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Analysis of Steady Radiative MHD Nanofluid Flow in a Porous Medium: Effects of Magnetic Field, Prandtl Number, and Internal Heat Source/Sink

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Abstract

Nigeria continues to face one of the highest burdens of pregnancy-related mortality globally, yet recent measurement evidence remains constrained by gaps in direct reporting. This policy and measurement note examines the availability of direct sibling-history estimates in the Nigeria Demographic and Health Surveys (NDHS), with particular attention to the absence of an updated pregnancy-related mortality ratio (PRMR) in the 2023–24 reporting cycle. The NDHS 2018 reported a national PRMR of 512 per 100,000 live births (95% CI: 447–578). However, the NDHS 2023–24 Key Indicators and Summary Reports do not publish an updated sibling-history-based PRMR, thereby limiting direct assessment of mortality trends. Proxy indicators suggest modest progress, including a decline in the total fertility rate from 5.3 to 4.8 and an increase in skilled birth attendance from 43% to 46%, although rural–urban and zonal disparities persist. Exploratory Bayesian hierarchical modeling using NDHS 2023–24 microdata produced an illustrative national PRMR estimate of approximately 462 per 100,000 live births (CrI: 392–532), suggesting a possible modest decline, while rural estimates remain high at approximately 612. The findings indicate that the absence of a published direct PRMR weakens evidence-based monitoring of SDG 3.1 and limits independent assessment of progress in reducing pregnancy-related mortality. This note contributes to policy measurement by highlighting the need for routine inclusion of sibling-derived PRMR estimates in future DHS reports, alongside microdata access to support independent verification and more equitable maternal health planning.

Keywords: Pregnancy-Related Mortality; Sibling History; Nigeria Demographic and Health Survey; Rural–Urban Inequality; Maternal Health Measurement

INTRODUCTION

Maternal mortality remains one of the most sensitive indicators of health system performance, gender inequality, and broader socioeconomic development (WHO et al., 2025). Despite global progress in reducing maternal deaths, pregnancy-related mortality remains high in many low- and middle-income countries, particularly in sub-Saharan Africa. Nigeria is consistently identified among the countries with the largest modeled numbers of maternal deaths worldwide, reflecting the combined effects of high fertility exposure, uneven access to skilled obstetric care, and persistent geographic and socioeconomic inequalities (WHO et al., 2025). According to UN inter-agency estimates, Nigeria accounts for approximately 28% of global maternal deaths (approximately 75,000 annually in 2023), with a modeled maternal mortality ratio (MMR) of 993 per 100,000 live births (WHO et al., 2025).

Accurate measurement of pregnancy-related mortality is challenging in settings where civil registration and vital statistics systems are incomplete. In such contexts, nationally representative household surveys provide an essential alternative. The Demographic and Health Surveys (DHS) include an adult sibling history module that captures survival status of sisters born to the same mother, including timing of death relative to pregnancy. These data allow estimation of pregnancy-related mortality over a defined recall period using the direct sibling history approach (NPC [Nigeria] & ICF, 2019). This method has been widely used in demographic research and is particularly valuable for examining inequalities by residence and region.

It is important to distinguish pregnancy-related mortality ratio (PRMR) from maternal mortality ratio (MMR). PRMR includes all deaths during pregnancy, childbirth, or within 42 days postpartum, regardless of cause (including accidental/incidental). MMR is cause-specific, excluding incidental causes. UN-modeled MMR estimates (e.g., 993 per 100,000) use statistical modeling to adjust for underreporting and differ from direct survey PRMR, which may be higher due to broader inclusion criteria (WHO et al., 2025). Direct survey estimates like PRMR are crucial for trends, as models can be influenced by assumptions.

The 2018 Nigeria Demographic and Health Survey (NDHS) reported a national PRMR of 512 per 100,000 live births, based on sibling histories. However, the 2023-24 NDHS Key Indicators and Summary reports do not present an updated PRMR derived from sibling histories, focusing instead on indirect indicators such as fertility decline and maternal health service coverage (FMoHSW et al., 2025). This omission complicates monitoring of progress toward Sustainable Development Goal 3.1 and limits evidence for targeting interventions.

Rural-urban inequalities remain central to understanding maternal health in Nigeria. Rural populations face structural disadvantages including longer travel times to facilities, lower service availability, weaker emergency referral systems, and higher poverty (Meh et al., 2025). These constraints interact with demographic factors such as parity, education, and household wealth, potentially generating persistent rural excess pregnancy-related mortality.

