sum_{i \in (s,t)} w_i\, \widehat{p}_{ist}}{\sum_{i \in (s,t)} w_i},$$

where w_i denotes the normalised sampling weight and $\widehat{p}_{ist}$ is the posterior mean fertility-preference probability for woman i. The resulting estimates represent population-weighted state-year fertility preferences and were used to construct national and spatial summaries.

To characterise the magnitude of changes in fertility preference across states between consecutive survey rounds, we calculated the difference between posterior weighted state-year estimates:

$$\Delta_{s,t} = \left| \widehat{P}_{s,t} - \widehat{P}_{s,t-1} \right|.$$

Here, $\widehat{P}_{s,t}$ denotes the posterior weighted mean fertility preference for state s at survey year t. Larger values indicate greater changes in fertility preference between consecutive survey rounds, whereas smaller values indicate greater stability between observations. Because the intervals between survey rounds were not identical, this measure was interpreted as the magnitude of change between consecutive survey observations rather than as an annualized rate of change.

Penalised complexity (PC) priors were assigned to the principal hyperparameters of the spatial and latent-effect components. For the spatial standard deviation $\sigma_s = 1/\sqrt{\tau_s}$, the prior was specified as

$$\Pr(\sigma_s > 1) = 0.01.$$

For the BYM2 mixing parameter, the prior was specified as

$$\Pr(\phi < 0.5) = \frac{2}{3}.$$

Fixed-effect coefficients were assigned diffuse Gaussian priors:

$$\beta_j \sim \mathcal{N}(0, 10^3),$$

while weakly informative PC priors were assigned to the precision parameters of the nonlinear and random-effect components to control their complexity while allowing the data to determine the magnitude of the latent variation.

To assess the robustness of posterior inference to alternative prior assumptions, the final Bayesian hierarchical model was refitted under six prior specifications while retaining the same outcome definition, covariate structure, survey-design specification, spatial adjacency structure, and latent-effect structure.

The six scenarios comprised: (i) the baseline prior specification; (ii) a more diffuse fixed-effect prior; (iii) a more informative fixed-effect prior; (iv) stronger spatial shrinkage; (v)

weaker spatial shrinkage; and (vi) an alternative prior specification for the BYM2 mixing parameter ϕ.

For each specification, model fit was evaluated using the Deviance Information Criterion (DIC) and Watanabe–Akaike Information Criterion (WAIC). Posterior estimates and 95% credible intervals for the fixed effects were compared across prior specifications, with particular attention to the survey-year effects and key socio-demographic associations. The posterior distribution of the BYM2 mixing parameter was also examined to determine whether the estimated balance between structured and unstructured spatial variation was sensitive to prior choice.

The sensitivity analysis was interpreted as a robustness assessment rather than as a procedure for selecting a preferred prior. Substantive conclusions were considered robust when posterior estimates and their uncertainty remained broadly stable across the alternative prior specifications.

Models were estimated using Integrated Nested Laplace Approximation (INLA) implemented within the R-INLA framework. INLA provides computationally efficient Bayesian inference for latent Gaussian models while maintaining high approximation accuracy.

Model performance was assessed using the Deviance Information Criterion (DIC), Watanabe–Akaike Information Criterion (WAIC), and marginal log-likelihood. Lower DIC and WAIC values were interpreted as evidence of comparatively better model fit.

Model fit statistics were considered jointly with posterior estimates, credible intervals, and the prior sensitivity analysis rather than being used as the sole basis for model assessment.

Posterior fitted probabilities were aggregated to state-year combinations using the survey-weighted estimator described above to generate smoothed fertility-preference surfaces across Nigeria. Posterior estimates of the nonlinear age and age-at-first-union functions were examined to characterise variation in fertility preferences across reproductive life-course stages.

Variance decomposition was used to assess the relative contributions of structured and unstructured spatial heterogeneity through the BYM2 mixing parameter.

The resulting posterior summaries and spatial visualisations provide insights into persistent regional fertility regimes, spatial heterogeneity in reproductive preferences, nonlinear life-course patterns, and the magnitude of fertility-preference transitions across Nigeria.

3 Results

Table 1 shows the weighted characteristics of women included in the analysis across the five NDHS waves. The mean age increased from 30.25 years in 2003 to 31.73 years in 2024. The mean number of living children varied little across the surveys, ranging from 3.03 in 2008 to 3.35 in 2018.

The age distribution was fairly similar across the survey years. Women aged 25–29 years made up the largest age group in 2003 (25.9%), 2008 (28.4%), and 2013 (25.1%). In 2018 and 2024, women aged 25–29 and 30–34 years accounted for most of the sample. The proportion of women aged 40–44 years increased from 9.8% in 2003 to 12.2% in 2024.

There were differences in educational attainment across the survey years. The proportion of women with no formal education was 37.6% in 2003 and 33.1% in 2024, while those with higher education increased from 7.9% to 17.1%. Women with secondary education accounted for 29.5% of the sample in 2003 and 36.9% in 2024. Partner's educational attainment also changed, with the proportion having higher education increasing from 20.2% in 2003 to 26.8% in 2024.

Women's participation in household decision-making differed across the surveys. The proportion reporting involvement in decisions about their own healthcare increased from 26.7% in 2003 to 53.1% in 2024. Participation in decisions about large household purchases increased from 23.1% to 46.9%, while participation in decisions about visits to family increased from 39.7% to 62.8%.

Media exposure was reported by 86.6% of women in 2003 and 87.0% in 2013, but this fell to 69.5% in 2018 and 63.2% in 2024. The proportion of women who were employed was relatively high throughout the study period, ranging from 66.9% in 2024 to 76.1% in 2013.

The distribution of place of residence varied across the survey years. The proportion of women living in urban areas increased from 41.2% in 2003 to 56.4% in 2013, declined to 43.6% in 2018, and increased again to 49.1% in 2024. The corresponding proportion living in rural areas was 58.8% in 2003 and 50.9% in 2024.

Table 1: Descriptive characteristics of the study population by survey year

Variable	Category	2003	2008	2013	2018	2024
Age group	15–19	128 (7.3; 5.5–9.2)	238 (4.5; 3.8–5.1)	332 (5.0; 4.3–5.8)	693 (5.8; 5.2–6.3)	430 (4.6; 4.1–5.2)
	20–24	317 (17.6; 15.6–19.6)	810 (16.7; 15.5–18.0)	1102 (16.3; 15.2–17.5)	2185 (17.4; 16.6–18.2)	1560 (16.4; 15.3–17.5)
	25–29	512 (25.9; 23.3–28.5)	1375 (28.4; 26.9–29.8)	1707 (25.1; 23.8–26.4)	2975 (23.7; 22.8–24.6)	2177 (22.1; 21.1–23.1)
	30–34	362 (18.4; 16.4–20.3)	1029 (21.4; 20.1–22.7)	1452 (21.6; 20.4–22.9)	2533 (20.3; 19.5–21.1)	2087 (20.3; 19.4–21.2)
	35–39	272 (14.3; 12.3–16.3)	704 (14.1; 13.1–15.2)	1110 (16.4; 15.4–17.4)	2097 (16.3; 15.4–17.1)	1725 (16.4; 15.5–17.2)
	40–44	205 (9.8; 8.1–11.6)	460 (9.3; 8.4–10.1)	653 (9.1; 8.3–9.9)	1267 (9.4; 8.8–10.1)	1259 (12.2; 11.4–13.0)
	45–49	135 (6.7; 5.3–8.0)	271 (5.6; 4.9–6.3)	470 (6.5; 5.7–7.2)	969 (7.1; 6.6–7.7)	831 (7.9; 7.2–8.6)
Decision-making: own health care	No	1388 (73.3; 69.8–76.8)	2390 (48.9; 46.6–51.1)	3305 (48.3; 46.2–50.4)	6904 (54.1; 52.5–55.6)	4359 (46.9; 45.1–48.7)

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Table 1 continued

Variable	Category	2003	2008	2013	2018	2024
	Yes	543 (26.7; 23.2–30.2)	2497 (51.1; 48.9–53.4)	3521 (51.7; 49.6–53.8)	5815 (45.9; 44.4–47.5)	5710 (53.1; 51.3–54.9)
Decision-making: large household purchases	No	1457 (76.9; 74.2–79.5)	2768 (57.6; 55.5–59.6)	3378 (49.6; 47.5–51.7)	7514 (59.7; 58.3–61.2)	5009 (53.1; 51.4–54.8)
	Yes	474 (23.1; 20.5–25.8)	2119 (42.4; 40.4–44.5)	3448 (50.4; 48.3–52.5)	5205 (40.3; 38.8–41.7)	5060 (46.9; 45.2–48.6)
Decision-making: visits to family	No	1115 (60.3; 56.8–63.7)	1784 (36.5; 34.0–39.0)	2646 (39.2; 36.9–41.4)	4659 (36.2; 34.9–37.5)	3356 (37.2; 35.4–39.0)
	Yes	816 (39.7; 36.3–43.2)	3103 (63.5; 61.0–66.0)	4180 (60.8; 58.6–63.1)	8060 (63.8; 62.5–65.1)	6713 (62.8; 61.0–64.6)
Religion	Christian	929 (45.2; 40.0–50.4)	4833 (99.1; 98.8–99.4)	6781 (99.3; 99.0–99.6)	12676 (99.7; 99.5–99.9)	10024 (99.6; 99.4–99.8)
	Muslim	979 (54.0; 48.8–59.2)	35 (0.6; 0.3–0.8)	23 (0.3; 0.1–0.6)	36 (0.3; 0.1–0.5)	41 (0.4; 0.1–0.6)
	Other	23 (0.8; 0.4–1.2)	19 (0.3; 0.2–0.5)	22 (0.4; 0.2–0.5)	7 (0.0; 0.0–0.1)	4 (0.0; 0.0–0.1)

