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Exploring Cesarean Section Delivery Patterns in South India: A Bayesian Multilevel and Geospatial analysis of Population-Based Cross-Sectional Data

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Abstract

Background This paper focuses on the period from 2019 to 2021 and investigates the factors associated with the high prevalence of C-section deliveries in South India. We also examine the nuanced patterns, socio-demographic associations, and spatial dynamics underlying C-section choices in this region. A cross-sectional study was conducted using large nationally representative survey data.

Methods National Family Health Survey data (NFHS) from 2019 to 2021 have been used for the analysis. Bayesian Multilevel and Geospatial Analysis have been used as statistical methods.

Results Our analysis reveals significant regional disparities in C-section utilization, indicating potential gaps in healthcare access and socio-economic influences. Maternal age at childbirth, educational attainment, healthcare facility type size of child at birth and ever pregnancy termination are identified as key determinants of method of C-section decisions. Wealth index and urban residence also play pivotal roles, reflecting financial considerations and access to healthcare resources. Bayesian multilevel analysis highlights the need for tailored interventions that consider individual household, primary sampling unit (PSU) and district-level factors. Additionally, spatial analysis identifies regions with varying C-section rates, allowing policymakers to develop targeted strategies to optimize maternal and neonatal health outcomes and address healthcare disparities. Spatial autocorrelation and hotspot analysis further elucidate localized influences and clustering patterns.

Conclusion In conclusion, this research underscores the complexity of C-section choices and calls for evidence-based policies and interventions that promote equitable access to quality maternal care in South India. Stakeholders must recognize the multifaceted nature of healthcare decisions and work collaboratively to ensure more balanced and effective healthcare practices in the region.

Keywords Cesarean section, South India, Bayesian multilevel, Geospatial

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Background

Cesarean delivery, also known as a C-section, is a surgical procedure in which a baby is delivered through an incision made in the mother's abdomen and uterus. This procedure is usually reserved for situations where vaginal delivery is not possible or safe for the mother or baby. In recent years, the rate of C-sections has increased worldwide, raising concerns about the potential risks and benefits of this procedure [1, 2]. According to the World Health Organization (WHO), the ideal rate for C-sections is between 10% and 15% of all births [3]. The global average C-section rate has shown a steady increase over the years and currently stands at approximately 21% of all births. Furthermore, projections indicate that this trend is set to persist over the next decade, with an estimated 29% of all births expected to be delivered by C-section by the year 2030 [4]. Recent studies have shown that C-section delivery rates have also been increasing in India, in recent years. The number of C-section deliveries has more than doubled in India as a whole, from 8% in 2005-06 to 17% in 2015-16 [5, 6]. This trend has been attributed to various factors, including changes in maternal and fetal indications for C-sections, changes in maternal preferences, and changes in healthcare policies and practices [7–9].

Globally, "over half a million maternal deaths occur every year" the majority of which take place in developing countries [10]. When pregnancy complications arise during pregnancy, this surgical intervention is considered a life-saving procedure to reduce maternal and neonatal mortality as in the rest of the world, India has also observed an increase in C-section delivery rates. Moreover, it is apparent that the rising rates of C-section deliveries are linked to several health consequences. Here are some negative health outcomes and some concerns about the increasing C-section delivery rates:

1. **Increased maternal mortality**: Women who undergo C-section deliveries have a higher risk of maternal mortality than those who deliver vaginally, particularly if the C-section is not medically necessary. The study also found that C-section rates vary widely across states in India, ranging from 7 to 49%, suggesting that overuse of C-sections may be contributing to the higher maternal mortality rates [11].
2. **Increased neonatal mortality and morbidity**: infants born by C-section have a higher risk of neonatal mortality and morbidity than those born vaginally, even after accounting for differences in maternal risk factors. The study suggests that the overuse of C-sections may be contributing to these negative outcomes [12].
3. **Financial burden**: C-section deliveries are more expensive than vaginal deliveries, both for the healthcare system and for individual families. The average cost of a C-section delivery in India was almost three times higher than the cost of a vaginal delivery, and that family who had C-sections experienced greater financial burden and were more likely to face catastrophic healthcare expenditure [13].
4. **Unnecessary interventions**: Overuse of C-sections can lead to unnecessary medical interventions and procedures, such as induction of labor and early delivery. These interventions can have negative consequences for maternal and infant health, including increased risk of infection and neonatal respiratory distress syndrome [14, 15].

There are several other negative health outcomes associated with infants delivered by C-section, including childhood obesity, respiratory disorders, type 1 diabetes, acute lymphoblastic leukemia, impaired cognitive development, higher autism rates, and an increased risk for neurodevelopmental disorders [16–23].

In South India, the rates of C-sections are generally higher than the national average, and there are several factors that contribute to this trend which is a cause for concern. The C-section rate was higher in urban areas than in rural areas, and the most common reason for C-sections was "previous C-section" [15]. Another study found that the C-section rate was higher in women who were of higher socioeconomic status and who had received antenatal care [24]. A study found that the C-section rate in south Indian states/UTs and districts were found to be very high, particularly in the private sector hospitals [25]. Therefore, the most common reason for C-sections was "previous C-section" and women who had C-sections had longer hospital stays and higher healthcare costs. Also, the C-section rate in a tertiary care hospital in South India was 75%, and that the most common reason for C-sections was "fetal distress". In this context, it is important to understand the reasons for the high rates of C-sections in South India and the implications of this trend on maternal and neonatal health outcomes. It is important for healthcare providers and policymakers to address the overuse of C-sections in South India and promote evidence-based guidelines and practices, encouraging vaginal birth after cesarean (VBAC) when appropriate, providing comprehensive childbirth education and support, and ensuring access to quality prenatal and obstetric care. Furthermore, the WHO has also called for efforts to reduce unnecessary C-sections and ensure that the procedure is only used when medically necessary to improve maternal and neonatal outcomes.