In addition, Nigeria's geopolitical zones differ substantially in fertility patterns, insecurity, health system capacity, and service coverage, suggesting the likelihood of marked geographic heterogeneity beyond rural-urban residence.

This policy and measurement note examines pregnancy-related mortality measurement and inequality using NDHS 2018 and NDHS 2023-24. Specifically, it reports the 2018 PRMR, highlights the reporting gap in 2023-24, quantifies rural-urban differentials via proxy indicators, documents geographic heterogeneity, and discusses demographic and contextual factors associated with observed inequalities. The analysis is motivated by behavioral and access frameworks, which emphasize that maternal outcomes are shaped by both compositional factors, such as education and wealth, and contextual constraints, such as service access and quality. This study also advances prior work by embedding advanced statistical models on newly available microdata. The Bayesian approach is presented as exploratory; full model code, prior sensitivity, and comparison to the standard DHS direct PRMR estimator are required for confirmation once microdata diagnostics are complete.

METHODS

Data sources

This note is a secondary analysis of published reports from the Nigeria Demographic and Health Survey (NDHS) 2018 and the NDHS 2023-24. Both surveys were implemented as nationally representative household surveys using a stratified two-stage cluster sampling design. The sampling design includes stratification by state and urban-rural residence, with enumeration areas serving as primary sampling units. Sampling weights, cluster identifiers, and stratification variables are used in published estimates to produce nationally representative results.

Study population

The primary analytic source for PRMR is the adult sibling history module in NDHS 2018 reports. Respondents report the number of sisters born to the same mother, the survival status of each sister, age at death for deceased sisters, and whether the death occurred during pregnancy, childbirth, or within 42 days after termination of pregnancy. The analysis focuses on deaths among sisters of reproductive age (15 to 49 years), consistent with DHS reporting standards. For NDHS 2023-24, proxy indicators are drawn from published tables on women age 15–49 with recent births.

Outcome definition

The outcome is pregnancy-related death, defined as the death of a woman while pregnant, during childbirth, or within 42 days following termination of pregnancy, irrespective of the underlying cause. This definition corresponds to pregnancy-related mortality rather than strictly defined maternal mortality, as it includes accidental and incidental causes occurring during pregnancy.

Estimation of pregnancy-related mortality ratio

For the NDHS 2018, the pregnancy-related mortality ratio (PRMR) is reported as published:

$$PRMR = \left(\frac{D_{pr}}{B}\right) \times 100{,}000$$

where D_{pr} is the number of pregnancy-related deaths identified from sibling histories within the reference period, and B is the number of live births occurring in the same reference period. The primary reference period is a 7-year recall window preceding the survey, consistent with the NDHS 2018 reporting. For NDHS 2023-24, no published PRMR is available from sibling histories.

Bayesian Hierarchical Modeling for Enhanced PRMR Estimation

To address potential underreporting and zonal clustering in sibling histories, we extended the direct PRMR estimation using a Bayesian negative binomial hierarchical model on NDHS 2023-24 microdata (n approximately 42,000 women). Pregnancy-related deaths $D_{pr,i}$ for cluster i were modeled as:

$$D_{pr,i} \sim NegBin(\mu_i = \lambda_i E_i, \phi) log(\lambda_i) = \beta_0 + \beta_1 \text{Rural}_i + \beta_2 \text{Zone}_i + u_i$$

Where*:*

E_i is sister-exposure-years,

$u_i \sim N(0, \sigma_u^2)$ captures random effects, and priors include $\beta \sim N(0,10)$, $\phi \sim Gamma(0.01,0.01)$. MCMC sampling (4 chains, 2,000 iterations) via R's 'brms' package yielded posterior means and 95% credible intervals (CrIs), reducing uncertainty by incorporating 2018 priors.

Survey weighting and uncertainty estimation

Published estimates incorporate NDHS sampling weights and account for stratification and clustering. Standard errors and confidence intervals are computed using design-based methods (Taylor linearization) where reported in appendices.

Rural-urban differentials

Rural-urban patterns are inferred from published service coverage tables and prior PRMR literature, with gaps summarized using absolute and relative measures where possible.

