Geographic variation in caesarean delivery in India

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Abstract

Background: The rate of caesarean delivery has increased markedly both globally and within India. However, there is considerable variation within countries. No previous studies have examined the relative importance of multiple geographic levels in shaping the distribution of caesarean delivery and to what extent they can be explained by individual-level risk factors.

Objectives: To describe geographic variation in caesarean delivery and quantify the contribution of individual-level risk factors to the variation in India.

Methods: We conducted four-level logistic regression analysis to partition total variation in caesarean delivery to three geographic levels (states, districts and communities) and quantify the extent to which variance at each level was explained by a set of 20 sociodemographic, medical and institutional risk factors. Stratified analyses were conducted by the type of delivery facility (public/private).

Results: Overall prevalence of caesarean delivery was 19.3% in India in 2016. Most geographic variation was attributable to states (44%), followed by communities (32%), and lastly districts (24%). Adjustment for all risk factors explained 44%, 52% and 46% of variance for states, districts and communities, respectively. The proportion explained by individual risk factors was larger in public facilities than in private facilities at all three levels. A substantial proportion of between-population variation still existed even after clustering of individual risk factors was comprehensively adjusted for.

Conclusions: Diverse contextual factors driving high or low rate of caesarean delivery at each geographic level should be explored in future studies so that tailored intervention can be implemented to reduce the overall variation in caesarean delivery.

KEYWORDS
caesarean, geography, global health, India, multilevel modelling, variation
1 | INTRODUCTION

Caesarean delivery is an essential component of obstetric care that can be a life-saving intervention for mothers and infants when its use is medically justified. On the other hand, medically unnecessary caesarean surgery may produce additional short-term and long-term health risks for women and newborns. While the World Health Organization (WHO) has recommended an optimal country-level caesarean delivery rate of approximately 10%–15% at population level, caesarean delivery rates have continued to rise throughout the twenty-first century, expanding from a global average of 12.1% in 2000 to 21.1% in 2015. India has also seen a steady rise in the use of caesarean deliveries as in the global trend, with the national rate more than doubling from 7.1% in 2006 to 17.2% in 2016. However, an exclusive focus on country-level averages often masks large within-country variations. For example, the India National Family Health Survey (NFHS) 2016 recorded a caesarean delivery rate of 57.7% in the state of Telangana, but only 5.8% in the state of Nagaland.

Planning and management of the healthcare system in India revolves around several important geographic levels. Firstly, India is composed of 36 states and union territories, each of which has its own publicly funded healthcare infrastructure. Basically, state governments support payments only for services provided by public providers. Services in private facilities are paid by patients’ out-of-pocket expenditures. The next administrative unit is the district level, which takes charge of distributing healthcare and public health services to each of the 640 districts in India. Finally, at the community level, there are community health workers who engage in activities to link the multitude of communities across India to the formal healthcare system, often addressing diverse social and cultural barriers.

Although a number of factors - both internal and external to the healthcare system - operate across multiple geographic levels to shape variation in caesarean delivery rates across India, prior studies are mostly based on a single-level or, at most, a two-level analysis of population means, and therefore missed important aspects of this context. Relying only on a single geographic level at a time often leads to a ‘missing unit problem’—that is, the relative importance of any given unit can only be truly estimated when all levels that are thought to influence the outcome are simultaneously considered, and therefore, incomplete consideration of all geographic scales may lead to over- or underestimation of their importance. Additionally, few studies have examined the extent to which clustering of correlated risk factors may explain variations in caesarean delivery. As described in previous studies, a number of individual determinants may affect the prevalence of caesarean delivery including sociodemographic, health, medical and institutional factors, which may be differentially dispersed across the multiple geographic levels of India.

Therefore, our study aims to: (1) describe the distribution of caesarean delivery across individual-level demographic, medical, socioeconomic and institutional factors overall and across 36 states/union territories; (2) assess the extent of variation in caesarean delivery attributable to three geographic/population levels (states, districts and communities); (3) estimate the proportion of variance in caesarean delivery at each population level explained by a set of 20 individual-level demographic, socioeconomic, health/medical and institutional factors; and (4) finally examine aims 1–3 by type of delivery facility (i.e. public vs. private).