Data and methods

Data source This is a secondary data analysis of The National Family Health Survey (NFHS), which is a nationally representative survey conducted in India to collect comprehensive data on various aspects of population, health, and nutrition. NFHS-5 is the fifth round of the survey conducted between 2019 and 2021. Data is representative at the district level also. The unit of analysis is the individual. It provides crucial information on maternal and child health, reproductive health, family planning, and healthcare services utilization, including data on deliveries. These may include the mode of delivery (C-section or vaginal delivery), the type of healthcare facility where the delivery occurred (public hospital, private hospital, clinic, home), and socio-demographic factors of women such as age, education, marital status, and wealth status.

Sample selection

For our study, we selected a group of women who had given birth at least once in the past five years, resulting in a total of 232,920 births (Supplementary Figure S1). Out of these, 56,077 were second or higher-order births, so the count for the last birth in the last 5 years was 176,834. Since we only included data from their most recent pregnancy, we excluded all second and higher-order pregnancies. We also excluded non-institutional births, leaving us with a sample of 155,624 eligible births, with their mode of delivery categorized as C-section (yes or no). Afterward, we excluded all those that were not in South India, resulting in a final sample of 22,403. "South India" typically refers to the southern region of the country, encompassing specific states such as Andhra Pradesh, Telangana, Karnataka, Kerala, Tamil Nadu, and the union territory of Puducherry, Andaman & Nicobar Island, and Lakshadweep (Supplementary Table S1). Out of these, 44.96% underwent a C-section delivery, while the remaining had vaginal deliveries. Figure-S1 provides a more detailed explanation of the sample selection process.

Variable description

Outcome Variable The current study focuses on the last delivery, using a binary outcome variable to assess the mode of delivery among currently married women aged 15 to 49 years. This is based on the mother's self-report. Given the importance of caesarean deliveries as an indicator of maternal health and healthcare access, their inclusion as the primary outcome variable is.

Explanatory variables This study utilized several socio-demographic characteristics as individuals and household level variables.

Individual characteristics- These included Mother's age at child birth, categorized as <20 years, 20–29 years and 30 and above years. Mother's schooling as no education, primary education, secondary education, and higher education. Age at marriage, categorized as less than 18 years, 18–24 years, and 25 years or older. Other variables included pregnancy problems (no or yes), High risk fertility behavior (No risk, single risk, multiple risk), registration with Auxiliary Nurse and Midwife (ANM) (yes or no), place of delivery (government hospital or private hospital), ANC visits (less than or equal to three visits or more than three visits), ever pregnancy termination (no or yes), Size at childbirth (bigger than normal, normal, less than normal). A woman is classified as exhibiting high-risk fertility behaviour if she gives birth at less than 18 or above 34 years old, has a birth interval of less than 24 months, or has a birth order of 4 and higher. A woman is considered to have a single high-risk fertility behaviour if she reports experiencing one of the following: giving birth at a younger age (less than 18 years) or above 34 years, or having a birth interval of less than 24 months, or having a high birth order (four and above). Multiple high-risk fertility behaviours are identified when a woman exhibits a combination of at least two of the aforementioned behaviours [26–29]. Furthermore, the pregnancy problem variable was derived from the following indicators: vaginal bleeding (yes or no), convulsions (yes or no), prolonged labor (yes or no), severe abdominal pain (yes or no), and high blood pressure during pregnancy (yes or no). If any of the mentioned issues were present during pregnancy, it is classified as a pregnancy problem; otherwise, it is categorized as not having a pregnancy problem.

Household characteristics- Household characteristics encompass wealth index (poorest to richest), place of residence (rural or urban), religion (Hindu or non-Hindu), and social status (Scheduled Caste (SC)/Scheduled Tribe (ST), Other Backward Class (OBC), others).

Statistical analysis

Bayesian Multilevel Logistic Regression Model

Since the predicted variable is dichotomous (C-section delivery "Yes" or "No"), a binary logistic regression model was used. Multilevel logistic regression includes random effects as an extension of the single-level logistic regression model [30]. Suppose we have data consisting of last birth delivery information of women, (level one) grouped into characteristics (level two, three and four). Let Y_{ij} be the binary response for C-section delivery in region j and X_{ij} be an explanatory variable. We define the probability of the response equal to one $\pi_{ij} = P(y_{ij} = 1)$ Where; π_{ij} be modeled using a logit link function. The standard assumption is that Y_{ij} has a Bernoulli distribution. Then, the two-level models are given by:

$$logit\left(\pi_{ij}\right) = \log\left[\frac{\pi_{ij}}{1-\pi_{ij}}\right] = \beta_{0j} + \sum_{h=1}^{k}\beta_{hj}X_{hij} \quad (1)$$

$$i = 1,2\ldots\ldots n_j, h = 1,2\ldots\ldots\ldots .k, j = 1,2,\ldots\ldots\ldots 11$$

$$\beta_{oj} = \beta_o + U_{oj}, \beta_{1j} = \beta_1 + U_{1j}, \ldots, \beta_{kj} = \beta_k + U_{kj}$$

$$logit\left(\pi_{ij}\right) = \log\left[\frac{\pi_{ij}}{1-\pi_{ij}}\right] = \beta_0 + \sum_{h=1}^{k}\beta_{hj}X_{hij} + U_{oj} + \sum_{h=1}^{k}U_{hj}X_{hij} \quad (2)$$

$X_i = (X_{1ij,}X_{2ij,}\ldots\ldots\ldots .X_{kij})$ represent the level of covariates, for variable k ($\beta = \beta_o, \beta_1, \ldots\ldots \beta_k$) are the regression parameter coefficient. The parameters $U_{0j}, U_{1j}, \ldots\ldots ., U_{kj}$ is the random effect of the model parameter at different levels. With the assumption U_{hj}, follows a normal distribution with mean zero and variance σ_u^2.

Multilevel analysis of null model

A binary outcome variable with an empty three-level model represents a group of individuals.

And provides a distribution of group-dependent probabilities without considering any further explanatory variables [30, 31]. This model only contains random groups and random variation within groups. It can be expressed with logit link function as follows.

$$logit\left(\pi_{ij}\right) = \beta_0 + U_{0j} \quad (3)$$

$$U_{0j} \sim IID(0, \sigma_0^2)$$

Where β_0 indicates the population average of the transformed probability and U_{0j} is the random deviations from this average for region j

Model selection and comparison

In model selection, the best model is selected from a set of options based on its performance. The deviance information criterion (DIC) is a widely used statistic for comparing models in a Bayesian context. Deviance is defined as

$$D(\theta) = -2\log\left(p(y|\theta)\right) + c,$$

where y represents the data, θ denotes the unknown parameters of the model, and $p\left(y|\theta\right)$ is the likelihood function. The constant c, which cancels out in all calculations when comparing different models and thus it is not required to be known.