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Table 1 continued

Variable	Category	2003	2008	2013	2018	2024
Woman's employment	No	557 (29.2; 26.4–32.1)	1216 (24.7; 22.9–26.5)	1630 (23.9; 22.2–25.6)	3525 (28.2; 26.9–29.4)	3182 (33.1; 31.4–34.8)
	Yes	1374 (70.8; 67.9–73.6)	3671 (75.3; 73.5–77.1)	5196 (76.1; 74.4–77.8)	9194 (71.8; 70.6–73.1)	6887 (66.9; 65.2–68.6)
Partner's education	No education	540 (28.9; 25.0–32.7)	913 (16.8; 15.1–18.6)	1212 (18.7; 16.5–20.9)	3567 (28.8; 27.1–30.6)	2462 (26.6; 24.4–28.8)
	Primary	469 (22.0; 19.2–24.8)	1110 (22.6; 21.0–24.2)	1388 (20.0; 18.6–21.4)	1829 (13.8; 12.9–14.6)	1021 (9.9; 9.0–10.8)
	Secondary	557 (28.9; 25.8–32.0)	1818 (38.8; 36.9–40.8)	2661 (39.8; 37.7–41.9)	4695 (36.4; 35.0–37.7)	3858 (36.8; 35.1–38.4)
	Higher	365 (20.2; 16.9–23.6)	1046 (21.7; 19.7–23.8)	1565 (21.5; 19.8–23.1)	2628 (21.0; 19.5–22.6)	2728 (26.8; 25.1–28.4)
Wealth index	Poorest	287 (14.2; 10.7–17.7)	621 (10.5; 8.8–12.2)	525 (8.0; 6.8–9.2)	2520 (18.7; 17.0–20.3)	1672 (16.3; 14.3–18.3)
	Poorer	291 (14.4; 11.6–17.3)	710 (13.0; 11.3–14.7)	975 (14.1; 12.6–15.7)	2500 (19.3; 17.9–20.8)	1630 (17.6; 16.0–19.2)
	Middle	370 (18.9; 15.9–21.9)	901 (16.8; 15.1–18.4)	1410 (18.8; 16.9–20.6)	2631 (19.6; 18.2–21.0)	1945 (20.1; 18.5–21.6)

Continued on next page

Table 1 continued

Variable	Category	2003	2008	2013	2018	2024
	Richer	454 (23.5; 19.8–27.1)	1200 (24.3; 22.2–26.5)	1781 (25.7; 23.6–27.8)	2622 (20.4; 19.0–21.7)	2231 (21.6; 20.1–23.1)
	Richest	529 (29.0; 24.2–33.7)	1455 (35.4; 32.3–38.6)	2135 (33.4; 30.6–36.2)	2446 (22.0; 20.2–23.9)	2591 (24.5; 22.7–26.3)
Woman's education	No education	699 (37.6; 33.4–41.8)	1252 (23.1; 20.9–25.3)	1623 (25.1; 22.6–27.5)	4836 (38.4; 36.6–40.1)	3041 (33.1; 30.7–35.5)
	Primary	523 (25.0; 21.9–28.0)	1255 (24.6; 22.8–26.3)	1535 (22.0; 20.5–23.5)	2060 (15.2; 14.2–16.1)	1289 (12.9; 11.9–13.9)
	Secondary	550 (29.5; 25.7–33.3)	1745 (38.2; 36.1–40.3)	2692 (39.4; 37.0–41.7)	4286 (33.7; 32.2–35.1)	3884 (36.9; 35.2–38.6)
	Higher	159 (7.9; 6.2–9.7)	635 (14.1; 12.3–15.9)	976 (13.6; 12.1–15.1)	1537 (12.8; 11.5–14.2)	1855 (17.1; 15.9–18.4)
Media exposure	No	266 (13.4; 10.7–16.1)	794 (13.3; 11.9–14.7)	1012 (13.0; 11.7–14.3)	4131 (30.5; 29.0–31.9)	3529 (36.8; 34.6–38.9)
	Yes	1665 (86.6; 83.9–89.3)	4093 (86.7; 85.3–88.1)	5814 (87.0; 85.7–88.3)	8588 (69.5; 68.1–71.0)	6540 (63.2; 61.1–65.4)
Residence	Urban	850 (41.2; 36.5–46.0)	2174 (48.6; 45.8–51.3)	3585 (56.4; 53.8–59.1)	5014 (43.6; 41.8–45.4)	4921 (49.1; 46.9–51.4)

Continued on next page

Table 1 continued

Variable	Category	2003	2008	2013	2018	2024
	Rural	1081 (58.8; 54.0–63.5)	2713 (51.4; 48.7–54.2)	3241 (43.6; 40.9–46.2)	7705 (56.4; 54.6–58.2)	5148 (50.9; 48.6–53.1)

Note: Values are unweighted numbers followed by weighted percentages and design-based 95% confidence intervals in parentheses. Weighted percentages account for the DHS sampling weights.

Table 2: Predictive diagnostics for the competing Bayesian hierarchical models

Model	DIC	pDIC	WAIC	pWAIC	MLL	Mean log-CPO	CPO failures	Mean PIT	SD PIT	Brier	Cal. int.	Cal. slope	PPC mean	PPC 2.5%	PPC 97.5%
Model 1	42039.58	1.00	42040.28	1.35	-21022.30	-0.5770	0	0.8018	0.3294	0.18975	1.0746	Not estimable	0.74494	0.73899	0.75082
Model 2	26076.56	1115.04	26465.08	1260.81	-13284.85	-0.3611	0	0.8856	0.2345	0.10136	-0.0674	1.1609	0.74198	0.73764	0.74676
Model 3	29654.89	23.99	29672.34	33.04	-14957.53	-0.4071	0	0.8674	0.2564	0.12700	-0.00004	1.0010	0.74481	0.73907	0.74981
Model 4	23729.12	1112.98	24079.42	1220.79	-12168.83	-0.3285	0	0.8964	0.2231	0.08979	-0.0828	1.2064	0.74204	0.73698	0.74564

Note: DIC = Deviance Information Criterion; pDIC = effective number of parameters based on DIC; WAIC = Watanabe–Akaike Information Criterion; pWAIC = effective number of parameters based on WAIC; MLL = marginal log-likelihood; CPO = conditional predictive ordinate; PIT = probability integral transform; PPC = posterior predictive check; Cal. int. = calibration intercept. Lower DIC, WAIC and Brier scores indicate better predictive performance. Calibration intercepts closer to zero and calibration slopes closer to one indicate better calibration. The PPC reports the posterior predictive mean and 95% posterior predictive interval for the weighted prevalence. Marginal log-likelihood is reported descriptively because it is sensitive to prior specification.

Table 2 compares the fit and predictive performance of four competing model specifications. The model without covariates had the highest DIC (42,039.58) and WAIC (42,040.28), indicating the poorest performance among the models considered. Incorporating the random-effect structure substantially reduced the DIC and WAIC to 26,076.56 and 26,465.08, respectively. The fixed-effects-only model also improved on the model without covariates, with a DIC of 29,654.89 and WAIC of 29,672.34, but performed less well than the random-effects-only model.

The full model, which combined the fixed effects with the age, marital-duration, state, PSU and stratum effects, had the lowest DIC (23,729.12) and WAIC (24,079.42) of the four specifications. It also had the least negative marginal log-likelihood ($-12,168.83$). These information criteria therefore supported the full model as the preferred specification. Because marginal likelihood is sensitive to prior specification, it was treated as a supplementary measure rather than as the sole criterion for model selection. Additional assessment of predictive adequacy showed that the full model had the lowest Brier score (0.0898) and the highest mean log-CPO (-0.3285) among the four models, with no CPO failures. The posterior predictive check also placed the observed prevalence within the 95% posterior predictive interval. Calibration and temporal predictive diagnostics were considered alongside these measures to provide a broader assessment of model performance.

The stability of the posterior fixed effects was particularly evident for the principal temporal, reproductive, socioeconomic, and spatial covariates (Supplementary Table 5). The odds ratio for the 2024 survey-year effect ranged from 0.58 to 0.59 across the six prior specifications, while the association with the number of living children remained between 0.59

and 0.60. The odds ratio for Muslim religious affiliation ranged from 1.93 to 2.04, and the estimates for women's participation in healthcare decisions, large household purchases, and visits remained consistently below unity. The educational and wealth gradients were similarly stable across prior specifications. These results demonstrate that the direction and substantive magnitude of the principal associations were preserved under plausible alternative prior assumptions.

The spatial component was also robust to prior specification. The posterior mean of the BYM2 mixing parameter ϕ ranged from 0.863 to 0.882 across the six sensitivity models, compared with 0.868 (95% CrI: 0.586–0.983) under the baseline specification (Supplementary Table 6). This consistency indicates that the inferred contribution of the structured spatial component was not substantially altered by reasonable changes in the prior distribution. Taken together, the model-fit, fixed-effect, and hyperparameter sensitivity analyses provide evidence that the principal inferences from the revised Bayesian hierarchical model are robust to reasonable prior uncertainty.