2 | METHODS

2.1 Data source, study design and study population

Data for this study were derived from the India NFHS-4, collected in 2016. NFHS is a nationally representative survey that comprehensively provides information on indicators related to maternal and child health. NFHS-4 adopted a stratified two-stage sampling for both rural and urban areas. Villages and census enumeration blocks served as the primary sampling units (PSU) in rural and urban areas, respectively, and were selected with probability proportional to population size in the first stage, followed by a random selection of households within each PSU at the second stage.
Our study sample was defined as women who had an institutional delivery for the most recent single live birth (excluding twins) during the 5 years preceding the survey. More detailed descriptions of data collection processes are provided in DHS technical documentation.\(^5\)

### 2.2 | Geographic level

Four levels of analysis were conceptualised and operationalised for the purpose of this study where the individual (within-population) unit of inference was defined as child (or mother) (level 1) and three geographic (between-population) units of inference included communities (level 2), districts (level 3) and states/union territories (level 4). Each level has political, administrative, social and cultural implications that could potentially affect the distribution of caesarean delivery. For example, in India, states (and union territories) are the highest administrative/political level at which federal health policies operate. Districts are the lowest administrative level at which the elected district councils plan the provision of diverse resources, services and infrastructures for health. Lastly, communities represent women’s and children’s local environments, which is generally villages for rural areas and survey blocks for urban areas.

### 2.3 | Outcome

The outcome was caesarean delivery, which was derived from the ‘woman’s questionnaire’ pertaining to the question ‘Was (NAME) delivered by cesarean section, that is, did they cut your belly open to take the baby out?’ Caesarean delivery was coded as yes or no.

### 2.4 | Exposure

In order to examine the extent to which variation in caesarean delivery was accounted for by individual characteristics, we identified a set of 20 covariates based on literature review and theoretical frameworks. Sociodemographic characteristics included mother’s age at childbirth, birth order, baby gender, religion, caste, type of residence (urban or rural), maternal education, household wealth quintile and paternal education. Health and medical factors included low birthweight, mother’s perception of baby size at birth, maternal height, BMI, smoking, chewing tobacco, drinking alcohol, and history of miscarriage, abortion or stillbirth. Institutional factors included insurance coverage and antenatal care, and the type of delivery facility. The type of facility was categorised into public and private. Public facilities included the following: government or municipality hospital, government dispensary, urban health centre or post, an urban family welfare centre, community health centre, block primary health centre and subcentre. Private facilities included the following: private hospital, maternity home, and clinic, non-government organisation and trust hospital and clinic. The categorisation and unit of each exposure variable can be referred to Table S2.

### 2.5 | Statistical analysis

We estimated unadjusted rates of caesarean delivery for the country of India and by state and district. Then, we presented ‘adjusted’ distributions of caesarean delivery for India, which consider all geographic levels simultaneously and quantified the extent to which accounting for clustering of individual factors explains geographic variation in caesarean delivery in each level. While these analyses are explicitly focused on examining variation (random effects) in caesarean delivery, we present measures of association (fixed effects) for each of the 20 individual factors included in adjusted models.

A series of four-level random intercept logistic regression model was utilised to acquire variance estimates for each geographic level (state, district and communities) while simultaneously accounting for each of the other level. In our data set, respondents within the same community, which served as a PSU in the sampling of NFHS, are likely to be more alike than respondents of different communities. Our four-level model addresses this clustering problem arising from survey sampling design by including community random effects.\(^20,21\)

Multilevel modelling was performed via Markov Chain Monte Carlo estimation procedures using a Gibbs sampler with default prior distributions of iterative generalised least squares estimation as starting values, a burn-in of 500 cycles and monitoring of 5000 iterations of chains. We checked the chains of the loading estimates for all parameters for convergence.