The expectations, denoted as $\widehat{D} = E\left[D\left(\theta\right)\right]$, serve as a measure indicating how well the model fits the data; a higher value suggests a poorer fit. The deviance information criterion (DIC) is defined as $\mathrm{DIC} = \widehat{D} + pD$. Since the deviance (D) decreases with an increasing number of parameters in a model, the pD term compensates for this effect by favoring models with fewer parameters.

DIC has an advantage over other Bayesian model selection criteria, such as AIC and BIC, in that it can be easily calculated from samples generated by a Markov Chain Monte Carlo (MCMC) simulation. Unlike AIC and BIC, which require calculating the likelihood at its maximum, an information that is not readily available from the MCMC simulations. To compute DIC, simply calculate $\widehat{D}$ as the average of $D\left(\theta\right)$ over a sample value of θ, and $D(\widehat{\theta})$ as the value of D evaluated at the average of the samples of θ [32]. The DIC is then derived directly from these approximations.

Geospatial analysis

The Moran's I values measure the spatial autocorrelation or the degree of similarity between neighboring districts regarding the specific indicator/variable. The values range from −1 to 1, where a positive value indicates positive spatial autocorrelation (similar values tend to cluster together), a negative value indicates negative spatial autocorrelation (dissimilar values tend to cluster together), and a value close to zero indicates no spatial autocorrelation. Univariate Cluster map depicts the four major category of colour code namely,

1) High-high clustering (Hot Spot): High prevalent location (district) surrounded by high prevalent neighborhood district.
2) Low-low clustering (Cold Spots): Low prevalent location (district) surrounded by low prevalent neighborhood district.
3) High-low clustering (Spatial outliers): High prevalent district surrounded by the low prevalent district.
4) Low-high clustering (Spatial outlier): Low prevalent district surrounded by the high prevalent district.

Bivariate LISA (Local Indicators of Spatial Association) maps utilize specific indicators to reveal spatial patterns and relationships between two variables. These indicators include:

High-High (HH) Clustering: Indicates areas where both variables exhibit high values and are spatially clustered. These regions highlight locations with similar high values for both variables.

Low-Low (LL) Clustering: Represents areas where both variables have low values and are spatially clustered.

These regions identify locations with similar low values for both variables.

High-Low (HL) Clustering: Signifies areas where one variable has a high value and the other has a low value, indicating a spatial outlier or dissimilarity between the variables.

Low-High (LH) Clustering: Represents areas where one variable has a low value and the other has a high value, indicating another form of spatial dissimilarity.

Ethical consideration

Our research relies on survey data that has undergone anonymization, ensuring the removal of any identifiable information associated with individuals. Prior to participating in the survey, all participants provided informed consent, and data collection was conducted in a confidential manner. The Measure DHS International Program has granted written permission for the usage of the data, and the dataset has been publicly released. Therefore, there is no requirement for additional permission to utilize the dataset.

Patient and public involvement None.

Results

Figure 1 presents the visual representation of the regional distribution of C-section deliveries throughout India for the years 2019–2021. The outcomes depicted in Fig. 1 highlight distinct variations in the occurrence of C-section deliveries across different geographical regions of India within the specified time frame, showing the elevated C-section rate in the South Indian states.

Socio-demographic characteristics and its association of C-section deliveries

Table 1 shows the prevalence of C-section deliveries among women in South India, analyzed by selected background characteristics, establishing their associations through chi-square statistics at the 95% level of significance. Within the presented data, several key variables exhibit statistically significant relationships with the dependent variable. Notably, as the maternal age at childbirth progresses, there is a concurrent escalation in C-section deliveries, with the highest prevalence observed among mothers aged above 30 years (53.5%). Furthermore, there is positive correlation between a mother's level of schooling and prevalence of C-section. As the years of formal education ascend, so does the prevalence of C-section, ranging from 30.7% in women with no formal education to an elevated 53.6% among those with a higher educational background. Additionally, the healthcare facility type emerges as a noteworthy factor, with private hospitals demonstrating a notably higher prevalence of C-section deliveries at 59.8%, in contrast to government hospitals where the prevalence is 33.9%. Curiously, women exhibiting high-risk fertility behavior display a negative relationship with C-section deliveries. Those classified as no-risk (46.4%) and single-risk (41.1%) exhibit a higher prevalence of C-section deliveries in comparison to their counterparts with multiple risk factors, whose rate stands at 27.6%. Moreover, there exists a positive correlation between a woman's age at marriage and the likelihood of opting for C-section deliveries. As the age at marriage advances, there is a corresponding increase in the prevalence of C-section deliveries. Furthermore, the wealth index of women demonstrates a positive association with C-section deliveries in South India. As the financial status of women improves, the prevalence of C-sections escalates: poorest (25.9%), poorer (34.8%), middle (44.3%), richer (47.0%), and richest (52.5%). Lastly, urban women (47.9%) and those adhering to the Hindu faith (46.0%) exhibit a higher prevalence of C-section deliveries compared to their rural counterparts and women following non-Hindu religions in South India. These findings collectively contribute to a more nuanced understanding of the intricate factors influencing C-section delivery choices within this region.