Table 3 presents the posterior odds ratios (ORs) and 95% credible intervals (CrIs) from the Bayesian hierarchical model. The estimates indicate that fertility preference was associated with survey period, number of living children, women's participation in household decision-making, religious affiliation, education, household wealth, and place of residence, although the strength and precision of associations varied across covariates.

Relative to the 2003 survey, the odds of desiring another child were lower in 2024 (OR = 0.58, 95% CrI: 0.44–0.77). The corresponding estimates for 2008 (OR = 1.09, 95% CrI: 0.75–1.58), 2013 (OR = 1.22, 95% CrI: 0.91–1.62), and 2018 (OR = 0.94, 95% CrI: 0.71–1.24) had credible intervals that included unity. Thus, among the survey-year comparisons with 2003 as the reference, the 2024 estimate provided the strongest evidence of a difference in fertility preference.

Each additional living child was associated with lower odds of desiring another child (OR = 0.60, 95% CrI: 0.58–0.61). Women's participation in household decision-making was also associated with lower odds of desiring another child. The corresponding odds ratios were 0.85 (95% CrI: 0.77–0.94) for healthcare decisions, 0.86 (95% CrI: 0.78–0.94) for large household purchases, and 0.89 (95% CrI: 0.80–0.98) for decisions concerning visits to relatives.

Compared with Christian women, Muslim women had higher odds of desiring another child (OR = 2.02, 95% CrI: 1.46–2.79). Women reporting other religious affiliations also had higher odds (OR = 2.67, 95% CrI: 1.06–6.70), although the wider credible interval indicates lower precision for this estimate.

Compared with women with no formal education, the odds of desiring another child were lower among women with primary education (OR = 0.70, 95% CrI: 0.62–0.80), secondary education (OR = 0.64, 95% CrI: 0.56–0.73), and higher education (OR = 0.62, 95% CrI: 0.53–0.73). Relative to the poorest wealth category, the odds were lower among women in the middle (OR = 0.79, 95% CrI: 0.68–0.92), richer (OR = 0.80, 95% CrI: 0.67–0.94), and richest (OR = 0.71, 95% CrI: 0.59–0.86) categories.

Partner educational attainment was not clearly associated with fertility preference, as the credible intervals for primary, secondary, and higher partner education included unity. Similarly, the associations with women's employment (OR = 1.07, 95% CrI: 0.98–1.17) and media exposure (OR = 0.99, 95% CrI: 0.90–1.10) were uncertain. Rural residence was associated with slightly higher odds of desiring another child than urban residence (OR = 1.17, 95% CrI: 1.00–1.37), with the lower credible limit close to unity.

Figure 1 shows the observed national prevalence of women wanting another child across the five survey waves. The national pattern was characterised by an initial decline followed by relative stability and then a pronounced reduction in 2024. The prevalence declined from approximately 78.4% in 2003 to 76.5% in 2008 and remained broadly stable at approximately 76.4% in both 2013 and 2018. By 2024, the prevalence had fallen substantially to approximately 69.3%. Thus, the national trajectory does not represent a uniform decline across the entire 21-year period; rather, the most pronounced change occurred between 2018 and 2024.

This descriptive temporal pattern is consistent with the posterior survey-year effects from the Bayesian hierarchical model. Relative to the 2003 reference year, only the 2024 effect showed clear evidence of lower fertility preference, with an OR of 0.58 (95% CrI: 0.44–0.77). The credible intervals for 2008, 2013, and 2018 included unity, indicating that the adjusted differences for these survey waves were not sufficiently precise to establish clear departures from the 2003 level.

The nonlinear association between women's age and fertility preference is shown in Figure 2. The posterior age effect declined progressively across the reproductive age range. The estimated effect was strongly positive at younger ages, decreased steadily with increasing age, crossed approximately zero during the early-to-mid 30s, and became increasingly negative at older ages. The relatively narrow credible band across much of the age range indicates substantial posterior support for the overall nonlinear age pattern. This finding demonstrates that the association between age and fertility preference is not adequately represented by a simple linear effect and is consistent with changing reproductive preferences across the life course.

The state-specific life-course analyses presented in Supplementary Figures S1 and S2 further indicate that these reproductive trajectories vary geographically. In particular, the nonlinear association between age at first union and fertility preference differed across states, indicating that reproductive timing interacts with the geographic context in which women form unions and make fertility decisions.

Figure 3 presents the posterior mean fertility-preference probabilities for the 37 states and the Federal Capital Territory across the five survey waves. Marked geographic differences were observed across the study period. In 2003, relatively high posterior probabilities were

Table 3: Posterior odds ratios and 95% credible intervals from the revised Bayesian hierarchical model

Variable	OR	2.5% CrI	97.5% CrI
Survey year			
2003 (reference)	1.00	–	–
2008	1.09	0.75	1.58
2013	1.22	0.91	1.62
2018	0.94	0.71	1.24
2024	0.58	0.44	0.77
Number of living children	0.60	0.58	0.61
Decision-making: healthcare			
Not involved (reference)	1.00	–	–
Involved	0.85	0.77	0.94
Decision-making: large purchases			
Not involved (reference)	1.00	–	–
Involved	0.86	0.78	0.94
Decision-making: visits			
Not involved (reference)	1.00	–	–
Involved	0.89	0.80	0.98
Religion			
Christian (reference)	1.00	–	–
Muslim	2.02	1.46	2.79
Other	2.67	1.06	6.70
Woman employed			
Not employed (reference)	1.00	–	–
Employed	1.07	0.98	1.17
Partner education			
No formal education (reference)	1.00	–	–
Primary	1.05	0.92	1.19
Secondary	0.99	0.88	1.13
Higher	1.04	0.90	1.20
Wealth index			
Poorest (reference)	1.00	–	–
Poorer	0.93	0.80	1.07
Middle	0.79	0.68	0.92
Richer	0.80	0.67	0.94
Richest	0.71	0.59	0.86
Woman's education			
No formal education (reference)	1.00	–	–
Primary	0.70	0.62	0.80
Secondary	0.64	0.56	0.73
Higher	0.62	0.53	0.73
Media exposure			
No exposure (reference)	1.00	–	–
Exposed	0.99	0.90	1.10
Residence			
Urban (reference)	1.00	–	–
Rural	1.17	1.00	1.37

Note: OR = odds ratio; CrI = credible interval. Reference categories are shown explicitly in the table. Values are posterior summaries from the baseline prior specification. The number of living children was modelled as a continuous covariate and therefore has no reference category. The family-planning service-contact effect had an extremely diffuse posterior distribution and is therefore reported qualitatively rather than using numerically extreme credible limits.

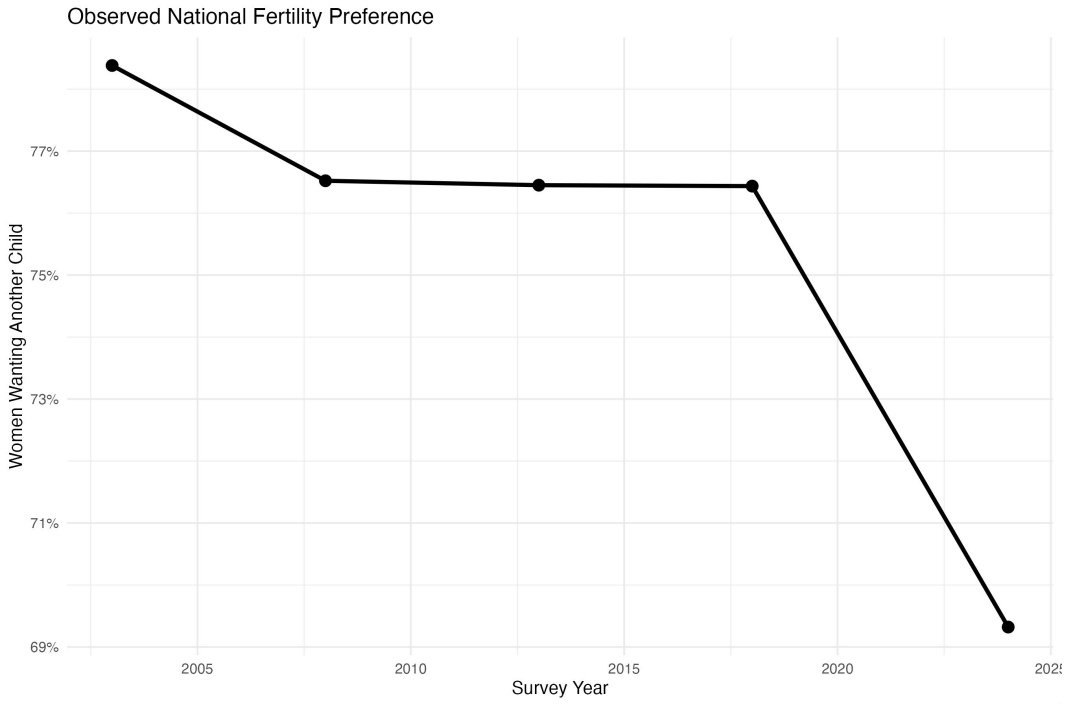


Figure 1: Posterior national temporal trend in fertility preference across Nigeria, 2003–2024. The prevalence declined between 2003 and 2008, remained relatively stable between 2008 and 2018, and declined more substantially in 2024.