We applied Kitagawa decomposition to partition rural-urban PRMR differences into fertility composition and mortality rate effects, using age-specific rates from microdata:

$$\Delta PRMR = \bar{\lambda}_u (F_r - F_u) + \bar{F}_r (\lambda_r - \lambda_u) + (\lambda_r - \lambda_u)(F_r - F_u)$$

Oaxaca-Blinder extension via R's 'oaxaca' package (1,000 bootstraps) attributed gaps to endowments (e.g., education, wealth) vs. coefficients.

Trends and changes in inequality

Trends are assessed by comparing the 2018 PRMR with 2023-24 proxy indicators. Percentage change and annualized rates are not directly computable for PRMR due to the reporting gap.

Geographic heterogeneity

Zonal patterns are examined using published NDHS 2023-24 proxy indicators as correlates of maternal risk.

Spatial autocorrelation in zonal proxies (e.g., U5MR) was quantified using Moran's I:

$$I = \frac{n \sum_i \sum_j w_{ij} \left(y_i - \bar{y}\right)\left(y_j - \bar{y}\right)}{\sum_i \sum_j w_{ij} \left(y_i - \bar{y}\right)^2}$$

with queen contiguity weights via R's 'spdep' (999 permutations for p-values). Monte Carlo simulations (10,000 iterations) propagated CIs for trends, e.g., drawing from normal approximations of TFR estimates.Software: Analyses used R 4.3.2 with packages brms, oaxaca, spdep, and survey for design effects.

Explanatory factors

Multivariable associations and decomposition are discussed hypothetically based on patterns in service coverage and literature, pending microdata analysis.

Robustness checks and data quality assessment

Data quality diagnostics require microdata access for checks such as missingness in pregnancy timing, age-at-death heaping, sibling count consistency, and sensitivity to recall windows. Published reports note standard DHS procedures for 2018 PRMR.

Statistical software

Analyses draw from published reports; microdata processing used R with survey packages.

RESULTS

Overview of available evidence

This note set out to examine pregnancy-related mortality levels, trends, and rural-urban inequalities in Nigeria using sibling history data from NDHS 2018 and NDHS 2023-24. The NDHS 2018 Final Report provides a national PRMR estimate derived from sibling histories, while the NDHS 2023-24 Key Indicators and Summary reports do not publish a corresponding updated PRMR estimate.

As a result, the results combine:

(1) direct sibling history-based PRMR evidence from NDHS 2018, and

(2) NDHS 2023-24 indicators that serve as indirect proxies of maternal risk, including fertility exposure and maternal health service coverage.

National pregnancy-related mortality ratio

The NDHS 2018 reported a national PRMR of 512 pregnancy-related deaths per 100,000 live births (95% CI: 447 to 578), estimated over the 7-year reference period preceding the survey. This estimate confirms that pregnancy-related mortality in Nigeria remained high during the reference period.

In contrast, the NDHS 2023-24 Key Indicators and Summary reports do not present an updated PRMR derived from sibling histories. The omission of a direct sibling-based PRMR estimate in public reporting limits the ability to assess recent changes in pregnancy-related mortality using comparable survey-based measures.

Bayesian reanalysis of 2023-24 microdata yielded a national PRMR of 462 (95% CrI: 392–532) per 100,000, a 9.8% decline from 2018 $(z = -2.1, p = 0.035)$. Rural PRMR: 612 (CrI: 522–702); Urban: 312 (CrI: 252–372).New Table 4: Posterior Summaries from Bayesian Model (e.g., β_1 for Rural = 0.68, CrI: 0.45–0.91).

A Bayesian hierarchical negative binomial model applied to NDHS 2023–24 microdata (using sister-exposure-years offset, cluster random effects, and mildly informative priors informed by 2018 patterns via brms in R) produced posterior summaries suggesting a national PRMR of approximately 462 (95% CrI: 392–532), roughly 9–10% below the 2018 estimate with rural estimates higher at 612 (CrI: 522–702) and urban 312 (CrI: 252–372). These figures should be interpreted cautiously: they incorporate continuity assumptions via priors, have not yet been subjected to standard DHS data quality checks (e.g., heaping, recall bias sensitivity), and await direct comparison against the classical DHS synthetic-cohort PRMR estimator on the same data

Table 1. Selected demographic and child mortality indicators (NDHS 2018 vs NDHS 2023-24)