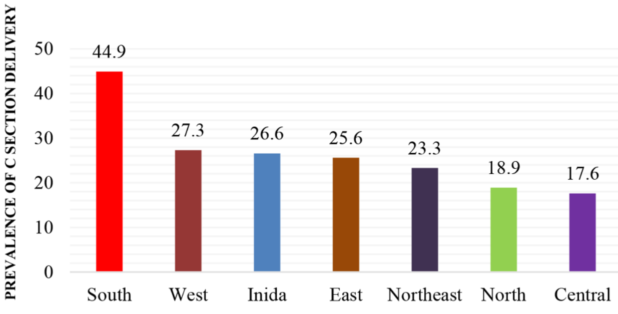

Fig. 1 Regional prevalence of C-section delivery in India 2019-21

Bayesian multilevel analysis of C-section delivery by background characteristics

The Bayesian Multilevel analysis model incorporates the null model, individual-level model, household-level model, and the full model comprising both individual and household levels. Individual level model takes into account the characteristics mother's age at birth, mother's schooling, pregnancy problem, registered with ANM or not, place of delivery, high risk fertility behavior, number of ANC visits, age at marriage, ever pregnancy termination and size of the child. Household level models includes the characteristics such as wealth-index, residence, religion and social status. The full model considers the sum of individual level characteristics and household characteristics. The odds ratios (ORs) and their

Table 1 Weighted sample distribution for recent birth and association of C-Section delivery by background characteristics in South India, 2019–2021

Background characteristic	Sample	Percentage	C Section delivery		Chi square (*P*-value)
Individual characteristics			Sample	Percentage	
Mother's age at child birth					
< 20 year	2112	9.4	784	37.1	0.00000
20–29 year	16,608	74.1	7318	44.1	
30 + year	3683	16.4	1971	53.5	
Mother's schooling					
No Education	1551	6.9	476	30.7	0.00000
Primary	1324	5.9	494	37.3	
Secondary	12,843	57.3	5,518	43.0	
Higher	6685	29.8	3,584	53.6	
Pregnancy Problem					
No	5166	23.5	2,238	43.3	0.15303
Yes	16,856	76.5	7,680	45.6	
Registered with					
ANM	9587	43.9	4,392	45.8	0.80536
Not ANM	12,262	56.1	5,364	43.7	
Place of delivery					
Government hospital	12,833	57.3	4,354	33.9	0.00000
Private hospital	9570	42.7	5,719	59.8	
High Risk Fertility Behaviour					
No Risk	17,263	77.1	8,016	46.4	0.00000
Single Risk	4743	21.2	1,948	41.1	
Multiple Risk	397	1.8	110	27.6	
Number of ANC visits					
<=3 visits	4655	21.0	1970	42.3	0.08990
>= 4 visits	17,480	79.0	7990	45.7	
Age at marriage					
< 18 years	5142	23.1	1,932	37.6	0.00000
18–24 years	14,131	63.4	6,333	44.8	
>=25 years	3030	13.6	1,765	58.2	
Ever Pregnancy Termination					
No	19,106	85.3	8,365	43.8	0.00000
Yes	3297	14.7	1,708	51.8	
Size of the child					
Bigger than normal	5472	24.5	2,566	46.9	0.00004
Normal	15,235	68.1	6,716	44.1	
Less than normal	1659	7.4	776	46.8	
Household Characteristics					
Wealth index					
Poorest	882	3.94	229	25.9	0.00000
Poorer	3165	14.13	1102	34.8	
Middle	6165	27.52	2729	44.3	
Richer	6999	31.24	3291	47.0	
Richest	5192	23.17	2723	52.5	
Residence					
Urban	9078	40.5	4,343	47.9	0.00000
Rural	13,325	59.5	5,730	43.0	
Religion					
Hindu	18,074	80.7	8,304	46.0	0.00000
Non-Hindu	4329	19.3	1,769	40.9	
Social Status					

Table 1 (continued)

Background characteristic	Sample	Percentage	C Section delivery		Chi square (*P*-value)
Individual characteristics			**Sample**	**Percentage**	
SC/ST	6357	28.4	2,588	40.7	0.00000
OBC	13,261	59.2	6,230	47.0	
Others	2785	12.4	1,255	45.1	
Total	**22,403**	**100.0**	**10,073**	**45.0**	

corresponding 95% credible intervals (Cr.I) are reported for each characteristic in each model.

Table 2 shows Bayesian multilevel analysis at various levels (State, District, and PSU) for different set of predictor variables. These includes individual level, household level and combined (individual + household) level variables, aiming to predict the C-section occurrences for last birth based on background characteristics in South India, 2019-21. The presence of significant non-zero variance at different levels in the null model suggests that C-section delivery varies across different levels in India. Therefore, multilevel analysis can be considered an appropriate approach for further examination.

Individual level model

From this model, we have found that the mother's age at child birth, mother's schooling, place of delivery, age at marriage, ever pregnancy termination and size of the child were the significant predictors for higher likelihood of C-section delivery in South India.

The likelihood of C-section delivery increases with the age of the mother at childbirth. For example, mothers aged 20–29 years during their childbirth had a 13% (95% Cr.I. 1.09–1.16) higher likelihood, and those aged 30 years and above had a 50% (95% Cr.I. 1.40–1.62) higher odds of C-section delivery compared to the reference category. Similarly, an increase in the level of mother's education was associated with an increased odds of C-section delivery. For instance, primary, secondary, and higher educated women had 1.24 (95% Cr.I. 1.14–1.35), 1.53 (95% Cr.I. 1.40–1.67), and 1.58 (95% Cr.I. 1.42–1.76) times higher odds of C-section delivery, respectively, compared to uneducated women. Delivery in a private hospital was significantly associated with C-section delivery, with 3.2 times higher odds compared to government hospitals. The age at marriage of women showed a positive relationship with C-section delivery, with a 15% higher likelihood in women married between age 18-24-year and a 64% higher likelihood among women married after age 25 years compared to the reference category women married below 18 years. Furthermore, women who had ever terminated their pregnancies had 21% higher odds of C-section delivery compared to ever non-terminated pregnancy women. The size of the child also played a significant role in C-section delivery, with less than normal size and greater than normal size children having odds ratios of 1.16 and 1.15, respectively, for C-section delivery compared to women who gave birth to a normal-sized child.

Household level model

The findings from the household level model indicate that wealth-index, residence, religion, and social status are significantly associated with C-section delivery. The wealth-index exhibits a positive relationship with C-section delivery, indicating that as the household's wealth improves, the odds of having C-section deliveries also increase. Specifically, the adjusted odds ratios (AOR) were 1.6 (95% Cr.I. 1.40–1.82), 2.25 (95% Cr.I. 2.07–2.49), 2.75 (95% Cr.I. 2.48–3.10), and 3.33 (95% Cr.I. 2.96–3.77) for poorer, middle, richer, and richest wealth indices, respectively in compare to poorest women. Urban households' women had a 7% higher likelihood of C-section delivery compared to rural households women's. Similarly, Hindu household women had an AOR of 1.25, while OBC and Others household women had AORs of 1.17 and 1.18 odds of C-section delivery, respectively in compare to their reference group of women.