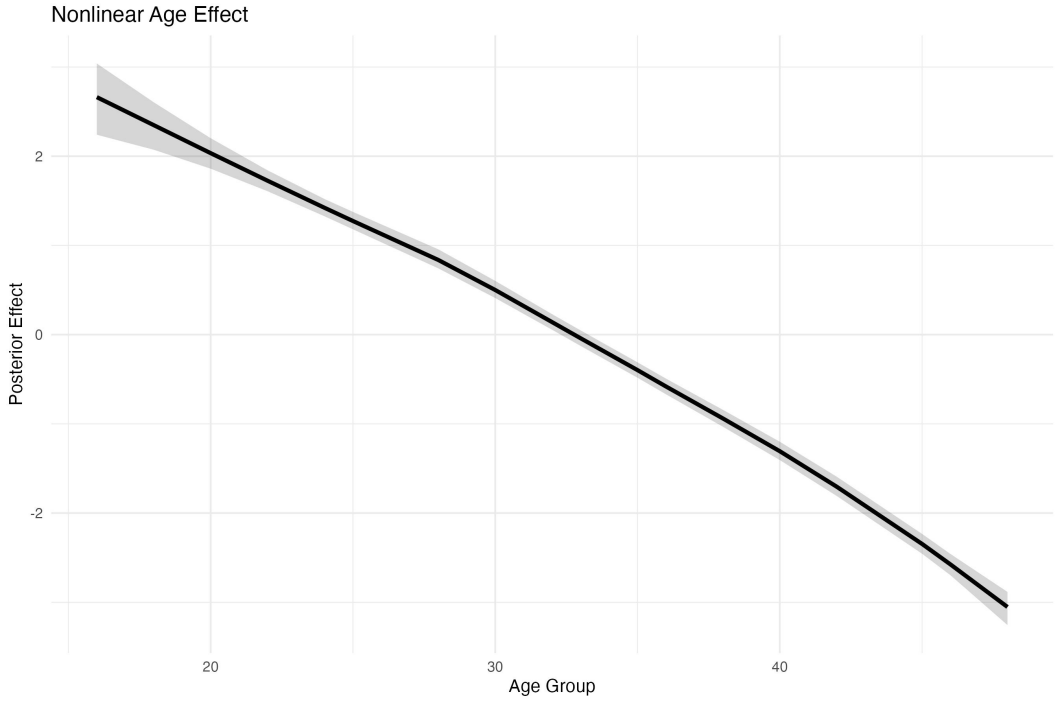


Figure 2: Nonlinear effect of age on fertility preference. The estimated age effect declines progressively across the age range, with increasingly negative values at older ages. Shaded regions represent 95% credible intervals.

observed across several northern states, including Yobe, Sokoto, Zamfara, Katsina, and Jigawa, whereas comparatively lower probabilities were observed across several southern states, particularly in the South-West and parts of the South-South.

This broad geographic contrast remained evident in 2008 and 2013, although the magnitude and spatial configuration of the state-level estimates changed across survey waves. By 2018, comparatively high posterior probabilities remained evident in several northern states, while lower probabilities were observed in states including Lagos, Ogun, Osun, Ekiti, Ondo, and parts of the South-East and South-South.

In 2024, posterior fertility-preference probabilities were lower across much of the country. Particularly low estimates were observed in several South-Western states, including Lagos, Ogun, Osun, Ekiti, and Ondo, as well as in Borno in the North-East. Relatively higher estimates persisted in states including Yobe, Sokoto, and Jigawa and in parts of the North-Central and North-West regions. Thus, the spatial distribution retained broad regional differences while also showing state-specific changes across survey waves.

The persistence of geographically clustered estimates after adjustment for the individual- and household-level covariates included in the model indicates that spatial variation remained in the fitted fertility-preference probabilities. The spatial surfaces therefore describe geographic differences in the estimated probabilities and their changes across survey waves; they do not imply a diffusion process between neighbouring states.

Figure 4 shows the spatial distribution of the width of the 95% credible intervals for the estimated fertility-preference probabilities. Posterior precision varied substantially across both states and survey periods. In 2003, relatively wider credible intervals were observed in parts of the South-South and southern regions, including states such as Bayelsa, Delta, and Akwa Ibom, while several northern states showed comparatively narrower intervals.

The spatial pattern of uncertainty changed across subsequent survey waves. In 2008, relatively high uncertainty remained evident in parts of the southern region, whereas the 2013 surface showed particularly pronounced uncertainty in parts of the North-West alongside continued variation elsewhere. By 2018 and 2024, wider credible intervals were increasingly visible across several southern states, including parts of the South-South and South-East, while many states in the northern and North-Central regions showed comparatively narrower

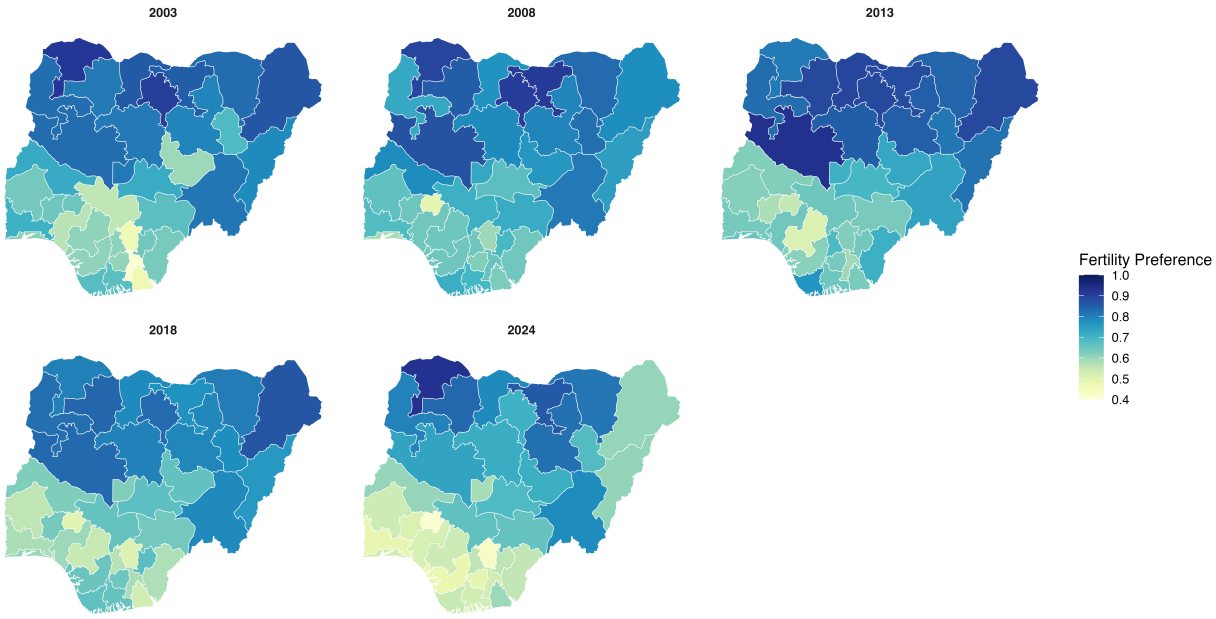


Figure 3: Posterior mean spatial surfaces of fertility preference across Nigerian states, 2003–2024. The maps show substantial geographic heterogeneity and persistent north–south fertility differentials over time, with northern states generally exhibiting higher fertility preference probabilities than southern states.

intervals.

These patterns indicate that the precision of state-level fertility- preference estimates was geographically heterogeneous and changed over time. The uncertainty surface should therefore be interpreted as a measure of posterior precision rather than as an indicator of the magnitude or direction of fertility preference. States with wider credible intervals represent locations where the estimated probabilities are less precisely determined, whereas narrower intervals indicate greater posterior precision.

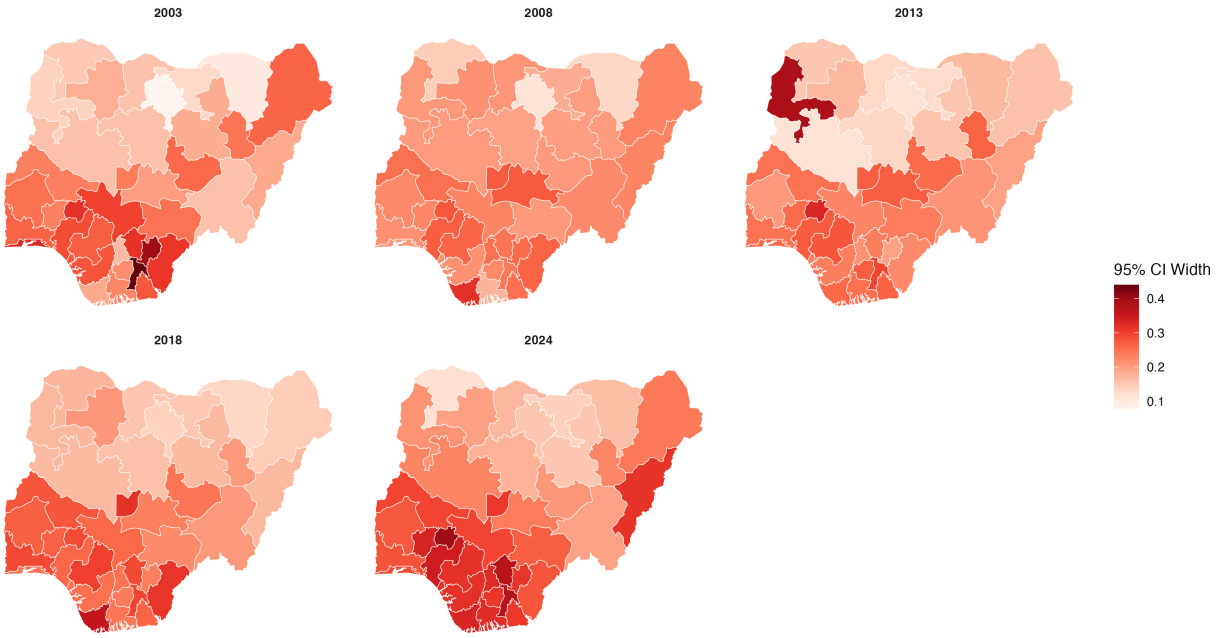


Figure 4: Posterior uncertainty surfaces for fertility preference across Nigerian states, 2003–2024. Higher uncertainty values indicate greater posterior variability in estimated fertility preference probabilities, reflecting heterogeneous and evolving demographic transition processes across regions.