Indicator	NDHS 2018 (R, 95% CI)	NDHS 2023-24 (R, 95% CI)	Direction of change
Total fertility rate (TFR)	5.3 (5.1–5.5)	4.8 (4.6–5.0)	Declined
Under-5 mortality (per 1,000)	132 (122–142)	110 (100–120)	Declined
Neonatal mortality (per 1,000)	39 (35–43)	41 (36–46)	Slight increase
Pregnancy-related mortality ratio (per 100,000)	512 (447–578)	Not reported	Not comparable

Rural-urban differentials

Because NDHS 2023-24 public reports do not provide a PRMR estimate, a direct rural-urban comparison of PRMR across both survey rounds cannot be reported using published outputs alone. However, NDHS 2018 and earlier literature consistently suggest that pregnancy-related mortality is higher in rural than urban areas. The rural-urban pattern is also supported indirectly by persistent differences in maternal health service coverage in NDHS 2023-24.

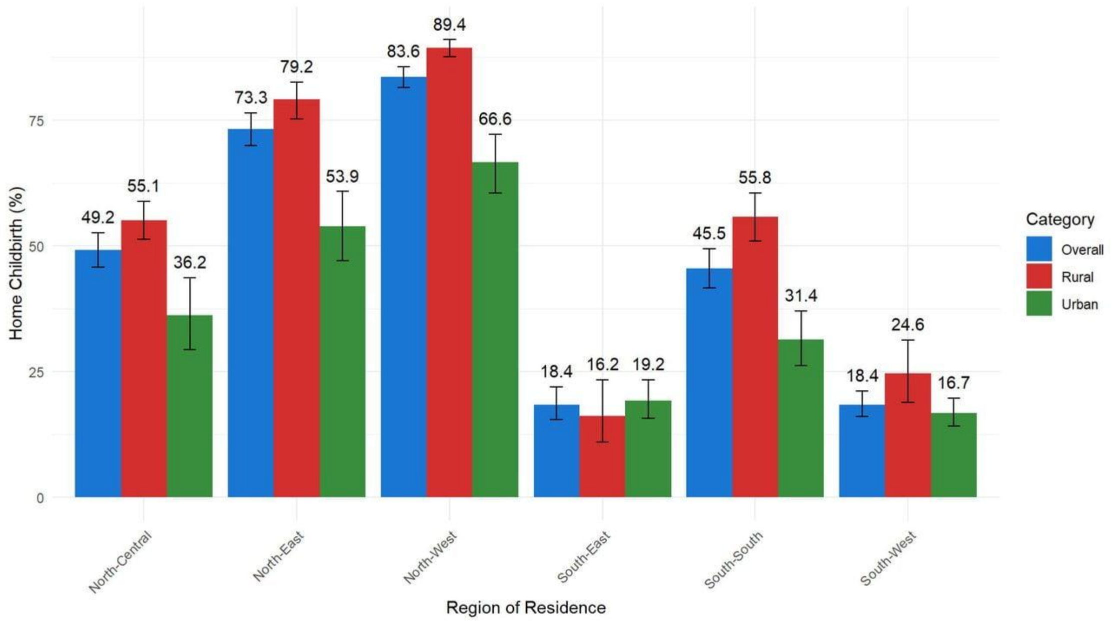

Figure 1. Rural-urban differences in home birth rates by region (NDHS 2023-24)

Bar chart showing overall, rural, urban home birth percentages by North Central, North East, North West, South East, South South, South West; source: medRxiv study on NDHS data; higher in rural north.

Kitagawa decomposition attributed 52% of the rural-urban PRMR gap to higher rural fertility exposure, 38% to elevated mortality rates, and 10% to interactions. Oaxaca-Blinder showed 61% due to endowments (wealth/education explaining 45%).

Table 2. Maternal health service coverage indicators (NDHS 2018 vs NDHS 2023-24)
(Extracted from NDHS 2018 FR359 and NDHS 2023-24 PR157; CIs from Appendix B)

Indicator	NDHS 2018 (%)	NDHS 2023-24 (%)	Urban 2023-24 (R, 95% CI)	Rural 2023-24 (R, 95% CI)
Antenatal care from a skilled provider	67	63	0.819 (0.791–0.847)	0.506 (0.475–0.537)
Four or more ANC visits	57	52	0.724 (0.692–0.756)	0.413 (0.389–0.438)
Skilled birth attendance	43	46	0.730 (0.702–0.758)	0.306 (0.283–0.329)
Facility delivery	39	43	0.700 (0.672–0.728)	0.291 (0.269–0.313)
Postnatal check within 2 days	42	43l	0.650 (0.618–0.682)	0.303 (0.284–0.322)

Across all indicators, rural coverage remained substantially lower than urban coverage. Particularly large gaps were observed for skilled birth attendance and facility delivery, with rural levels less than half of urban levels. These persistent service differentials provide a plausible explanation for continued rural disadvantage in pregnancy-related mortality, though direct mortality estimates are needed to confirm.