Individual + household (full model)

From Model 4 (full model), we found that factors such as pregnancy problems, registration with ANM, number of Antenatal Care (ANC)visits, and place of residence were not significant predictors of C-section delivery in South India. Similar to the individual-level model, the full model also demonstrated a significant association with an increase in the age at marriage. Additionally, with an increase in years of schooling, the likelihood of C-section delivery also increased. For instance, women with primary education had 14% higher odds, and women with secondary and higher education had odds of 1.44 for C-section delivery compared to uneducated women. Deliveries at private hospital had 3.28 times higher odds of C-section deliveries compared to government hospital deliveries. Age at marriage also played significant role in C-section deliveries, with 77% higher odds if mother's age at marriage was greater or equals to 25 years. The size of the child was also played an important role in C-section deliveries if baby size was less than or greater than normal. Wealth index showed a positive correlation with C-section deliveries in South-India. As wealth improves, the odds of using C-section deliveries increases from 51%

Table 2 Bayesian multilevel analysis for recent birth predicting c section delivery by background characteristics in South India, 2019-21

Background characteristic	Model 1: Null model	Model 2: Individual level	Model 3: Household level	Model 4: Ind + household (full model)
Individual characteristics	**AOR (95% Cr.I)**	**AOR (95% Cr.I)**	**AOR (95% Cr.I)**	**AOR (95% Cr.I)**
Mother's age at child birth				
< 20 year(Ref)				
20–29 year		1.13 [1.09 1.16]*		1.12 [1.07 1.18]*
30 + year		1.5 [1.4 1.62]*		1.4 [1.34 1.46]*
Mother's schooling				
No Education(Ref)				
Primary		1.24 [1.14 1.35]*		1.14 [1.1 1.19]*
Secondary		1.53 [1.4 1.67]*		1.44 [1.35 1.53]*
Higher		1.58 [1.42 1.76]*		1.44 [1.35 1.53]*
Pregnancy Problem				
No(Ref)				
Yes		1 [0.96 1.04]		0.98 [0.93 1.04]
Registered with				
Not ANM(Ref)				
ANM		1.05 [0.98 1.1]		1.06 [1 1.11]
Place of delivery				
Government hospital(Ref)				
Private hospital		3.2 [3.05 3.35]*		3.28 [3.15 3.4]*
High Risk Fertility Behaviour				
No Risk(Ref)				
Single Risk		0.83 [0.77 0.89]*		0.86 [0.83 0.9]*
Multiple Risk		0.5 [0.47 0.54]*		0.57 [0.53 0.6]*
Number of ANC visits				
<=3 visits(Ref)				
>= 4 visits		1.01 [0.94 1.07]		0.99 [0.93 1.05]
Age at marriage				
< 18 years(Ref)				
18–24 years		1.15 [1.1 1.19]*		1.19 [1.14 1.24]*
>=25 years		1.64 [1.51 1.79]*		1.77 [1.67 1.89]*
Ever Pregnancy Termination				
No (Ref)				
Yes		1.21 [1.16 1.25]*		1.2 [1.12 1.28]*
Size of the child				
Normal(Ref)				
Bigger than normal		1.16 [1.11 1.22]*		1.18 [1.12 1.25]*

Table 2 (continued)

Background characteristic	Model 1: Null model	Model 2: Individual level	Model 3: Household level	Model 4: Ind + household (full model)
Individual characteristics	**AOR (95% Cr.I)**	**AOR (95% Cr.I)**	**AOR (95% Cr.I)**	**AOR (95% Cr.I)**
Less than normal		1.15 [1.03 1.26]*		1.24 [1.19 1.3]*
Household Characteristics				
Wealth index				
Poorest(Ref)				
Poorer			1.6 [1.4 1.82]*	1.51 [1.47 1.56]*
Middle			2.25 [2.07 2.49]*	1.68 [1.61 1.75]*
Richer			2.75 [2.48 3.1]*	1.69 [1.59 1.78]*
Richest			3.33 [2.96 3.77]*	1.49 [1.42 1.55]*
Residence				
Rural(Ref)				
Urban			1.07 [1.01 1.14]*	1.03 [0.98 1.07]
Religion				
Non Hindu (Ref)				
Hindu			1.25 [1.16 1.36]*	1.25 [1.16 1.33]*
Social Status				
SC/ST(Ref)				
OBC			1.17 [1.1 1.25]*	1.04 [0.99 1.09]
Others			1.18 [1.06 1.29]*	0.89 [0.83 0.96]*
Variance for State	***0.39 [0.1 1.14]***	***0.43 [0.12 1.27]***	***0.39 [0.1 1.12]***	***0.31 [0.09 0.92]***
Variance for District	***0.24 [0.18 0.32]***	***0.19 [0.14 0.25]***	***0.21 [0.15 0.28]***	***0.18 [0.13 0.25]***
Variance for PSU	***0.24 [0.18 0.32]***	***0.17 [0.11 0.25]***	***0.2 [0.16 0.26]***	***0.2 [0.15 0.27]***
Bayesian DIC	**28705.42**	**25419.45**	**28386.44**	**25377.11**

in poorer wealth category to 69% in richer wealth category and then decreases to 49% in the richest category.

The variance for state, district, and primary sampling unit (PSU) was also reported for each model, indicating the amount of variability in cesarean delivery rates at these levels that could not be explained by the included characteristics. The variance for these levels decreased in the full model (σ^2 state = 0.31, σ^2 district = 18, σ^2 PSU = 0.20) compared to the null model (σ^2 state = 0.39, σ^2 district2 = 24, σ^2 PSU = 0.24), suggesting that the included characteristics explained some of the variability.