Figure 5 illustrates the posterior changes in state-level fertility-preference probabilities between consecutive survey waves. The results demonstrate substantial heterogeneity in both the direction and magnitude of change. Between 2003 and 2008, negative changes were prominent across several northern states, including parts of the North-West and North-Central regions, while positive changes were evident in a number of southern states. The pattern therefore did not represent a uniform national shift in fertility preference.

Between 2008 and 2013, the spatial configuration changed considerably. Positive changes were evident across several northern states, including parts of the North-West and North-East, whereas negative changes were more apparent across several southern states. This reversal in the geographic distribution of change indicates that states did not follow a common temporal trajectory.

Changes between 2013 and 2018 were generally smaller across much of the country. Nevertheless, localized increases and decreases remained visible, including reductions in parts of the northern and southern regions and relative increases in selected states. Thus, the relatively stable national pattern during this interval concealed continuing subnational reorganisation in fertility preference.

The most pronounced spatial changes occurred between 2018 and 2024. A particularly large negative change was evident in Borno, with substantial declines also apparent across parts of the North-East and other northern states. Negative changes were likewise observed across several states in the South-West and South-South, although the magnitude varied considerably between states. These findings demonstrate that the substantial national decline in fertility preference between 2018 and 2024 was not spatially uniform.

Taken together, the spatial-change maps demonstrate asynchronous fertility-preference transitions across Nigeria. States experienced different directions and magnitudes of change over the same survey interval, with some states showing pronounced reductions while others remained relatively stable or experienced smaller increases. This subnational heterogeneity would be obscured by national averages alone.

4 Discussion

This study examined fertility preference in Nigeria from 2003 to 2024 using a Bayesian hierarchical framework that accounted for individual and household characteristics, nonlinear reproductive-age effects, spatial variation, and temporal variation. The findings indicate a decline in population-level fertility preference across the study period, particularly by 2024, alongside persistent differences between states. The temporal pattern was not uniformly declining across all survey intervals, with an increase between 2008 and 2013 followed by

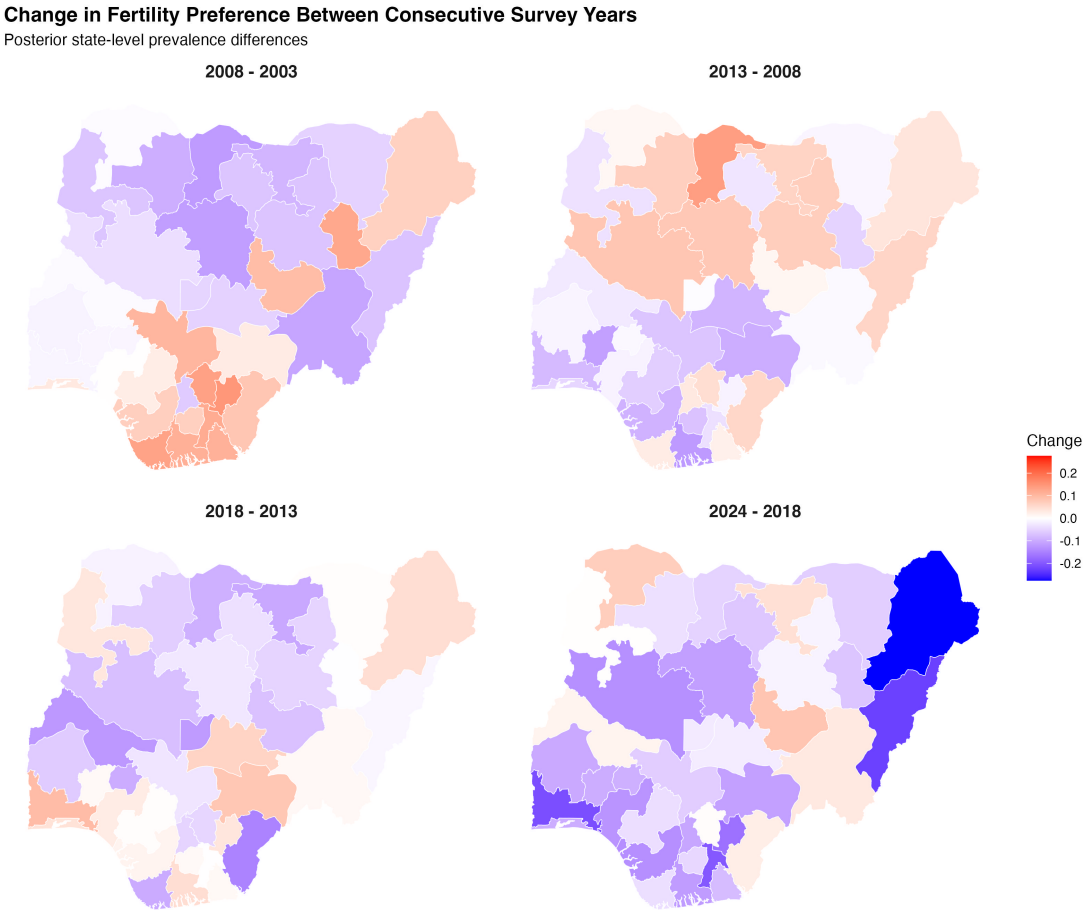


Figure 5: Spatial patterns in the magnitude of fertility-preference change across Nigerian states between consecutive survey rounds, 2003–2024. Higher values indicate greater changes in posterior fertility-preference probabilities between consecutive survey observations, whereas lower values indicate greater stability.

declines in the subsequent survey rounds. These findings describe differences in fertility preference across successive population samples rather than changes experienced by the same women over time.

The decline in fertility preference occurred alongside broader social and demographic changes in Nigeria, including increasing educational attainment, greater urbanisation, and increased participation of women in household decision-making. These patterns are consistent with demographic transition theory, which links fertility decline with changes in education, socioeconomic conditions, urban development, and reproductive norms [18, 2, 19]. However, the present analysis does not establish that these broader changes caused the observed decline in fertility preference. Rather, the findings suggest that changes in fertility preference should be considered within the wider social and demographic context in which reproductive decisions are made.

Women's education and participation in household decision-making were associated with lower fertility preference. Women participating in healthcare decisions, major household purchases, and decisions concerning visits had lower odds of wanting another child, while higher educational attainment was also associated with lower fertility preference. These findings are consistent with previous evidence linking women's empowerment and education with reproductive autonomy, fertility intentions, and fertility outcomes [20, 8]. The associations may reflect differences in women's autonomy, access to information and resources, and reproductive goals, although these mechanisms were not directly evaluated in the present analysis. The findings therefore support the relevance of education and women's decision-making in understanding fertility-preference differences, without establishing a causal pathway between these characteristics and fertility preference.

The inverse association between the number of living children and desire for another child is consistent with the relationship between previous childbearing and subsequent fertility preferences. Women with more living children may have different reproductive goals from those with fewer children. This finding is relevant to reproductive-health programming because fertility preferences are related to women's existing childbearing experience. Family-planning programmes should therefore accommodate women with different reproductive intentions, including those seeking to limit births and those requiring information and services

for spacing subsequent births. The relatively low prevalence of modern contraceptive use observed in the study also indicates that declining fertility preference should not necessarily be interpreted as evidence of adequate access to or uptake of effective fertility-regulation services [18, 21].

Religious affiliation was also associated with fertility preference, with Muslim women having higher odds of wanting another child than Christian women. Similar religious differences have been reported in African fertility research [22, 23]. However, religious affiliation should not be interpreted as a direct causal determinant of fertility preference. In Nigeria, religious affiliation is correlated with geographic location and other social and demographic characteristics, including education, marriage patterns, socioeconomic circumstances, family-size norms, and access to reproductive-health services. The observed association should therefore be interpreted as a demographic association within the fitted model rather than as evidence that religious affiliation itself determines fertility preference. Reproductive-health programmes should consequently remain responsive to the social and cultural contexts in which fertility decisions are made.

The nonlinear age effect showed a progressive decline in the estimated contribution of age to fertility preference across the observed age range. This is consistent with differences in reproductive preferences across the reproductive life course and with previous work on fertility intentions and reproductive ageing [24]. The plotted age effect represents a centred posterior latent effect on the log-odds scale rather than a predicted probability. The age association therefore indicates systematic variation in the estimated log-odds contribution of age, but does not by itself establish the processes underlying this relationship. The finding nevertheless supports the value of considering reproductive stage when interpreting fertility preferences among women aged 15–49.