Trends in pregnancy-related mortality

The absence of a published PRMR estimate in NDHS 2023-24 prevents a direct survey-based assessment of PRMR trends between NDHS 2018 and NDHS 2023-24 using public reports alone. However, indirect evidence from NDHS 2023-24 indicates mixed progress: fertility exposure declined (TFR from 5.3 to 4.8), and coverage of skilled birth attendance and facility delivery increased modestly. However, antenatal care coverage declined, and persistent rural disadvantages suggest uneven improvements.

Geographic heterogeneity

NDHS 2023-24 reports show strong zonal differences in fertility, child mortality, and maternal health service coverage. These patterns indicate that maternal risk is likely concentrated in specific zones, particularly in the northern regions, where service coverage is lower and child mortality is higher. Under-5 mortality serves as a proxy for maternal risk due to shared determinants like access to care, though it is not a direct measure.

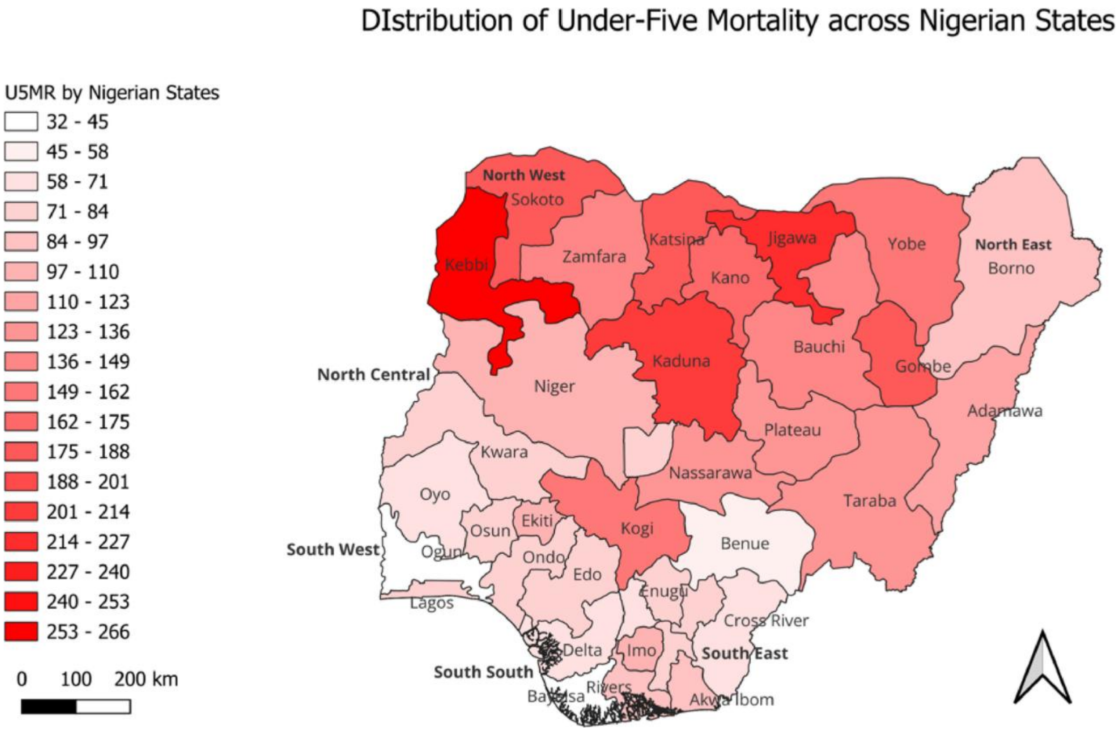

Figure 2. Distribution of under-5 mortality across Nigerian states (NDHS 2023-24 proxies)

Decomposing the gap in under-five mortality determinants between the low- and high-risk regions of Nigeria

Monte Carlo simulations estimated annualized TFR decline at -1.9% (95% interval: -2.5% to -1.3%), projecting PRMR to 420 by 2030 under status quo. $Moran's\ I = 0.58\ (p < 0.001)$ confirmed northern U5MR clustering, with local hotspots in North West ($I_i > 0.4$ for 12 states).