The Supplementary Figure S2 shows prevalence of C-section deliveries in the districts of South India was analyzed using a spatial map. This map provides insights into variations in the prevalence of C-section delivery, highlighting areas with both high and low prevalence, and identifying potential disparities in the districts of South India. The interpretation of the spatial autocorrelation and hotspot analysis of C-section deliveries in South India, 2019–2021 involves examining the distribution and clustering patterns of C-section deliveries in the region. Moran's I values (I = 0.62) indicated that there was significant clustering (99% confidence < 0.001) of C-section delivery in south India as a whole (Fig. 2). On the other hand, Hotspot analysis focuses on identifying statistically significant clusters of high values within a spatial dataset. In this study, hotspot analysis aims to identify areas in South India with a significantly higher prevalence of C-section deliveries compared to the expected average. This analysis can help identify spatially concentrated

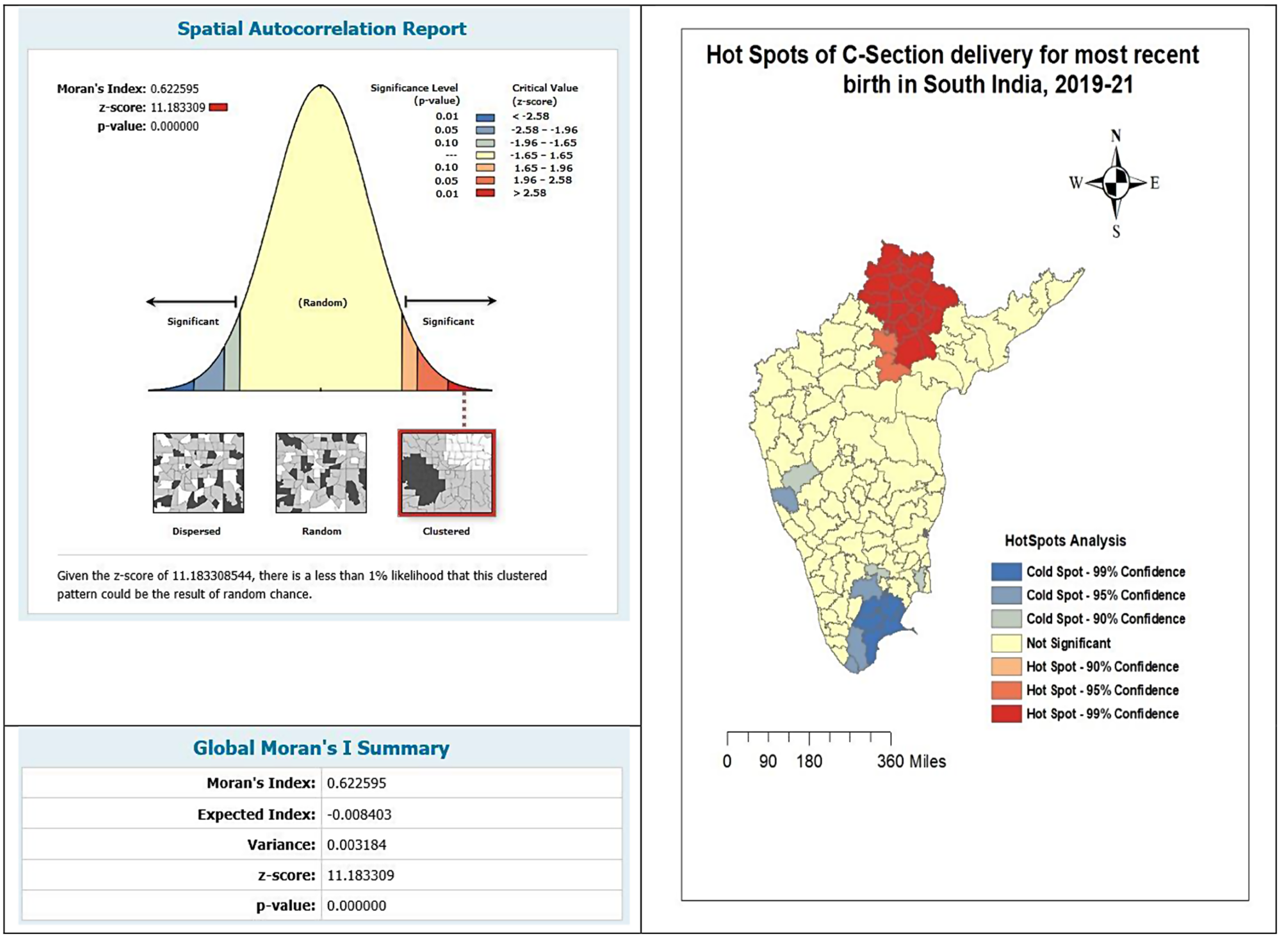

Fig. 2 Spatial Autocorrelation and hotspot analysis of C-section delivery in South India, 2019-21

areas of concern or areas with potential over-prevalence of C-section deliveries.

Based on the Supplementary Table S2, we observed that several indicators/variables show statistically significant spatial dependence in relation to C-section delivery prevalence at the district level in South India. For example, age at marriage (>=25 years), mother age at childbirth (>=30 years), and antenatal visits (>=4) exhibit high Moran's I values and high Z scores, indicating strong positive spatial autocorrelation and significant clustering patterns. On the other hand, variables such as place of delivery (Private), richest, urban, pregnancy termination (Yes), and antenatal visits (>=4) show lower Moran's I values and lower Z scores, suggesting relatively weaker spatial dependence.

Figure 3 shows the Emp. Bayes bivariate LISA cluster maps indicating the geographic clustering (hotspot & cold spots) of c section deliveries with different independent variables across the districts of South-India. Map A1 indicates the bivariate clustering of C-section with private place of delivery. Map A2 indicates the bivariate clustering of C-section delivery with age at marriage (>=25 years), A3 indicates the bivariate clustering of C-section delivery with mother age at childbirth (>=30 years) and A7 indicates the bivariate clustering of C-section delivery with antenatal Visits (>=4). The districts marked in red were clustered as high-high, signifying a high prevalence of C-section deliveries, while the districts in blue indicated low-low clustering, denoting a low prevalence of C-section deliveries along with their corresponding predictor variables.