An important finding was the persistence of differences in fertility preference between states. Higher posterior fertility-preference probabilities were generally observed across several northern states, while lower probabilities were more common in several southern states. States such as Yobe, Sokoto, Zamfara, Katsina, and Jigawa exhibited relatively high levels in several survey periods, whereas states including Lagos, Ogun, Osun, Ekiti, and Ondo generally showed lower levels in later surveys. The spatial distribution was not fixed across all

periods, however, as illustrated by the marked reduction observed in Borno by 2024. These findings are consistent with previous evidence of north–south fertility differentials in Nigeria [13, 25].

The state-level differences should be interpreted as model-based geographic variation after accounting for the covariates included in the model. They do not establish why particular states have higher or lower fertility preference. Differences in education, marriage patterns, religion, socioeconomic circumstances, urbanisation, and access to reproductive-health services may plausibly contribute to geographic variation, as suggested by previous research [13, 25], but these mechanisms were not separately evaluated in the present analysis. We therefore avoid attributing the residual state-level differences to any single contextual factor.

These geographic differences have implications for reproductive-health planning, but the findings do not identify which interventions would change individual fertility preferences within particular states. The results may instead help identify areas where more detailed demographic and health-service assessment is warranted. Strategies involving education, reproductive-health information, family-planning services, or women's empowerment should be guided by local population needs, service availability, and evidence on intervention effectiveness rather than by state-level fertility-preference estimates alone. This approach allows geographic information to complement, rather than replace, national reproductive-health strategies.

The changes between consecutive survey waves also varied across states. The change maps represent the absolute difference between posterior estimates in consecutive survey rounds and therefore describe the magnitude of change rather than its direction or annual rate. Larger values indicate greater differences between consecutive estimates, whereas smaller values indicate greater similarity between successive estimates. These measures should not be interpreted as evidence of spatial diffusion, directional propagation, or velocity because no diffusion process or spatially lagged temporal-change mechanism was modelled. The findings instead indicate that population-level changes in fertility preference were not identical across states and survey periods.

Posterior uncertainty provides an additional consideration when interpreting the geographic estimates. In this analysis, uncertainty was quantified using the width of the 95%

posterior credible interval around the posterior mean. Wider intervals indicate less precise model-based estimates and should not be interpreted as demographic volatility or instability. Differences in interval width may reflect the amount of information available for a state and survey period, including sample size, survey design, and the hierarchical structure of the model. Because these factors were not separately modelled as explanations for credible-interval width, no substantive demographic interpretation is assigned to differences in uncertainty.

The stability of the principal findings under alternative prior specifications strengthens confidence in the reported associations. Across the sensitivity scenarios, model-fit measures varied only modestly, while the main associations involving survey year, number of living children, women's decision-making, and religious affiliation remained broadly consistent. The posterior estimates of the spatial mixing parameter were also similar across the prior specifications considered. These results indicate that the principal substantive findings were not strongly dependent on the particular prior specifications evaluated.

The findings also have implications for population and public-health planning in Nigeria. The lower fertility preference observed in the most recent survey period may have implications for future population growth and demand for reproductive, maternal, and child health services. At the same time, persistent differences between states indicate that population-level fertility change is unlikely to be identical across the country. The associations observed for education and women's decision-making are consistent with the broader literature linking these characteristics with reproductive outcomes [20, 8]. Similarly, the importance of broader social and economic conditions is consistent with demographic-transition perspectives [18, 2, 19]. These findings support continued attention to education, women's empowerment, reproductive-health services, and geographically disaggregated demographic surveillance, while recognising that the present analysis cannot determine the causal effects of specific interventions [4].

This study has several strengths, including the use of five nationally representative DHS rounds spanning 21 years and a Bayesian framework that accounts for nonlinear age effects, individual and household characteristics, and state-level spatial variation. The analysis also examines both population-level fertility-preference estimates and changes between succes-

sive survey rounds while explicitly quantifying posterior uncertainty. Several limitations should nevertheless be considered. First, the repeated cross-sectional design prevents direct observation of individual fertility trajectories; therefore, temporal differences should not be interpreted as changes experienced by the same women. Second, although normalized survey weights were incorporated into the likelihood and PSU and stratum terms were included in the model, the complex survey design may not be represented in every respect by the hierarchical model. Third, the analysis reflects the defined analytic population and outcome and therefore does not represent women excluded by the eligibility criteria or those with missing outcome information. Fourth, number of living children was included to account for previous childbearing experience, but it does not capture all dimensions of reproductive history. Fifth, the relatively small number of survey rounds limits the temporal resolution of the analysis. Sixth, state-level estimates are ecological and should not be interpreted as evidence that individual women within a state share the characteristics represented by the state-level estimate. Seventh, fertility preference is self-reported and may be influenced by reporting or social-desirability considerations. Finally, unmeasured individual, household, and contextual factors may contribute to the observed associations and geographic differences.

Taken together, the findings provide evidence of temporal and geographic variation in fertility preference in Nigeria, while showing associations with education, wealth, women's decision-making, number of living children, religion, and age. These findings should be interpreted as population-level associations within a repeated cross-sectional framework rather than as evidence of individual fertility trajectories or causal effects. Further research using longitudinal data, richer contextual measures, and more detailed reproductive histories would be valuable for investigating the mechanisms underlying the observed population-level patterns.

5 Conclusions

Fertility preference in Nigeria varied across survey periods and states between 2003 and 2024, with lower population-level preference for additional children in the most recent survey period. The observed associations with education, wealth, women's decision-making,

number of living children, religion, and age indicate that fertility preferences differ across demographic and socioeconomic groups. These findings are consistent with previous evidence linking fertility preferences with broader social and demographic conditions in Nigeria and sub-Saharan Africa.

Geographic differences remained after accounting for the covariates included in the model, but these differences do not establish the contextual mechanisms responsible for state-level variation. Similarly, temporal differences between survey rounds should not be interpreted as individual fertility trajectories because the DHS data are repeated cross-sectional. The findings therefore provide population-level evidence that can support demographic surveillance and identify areas for further investigation, rather than evidence of causal effects or spatial diffusion.

Continued attention to female education, women's empowerment, reproductive-health services, and geographically informed demographic planning remains relevant to Nigeria's changing fertility landscape. Future research using longitudinal data and richer contextual information could help clarify the mechanisms underlying the observed geographic and temporal variation in fertility preference.

Declarations

Ethics approval and consent to participate

This study used secondary data from the Nigeria Demographic and Health Surveys. The surveys obtained ethical approval from the relevant authorities in Nigeria and the survey implementing organizations. The present study used de-identified secondary data and did not involve direct contact with or recruitment of participants. Therefore, no additional ethical approval was required for this analysis.

Consent for publication

Not applicable. This study used de-identified secondary survey data and contains no personally identifiable information.

Availability of data and materials

The datasets used in this study are available from the Demographic and Health Surveys Program upon registration and approval of a data access request. The data are available at `https://dhsprogram.com/`.

Competing interests

The authors declare that they have no competing interests.

Funding

No specific funding was received for this study.

Authors' contributions

EEU conceptualized the study and designed the methodology. FE and EEU implemented the methodology and conducted the analysis. AA critically reviewed the manuscript. EEU

wrote the first draft, and all authors contributed to the revision and finalization of the manuscript. All authors read and approved the final manuscript.

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Appendix

Supplementary Spatial Life-Course Dynamics

Supplementary Figure S1 shows the state-specific nonlinear effects of current age on fertility preference. Across the states, the curves generally decline as age increases, although the extent and rate of decline differ between states. In some states, the estimated effects remain relatively close to zero across much of the age range, while in others the curves decline further below zero. The curves also differ in how gradually or sharply the decline occurs. Thus, the overall pattern is broadly similar across states, but the magnitude and shape of the age-related association vary geographically. State names are included in the panels to make the individual state patterns easier to identify and compare.

Supplementary Figure S2 shows the state-specific nonlinear effects of marital duration on fertility preference. The curves generally decline as marital duration increases, although the rate and extent of decline vary across states. Some states show a more gradual decline, while others show a steeper reduction in the estimated effect over the duration range. The overall direction is therefore broadly similar across states, but the strength and shape of the association differ. State names are included in the panels to make the state-specific patterns easier to read and compare.

Supplementary Prior Sensitivity Analysis

The robustness of the Bayesian hierarchical model to alternative prior specifications was assessed by refitting the model under six prior scenarios while retaining the same outcome definition, covariate structure, survey-design specification, spatial adjacency structure, and latent-effect structure. The sensitivity analysis varied the diffuseness of the fixed-effect priors, the degree of shrinkage of the spatial variance, and the prior assigned to the BYM2 mixing parameter.