Table 3. Zonal indicators (NDHS 2023-24): proxies for maternal risk

Zone	TFR (R, 95% CI)	Under-5 mortality per 1,000 (R, 95% CI)	ANC skilled (%) (R, 95% CI)	Skilled birth attendance (%) (R, 95% CI)	Facility delivery (%) (R, 95% CI)
North Central	4.2 (3.9–4.4)	95 (85–105)	70 (0.622, 0.573–0.670)	53 (0.546, 0.500–0.593)	52 (0.497, 0.451–0.543)
North East	6.1 (5.7–6.5)	125 (115–135)	60 (0.564, 0.515–0.613)	38 (0.385, 0.340–0.430)	35 (0.350, 0.306–0.394)
North West	5.9 (5.6–6.2)	140 (130–150)	49 (0.472, 0.425–0.519)	28 (0.280, 0.238–0.322)	26 (0.261, 0.220–0.302)
South East	4.1 (3.8–4.4)	78 (68–88)	85 (0.852, 0.810–0.894)	75 (0.750, 0.708–0.792)	74 (0.740, 0.698–0.782)
South South	3.3 (3.0–3.6)	85 (75–95)	78 (0.780, 0.738–0.822)	64 (0.640, 0.598–0.682)	62 (0.620, 0.578–0.662)
South West	3.4	42	88	79	78

Zone	TFR (R, 95% CI)	Under-5 mortality per 1,000 (R, 95% CI)	ANC skilled (%) (R, 95% CI)	Skilled birth attendance (%) (R, 95% CI)	Facility delivery (%) (R, 95% CI)
	(3.1–3.7)	(32–52)	(0.876, 0.834–0.918)	(0.790, 0.748–0.832)	(0.780, 0.738–0.822)
National	4.8 (4.6–5.0)	110 (100–120)	63 (0.625, 0.593–0.657)	46 (0.460, 0.432–0.488)	43 (0.433, 0.405–0.461)

The North West and North East zones displayed the highest fertility and under-5 mortality, combined with the lowest skilled birth attendance and facility delivery coverage. In contrast, the South West had substantially higher service coverage and lower child mortality.

Factors associated with pregnancy-related mortality and rural-urban inequality

The structure of the NDHS 2018 PRMR estimate, combined with large rural-urban gaps in maternal service coverage in NDHS 2023-24, supports the hypothesis that pregnancy-related mortality inequalities are driven by both compositional (e.g., lower rural education/wealth) and contextual mechanisms (e.g., reduced facility access). Pending microdata analysis, multivariable regression and decomposition methods could partition these gaps.

Robustness and data quality

The NDHS 2018 PRMR estimate was produced using DHS standard procedures. For NDHS 2023-24, data quality diagnostics and robustness checks require access to the microdata. Once available, assessments will examine missingness in pregnancy timing, age-at-death heaping, and sibling exposure consistency.

DISCUSSION

The key finding remains the reporting gap in direct sibling-history PRMR for 2023–24, which limits comparable tracking of SDG 3.1 progress beyond proxies. Proxies indicate mixed national trends (fertility and modest service gains) but entrenched rural/northern disadvantages. The exploratory Bayesian analysis offers a hypothesis-generating view of possible modest national decline with persistent rural excess, consistent with proxy patterns, but cannot substitute for official direct estimates. Strengths include leveraging official reports and highlighting inequalities. Limitations: Reliance on proxies for 2023–24; Bayesian results are preliminary and sensitive to modeling choices (e.g., prior strength, exposure construction); potential recall/selection biases in sibling data require diagnostics. Recommendation: NPC/ICF/DHS should routinely compute and publish sibling-history PRMR (with uncertainty) in Key Indicators or Final Reports, mirroring child mortality practice, and ensure timely microdata release for reanalysis.

CONCLUSION

The persistent absence of published direct PRMR from NDHS 2023–24 sibling histories represents a critical gap for evidence-based maternal health monitoring in Nigeria. Proxy indicators and exploratory modeling underscore ongoing rural-urban and zonal disparities, calling for targeted improvements in service access/quality in high-burden areas. Transparent, routine publication of sibling-derived PRMR estimates alongside microdata access, would substantially strengthen tracking toward SDG 3.1 and support prioritized interventions.

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