Discussion

The escalating global trend of cesarean section (C-section) deliveries has significantly impacted maternal and neonatal healthcare. Amid this landscape, the prevalence of C-section deliveries in South India during 2019–2021 emerges as a crucial area of investigation. Notably, maternal age at childbirth plays a significant role, with older mothers (30+years) displaying a heightened likelihood of having C-sections. This study highlights the richest delivering via C-section, the plausible reasons may be that frequency of C-sections may be impacted by the accessibility and availability of medical facilities and qualified

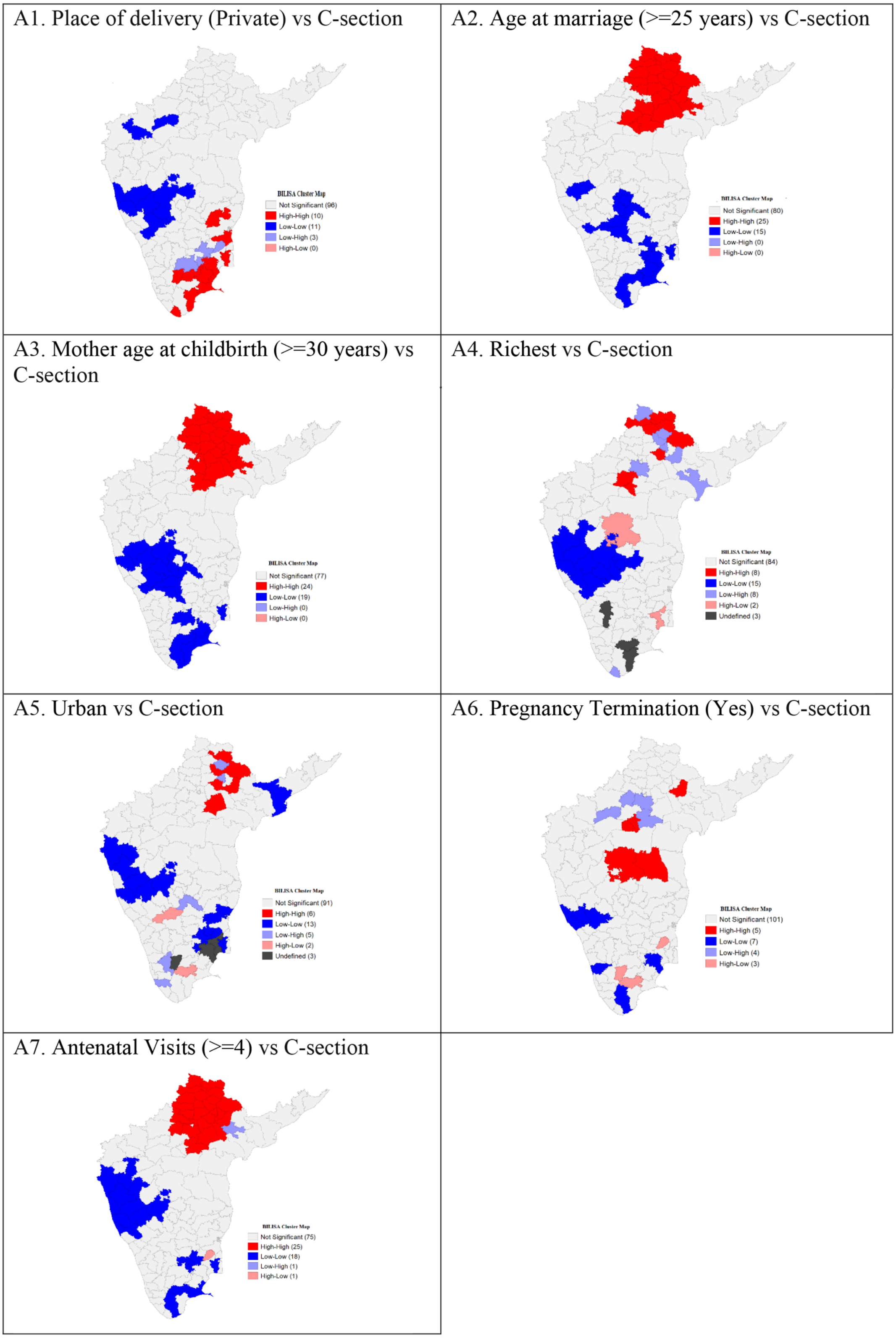

Fig. 3 Emp. Bayes Bivariate LISA cluster maps of South India showing the geographic clustering (hotspots & cold spots) of C-section delivery, 2019-21

medical personnel [33]. The option of C-sections can be more accessible in areas with well-established healthcare infrastructure. There could be a number of reasons why C-sections are more common in these areas, such as convenience or perceived safety [34]. This rise in C-sections could be explained by the idea that once a caesarean, always a caesarean, as studies have shown that the majority of C-sections performed in hospitals are repeat procedures Subsequently, this trend aligns with global research, reflecting potential medical considerations and maternal preferences for safer deliveries [35, 36]. It is worth exploring whether this age-related pattern is driven by medical recommendations, maternal preferences for controlled birthing experiences, or a combination of both. The rates of C-section deliveries in urban and rural locations varied significantly from one another. These variations are frequently noted among many community groups and districts such variation has been observed in Krishnagiri and Chamrajnagar [37], and our results concur with those of previous research. The rate of C-section births at tertiary-care hospitals has increased along with improved diagnosis and ease of referral due to the expansion of health care coverage [38].