Supplementary Table S1 presents the model-fit statistics across the alternative prior specifications. DIC ranged from 23,720.3 to 23,783.4, while WAIC ranged from 24,103.2 to 24,135.5, indicating broadly stable model fit across the prior specifications. The more

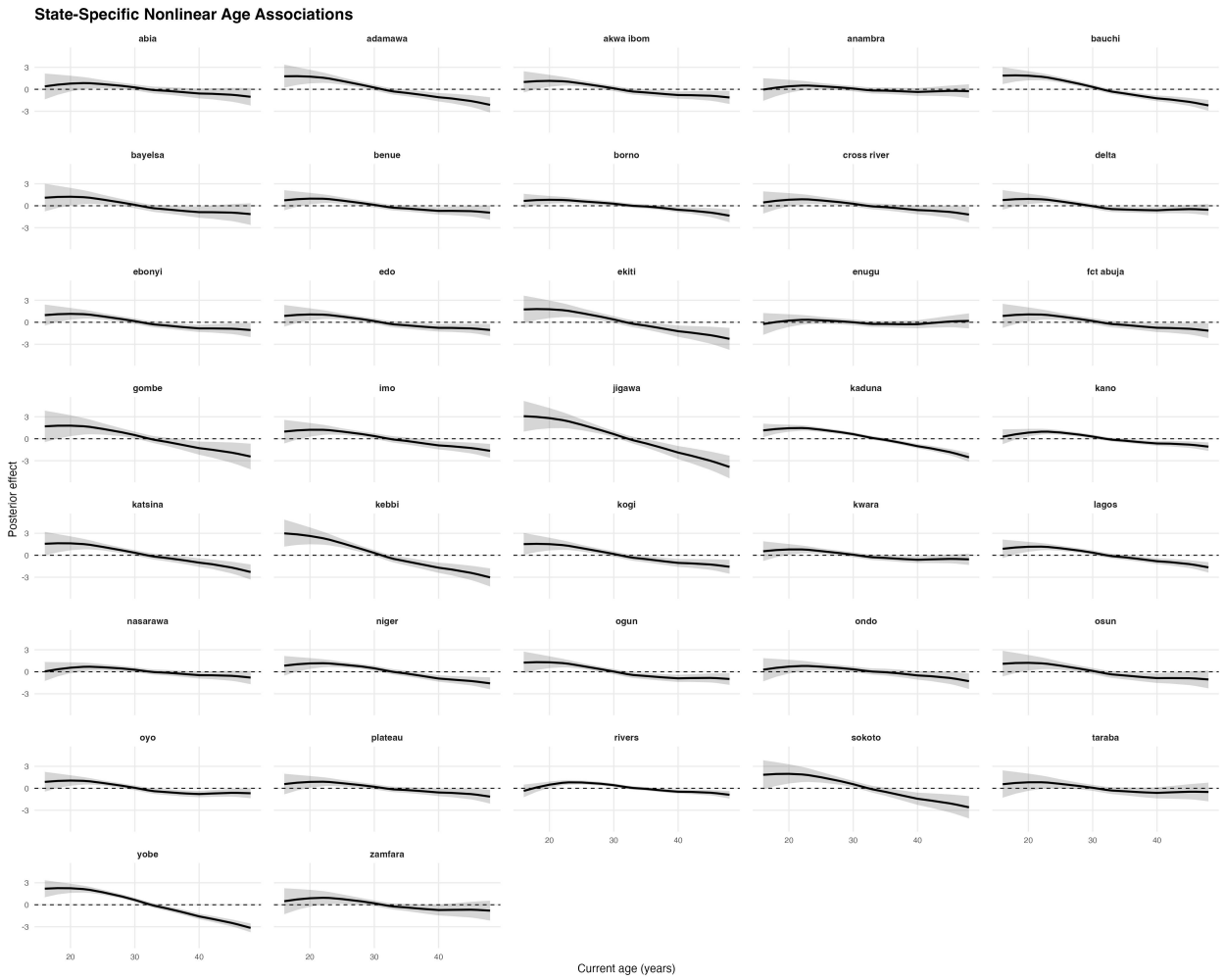


Figure 6: State-specific nonlinear effects of current age on fertility preference across Nigerian states. The curves generally decline with increasing age, with differences across states in the rate and magnitude of decline. In some states, the estimated effects remain close to zero across much of the age range. State names are included to facilitate identification and comparison.

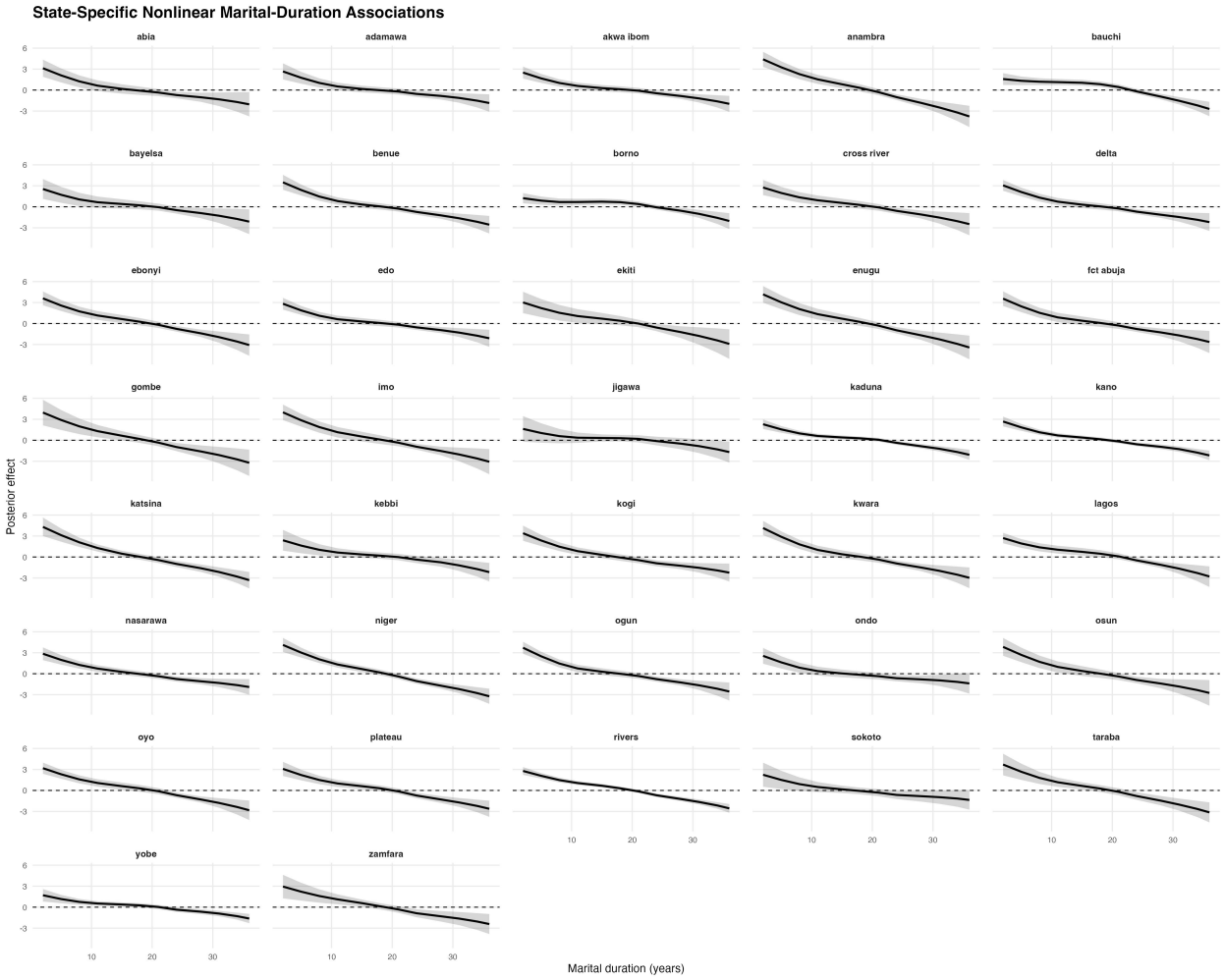


Figure 7: State-specific nonlinear effects of marital duration on fertility preference across Nigerian states. The curves generally decline with increasing marital duration, with differences across states in the rate and extent of decline. State names are included to facilitate identification and comparison.

informative fixed-effect prior produced the lowest DIC and WAIC; however, the differences were modest, suggesting that the principal conclusions were not strongly dependent on the choice of prior.

Table 4: Complete model-fit statistics under alternative prior specifications

Prior specification	**DIC**	p_{DIC}	**WAIC**	p_{WAIC}
Baseline	23,760.9	1,125.3	24,125.4	1,243.3
More diffuse fixed-effect prior	23,783.4	1,140.0	24,135.5	1,245.1
More informative fixed-effect prior	23,720.3	1,105.9	24,103.2	1,242.9
Stronger spatial shrinkage	23,763.4	1,125.9	24,126.6	1,242.7
Weaker spatial shrinkage	23,765.5	1,129.2	24,127.4	1,244.5
Alternative ϕ prior	23,764.6	1,126.6	24,127.4	1,243.0

Note: DIC = Deviance Information Criterion; WAIC = Watanabe–Akaike Information Criterion.