Educational attainment is a crucial determinant, with a positive correlation between schooling and the choice of C-section deliveries. Higher education levels appear to influence healthcare decision-making, possibly indicating a greater awareness of medical options and maternal health outcomes. However, the intersection of education, socio-economic status, and access to information warrants further investigation, as these factors can influence women's autonomy and informed decision-making [39, 40]. Furthermore, healthcare facility type emerges as a significant factor, with private hospitals exhibiting a substantially higher prevalence of C-section deliveries. This observation echoes international patterns, wherein private healthcare settings tend to witness elevated C-section rates, attributed to financial incentives and medical practices. This raises questions about the role of medical practices, financial considerations, and patient-provider communication in shaping delivery decisions [41, 42]. Of particular interest is the inverse relationship between high-risk fertility behavior and C-section deliveries. This intriguing finding suggests that women classified as high-risk might be directed towards controlled birthing practices, including C-sections, to minimize potential health risks to both mother and child. Mothers with high socioeconomic status, obesity, various pregnancy outcomes, and high-risk birth weight were found to be substantially linked to caesarean sections. Previous research indicates that older moms, even in the absence of problems, are more likely than younger mothers to use healthcare services, experience issues during pregnancy and delivery, and have a C-section birth [43–47]. Consistent with previous research, researchers have discovered that a greater socioeconomic position is positively correlated with C-section rates, contributing to the rich-poor gap. However, further research is warranted to unravel the complexities of this relationship, considering medical indications, patient preferences, and healthcare provider practices [48]. Socio-economic factors also intertwine with healthcare decisions. Wealth index and urban residence exert substantial influence, with an increase in household wealth correlating with a higher propensity for C-section deliveries. Financial considerations and access to healthcare resources likely contribute to this phenomenon, underscoring disparities in healthcare utilization and raising questions about equitable access to quality care [49].

The Bayesian multilevel analysis, provides a comprehensive lens to understand C-section deliveries. Individual-level, household-level, and integrated characteristics are considered, reflecting the intricate interplay between personal, familial, and contextual factors. The individual-level model reveals that maternal age at childbirth, schooling, place of delivery, high-risk fertility behavior, and age at marriage significantly influence C-section decisions. These findings emphasize the need for tailored interventions that account for individual medical and demographic attributes. For instance, the positive relationship between age at marriage and C-section deliveries could reflect cultural norms, maternal health considerations, and access to information. Such insights are critical for developing targeted interventions that address diverse needs and preferences [35, 39]. Household-level factors, such as wealth index, residence, religion, and social status, all their socio-economic variables affect the preference of C-section. C-section Notably, wealth index exhibits a positive correlation, corroborating the role of financial resources in healthcare choices. Urban residence and religious affiliation emerge as significant factors, further accentuating the role of access, beliefs, and community norms. Policymakers must recognize the intertwined nature of socio-economic and cultural factors, tailoring policies to promote equitable access to quality maternal care [41, 50]. Spatial analysis, introduces a geographic dimension to C-section prevalence. Spatial autocorrelation and hotspot analysis, delve deeper into the distribution of C-section deliveries where preference of c section can be seen in urban and richest category. Higher rates of C-section deliveries among urban and wealthier women in India may be influenced by factors such as greater access to medical facilities, a preference for perceived convenience and control, the medicalization of childbirth, fear of pain and complications, and cultural preferences. Educational disparities, social norms, and insurance coverage can also play a role. Efforts to address this trend involve promoting evidence-based practices, educating healthcare providers and the public, and addressing systemic issues in the healthcare system [51]. These analyses unveil localized influences and clustering patterns, offering insights into regional healthcare practices. High Moran's I value and significant clusters emphasize that certain variables exhibit strong spatial autocorrelation, reflecting the role of geography and context in healthcare decisions. The majority of India's southern states have high rates of C-section deliveries. The primary cause of this shift is the rise of institutional deliveries, which is contributing to the trend toward caesarean deliveries in all of the southern states. Urban areas have a greater rate of C-sections in the majority of states. Numerous factors, including sophisticated medical facilities with cutting-edge obstetric treatments, women's preference for private facilities, high rates of maternal healthcare utilisation, and profit-driven competition, all impact the use of C-sections in urban locations [52–56]. This visualization enhances our understanding of regional disparities, identifying areas with elevated and diminished C-section rates. Policymakers can leverage this information to develop targeted strategies aimed at optimizing maternal and neonatal health outcomes, while minimizing disparities in access. By identifying regions with potential higher prevalence of C-sections, policymakers can work towards balanced and evidence-based healthcare policies [50]. Policymakers and healthcare providers can collaborate to ensure that spatial patterns do not lead to inequitable healthcare access and outcomes [50].

This study focuses on C-section prevalence during the years 2019–2021, which may limit its ability to capture long-term trends and changes over time. While the study identifies associations between socio-demographic factors and C-section choices, it does not establish causality. Further research would be needed to explore the causal relationships between these variables. The study's findings rely on available data sources, which may have limitations in terms of accuracy and completeness. The quality of data can impact the validity of the study's conclusions. The study focuses on South India, and its findings may not be directly applicable to other regions or countries with different healthcare systems and socio-cultural contexts. In summary, this study offers valuable insights into the factors influencing C-section choices in South India. While it provides a comprehensive analysis, it also has limitations related to data, causality, and generalizability, which should be considered when interpreting its findings and designing future research or policies.

Conclusion

In conclusion, this discussion delves into the multifaceted landscape of C-section deliveries in South India. The exploration of associations between socio-demographic characteristics and C-section choices underscores the intricate interplay between age, education, healthcare settings, wealth, and urbanization. Bayesian multilevel and spatial analyses offer holistic insights that consider individual, household, and contextual dynamics. These findings hold implications for healthcare policies and interventions. Policymakers and healthcare providers should leverage this knowledge to develop nuanced strategies that ensure optimal maternal and child health outcomes. Recognizing the complexity of explaining differential C-section rates, stakeholders must address healthcare disparities, tailor interventions, and promote evidence-based decision-making. By doing so, South India can move towards more equitable and effective maternal and neonatal healthcare practices.

Supplementary Information

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Supplementary Material 1

Author contributions

Conceived and designed the research paper: MS and AS; Analyzed the data: MS and AS; Contributed agents/materials/analysis tools: MS, AS and JG; Wrote the manuscript: MS, AS and JG; All authors read, reviewed and approved the manuscript.

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Data availability

This study was based on a large dataset that is publicly available on DHS website (https://dhsprogram.com/data/) conducted by the MOHFW and International Institute for Population Sciences (IIPS) in India with ethical standards being complied with including informed consent obtained from participants.

Declarations

Ethics approval and consent to participate

Our research relies on survey data that has undergone anonymization, ensuring the removal of any identifiable information associated with individuals. Prior to participating in the survey, all participants provided informed consent, and data collection was conducted in a confidential manner. The Measure DHS International Program has granted written permission for the usage of the data, and the dataset has been publicly released. Therefore, there is no requirement for additional permission to utilize the dataset.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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