Table 5: Complete fixed-effect sensitivity analysis under alternative prior specifications

Effect	Baseline	Diffuse fixed-effect	Informative fixed-effect	Stronger spatial shrinkage	Weaker spatial shrinkage	Alternative ϕ prior
Demographic, reproductive and decision-making effects						
Survey year: 2008	1.09 (0.75–1.58)	1.10 (0.76–1.60)	1.11 (0.77–1.61)	1.09 (0.75–1.58)	1.09 (0.75–1.58)	1.09 (0.75–1.58)
Survey year: 2013	1.22 (0.91–1.62)	1.23 (0.92–1.64)	1.25 (0.94–1.66)	1.22 (0.91–1.63)	1.22 (0.91–1.62)	1.22 (0.91–1.62)
Survey year: 2018	0.94 (0.71–1.24)	0.96 (0.73–1.27)	0.96 (0.73–1.27)	0.94 (0.71–1.25)	0.94 (0.71–1.24)	0.94 (0.71–1.24)
Survey year: 2024	**0.58 (0.44–0.77)**	**0.59 (0.45–0.79)**	**0.58 (0.44–0.77)**	**0.59 (0.44–0.78)**	**0.58 (0.44–0.77)**	**0.58 (0.44–0.77)**
Number of living children	0.60 (0.58–0.61)	0.59 (0.58–0.61)	0.59 (0.58–0.60)	0.60 (0.58–0.61)	0.60 (0.58–0.61)	0.60 (0.58–0.61)
Decision-making: healthcare	0.85 (0.77–0.94)	0.85 (0.77–0.94)	0.83 (0.76–0.92)	0.85 (0.77–0.94)	0.85 (0.77–0.94)	0.85 (0.77–0.94)
Decision-making: large purchases	0.86 (0.78–0.94)	0.86 (0.78–0.94)	0.85 (0.77–0.93)	0.86 (0.78–0.94)	0.86 (0.78–0.94)	0.86 (0.78–0.94)
Decision-making: visits	0.89 (0.80–0.98)	0.88 (0.80–0.98)	0.87 (0.79–0.96)	0.89 (0.80–0.98)	0.89 (0.80–0.98)	0.89 (0.80–0.98)
Religion: Muslim	2.02 (1.46–2.79)	1.93 (1.39–2.67)	2.04 (1.47–2.83)	2.02 (1.46–2.80)	2.02 (1.46–2.79)	2.02 (1.46–2.80)
Religion: Other	2.67 (1.06–6.70)	2.67 (1.06–6.70)	2.66 (1.06–6.68)	2.67 (1.06–6.70)	2.67 (1.06–6.70)	2.67 (1.06–6.70)
Woman employed	1.07 (0.98–1.17)	1.06 (0.97–1.16)	1.05 (0.96–1.15)	1.07 (0.98–1.17)	1.07 (0.98–1.17)	1.07 (0.98–1.17)
Socioeconomic and contextual effects						
Partner education: primary	1.05 (0.92–1.19)	1.03 (0.91–1.18)	1.04 (0.91–1.19)	1.05 (0.92–1.20)	1.05 (0.92–1.19)	1.05 (0.92–1.20)
Partner education: secondary	0.99 (0.88–1.13)	0.98 (0.87–1.12)	0.96 (0.85–1.09)	1.00 (0.88–1.13)	0.99 (0.88–1.13)	1.00 (0.88–1.13)
Partner education: higher	1.04 (0.90–1.20)	1.02 (0.88–1.18)	1.02 (0.88–1.17)	1.04 (0.90–1.20)	1.04 (0.90–1.20)	1.04 (0.90–1.21)
Wealth index: poorer	0.93 (0.80–1.07)	0.95 (0.82–1.10)	0.95 (0.82–1.09)	0.93 (0.80–1.07)	0.93 (0.80–1.07)	0.93 (0.80–1.07)
Wealth index: middle	0.79 (0.68–0.92)	0.82 (0.70–0.95)	0.80 (0.69–0.93)	0.79 (0.68–0.92)	0.79 (0.68–0.92)	0.79 (0.68–0.92)
Wealth index: richer	0.80 (0.67–0.94)	0.82 (0.70–0.97)	0.81 (0.68–0.96)	0.80 (0.67–0.94)	0.80 (0.67–0.94)	0.80 (0.67–0.94)
Wealth index: richest	0.71 (0.59–0.86)	0.74 (0.61–0.89)	0.71 (0.59–0.86)	0.71 (0.59–0.86)	0.71 (0.59–0.86)	0.71 (0.59–0.86)
Woman's education: primary	0.70 (0.62–0.80)	0.71 (0.63–0.81)	0.70 (0.62–0.79)	0.70 (0.62–0.80)	0.71 (0.62–0.80)	0.70 (0.62–0.80)
Woman's education: secondary	0.64 (0.56–0.73)	0.66 (0.58–0.75)	0.62 (0.55–0.71)	0.64 (0.56–0.73)	0.65 (0.57–0.74)	0.64 (0.57–0.74)
Woman's education: higher	0.62 (0.53–0.73)	0.64 (0.54–0.75)	0.62 (0.52–0.73)	0.62 (0.53–0.73)	0.62 (0.53–0.73)	0.62 (0.53–0.73)
Media exposure	0.99 (0.90–1.10)	0.99 (0.89–1.10)	0.97 (0.88–1.08)	0.99 (0.90–1.10)	0.99 (0.90–1.10)	0.99 (0.90–1.10)
Family-planning service contact	0.92 (very wide)	0.90 (very wide)	0.99 (very wide)	0.92 (very wide)	0.92 (very wide)	0.92 (very wide)
Residence: rural	1.17 (1.00–1.37)	1.18 (1.01–1.38)	1.19 (1.02–1.39)	1.17 (1.00–1.37)	1.17 (1.00–1.37)	1.17 (1.00–1.37)

Note: Values are posterior odds ratios (ORs) with 95% credible intervals (CrIs). The reference category for survey year is 2003. Reference categories for categorical covariates are those specified in the analysis. The same model structure, covariates, survey-design specification, and spatial structure were retained across all six models; only prior specifications were varied.

The family-planning service-contact effect produced extremely diffuse posterior distributions across the sensitivity models and is therefore reported qualitatively as "very wide" rather than displaying numerically extreme upper bounds. This instability should be considered when interpreting this covariate.

Supplementary Table S3 summarises the posterior hyperparameters across the alternative prior specifications. The posterior distribution of the BYM2 mixing parameter remained concentrated toward the structured spatial component, with posterior mean ϕ ranging from 0.863 to 0.882 across the six models. Under the baseline specification, ϕ was 0.868 (95% CrI: 0.586–0.983). The consistency of this estimate across alternative prior specifications provides evidence that the inferred spatial structure is robust to reasonable prior uncertainty.

Table 6: Posterior hyperparameter sensitivity under alternative prior specifications

Prior specification	**Hyperparameter**	**Mean**	**2.5% CrI**	**97.5% CrI**
Baseline	Precision for age_group_id	1933.538	463.554	5924.380
Baseline	Precision for first_union_group_id	14671.053	376.008	86244.414
Baseline	Precision for state_id	3.784	2.184	6.061
Baseline	Phi for state_id	0.868	0.586	0.983
Baseline	Precision for psu_id	2.414	2.036	2.860
Baseline	Precision for stratum_id	5.021	3.528	6.978
More diffuse fixed-effect prior	Precision for age_group_id	2747.202	207.324	12982.433
More diffuse fixed-effect prior	Precision for first_union_group_id	8682.009	767.883	36232.193
More diffuse fixed-effect prior	Precision for state_id	3.786	2.142	6.099
More diffuse fixed-effect prior	Phi for state_id	0.881	0.653	0.983
More diffuse fixed-effect prior	Precision for psu_id	2.417	2.045	2.874
More diffuse fixed-effect prior	Precision for stratum_id	5.029	3.543	7.040
More informative fixed-effect prior	Precision for age_group_id	2116.309	405.326	7452.520
More informative fixed-effect prior	Precision for first_union_group_id	7380.508	856.924	27629.482
More informative fixed-effect prior	Precision for state_id	3.785	2.177	6.076
More informative fixed-effect prior	Phi for state_id	0.870	0.599	0.982
More informative fixed-effect prior	Precision for psu_id	2.413	2.031	2.855
More informative fixed-effect prior	Precision for stratum_id	5.022	3.511	6.992
Stronger spatial shrinkage	Precision for age_group_id	1964.018	349.468	6283.960
Stronger spatial shrinkage	Precision for first_union_group_id	8672.500	1028.328	35928.301
Stronger spatial shrinkage	Precision for state_id	4.106	2.417	6.500
Stronger spatial shrinkage	Phi for state_id	0.882	0.669	0.981
Stronger spatial shrinkage	Precision for psu_id	2.417	2.035	2.862
Stronger spatial shrinkage	Precision for stratum_id	5.036	3.526	7.016
Weaker spatial shrinkage	Precision for age_group_id	2615.430	231.861	11454.993
Weaker spatial shrinkage	Precision for first_union_group_id	10574.430	571.790	52138.162
Weaker spatial shrinkage	Precision for state_id	3.623	2.028	5.915
Weaker spatial shrinkage	Phi for state_id	0.863	0.514	0.991
Weaker spatial shrinkage	Precision for psu_id	2.412	2.035	2.858
Weaker spatial shrinkage	Precision for stratum_id	5.007	3.476	6.927
Alternative ϕ prior	Precision for age_group_id	2086.817	283.157	7394.474
Alternative ϕ prior	Precision for first_union_group_id	11082.796	483.636	56461.146
Alternative ϕ prior	Precision for state_id	3.788	2.157	6.137
Alternative ϕ prior	Phi for state_id	0.875	0.567	0.989
Alternative ϕ prior	Precision for psu_id	2.414	2.030	2.857
Alternative ϕ prior	Precision for stratum_id	5.026	3.519	7.021

Note: CrI = credible interval. The BYM2 mixing parameter ϕ represents the proportion of spatial variance attributable to the structured spatial component.

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