Multilevel logistic regression models were specified according to the following general structure:

\[
\text{logit} (\Pr (Y_{ijkl} = 1 | X)) = \beta_0 + \beta X_{ijkl} + u_{00jkl} + v_{0jkl} + f_{0ijkl},
\]

where the dependent variable \(Y\) (caesarean delivery) and independent variable \(X\) (representing a vector of covariates) were each assumed to follow a multilevel data structure whereby child \(i\) (level 1) is nested within community \(j\) (level 2), district \(k\) (level 3) and state \(l\) (level 4), with both fixed-effects \(\beta X_{ijkl}\) and random-effects parameters \(u_{00jkl}\) at community level, \(v_{0jkl}\) at district level and \(f_{0ijkl}\) at state level. The random-effects parameters are each assumed to follow a normal distribution with mean 0 and variances of \(u_{00jkl} \sim N(0, \sigma_u^2)\), \(v_{0jkl} \sim N(0, \sigma_v^2)\) and \(f_{0ijkl} \sim N(0, \sigma_f^2)\), respectively.\(^21-23\) Since logistic regression models do not have a level 1 residual term, the mother/child (level 1) variance was estimated as \(\pi^2/3\) (3.29) based on the method summarised by Goldstein et al.\(^24\)

Two model specifications were estimated based on the general modelling structure outlined above: a null/unadjusted model (M0), which included only an intercept term in the fixed part of the model, and a fully adjusted model (M1). In order to develop a more detailed quantification of geographic variability in caesarean delivery, which is our study aim 2, we calculated the proportion of total geographic variance attributable to each population level; that is variance partitioning coefficient (VPC) calculated as the variance at relevant level divided by the ‘total geographic variance’ in M0 and M1, respectively. Further, the proportion of between-population variance explained by the inclusion of the 20 individual characteristics in M1 compared with M0; that is proportional
### Table 1: Individual characteristics and caesarean delivery percentages for Indian women in the NFHS-4 (2016), overall and by the type of delivery facility

| Variable | Overall | Public | Private |
|----------|---------|--------|---------|
|          | Total births | Caesarean delivery N (%) | Total births | Caesarean delivery N (%) | Total births | Caesarean delivery N (%) |
| Total    | 136,985 | 26,446 (19.3) | 97,465 | 10,845 (11.1) | 39,520 | 15,601 (39.5) |
| Demographic factors | | | | | | |
| Mother’s age at childbirth (years) | | | | | | |
| <20      | 4351 | 659 (15.1) | 7784 | 764 (9.8) | 2475 | 875 (35.4) |
| 20–29    | 94,172 | 17,446 (18.5) | 70,192 | 7638 (10.9) | 29,197 | 11,285 (38.7) |
| 30–34    | 25,859 | 5692 (22.0) | 11,721 | 1524 (13.0) | 5609 | 2401 (42.8) |
| ≥35      | 12,603 | 2649 (21.0) | 4666 | 555 (11.9) | 1983 | 895 (45.1) |
| Birth order | | | | | | |
| First    | 50,939 | 12,943 (25.4) | 32,296 | 4951 (15.3) | 16,867 | 7593 (45.0) |
| Second   | 47,060 | 9780 (20.8) | 32,281 | 4026 (12.5) | 13,957 | 5649 (40.5) |
| Third    | 21,552 | 2614 (12.1) | 16,046 | 1041 (6.5) | 5214 | 1581 (30.3) |
| Four or more | 17,434 | 1109 (6.4) | 13,740 | 463 (3.4) | 3226 | 633 (19.6) |
| Baby gender | | | | | | |
| Male     | 62,128 | 12,046 (19.4) | 43,185 | 4894 (11.3) | 17,462 | 6925 (39.7) |
| Female   | 74,857 | 14,400 (19.2) | 51,178 | 5587 (10.9) | 21,802 | 8531 (39.1) |
| Religion | | | | | | |
| Hindu    | 106,420 | 20,236 (19.0) | 73,799 | 7745 (10.5) | 30,110 | 12,125 (40.3) |
| Muslim   | 15,586 | 3292 (20.8) | 9940 | 1318 (13.3) | 5441 | 1878 (34.5) |
| Christian| 8727 | 1531 (17.5) | 6619 | 794 (12.0) | 1845 | 697 (37.8) |
| Other    | 5982 | 1387 (23.2) | 4005 | 624 (15.6) | 1868 | 756 (40.5) |
| Socioeconomic factors | | | | | | |
| Maternal education | | | | | | |
| No education | 31,117 | 2766 (8.9) | 24,896 | 1246 (5.0) | 5146 | 1418 (27.6) |
| Primary graduate or less | 17,679 | 2291 (13.0) | 13,744 | 1119 (8.1) | 3375 | 1108 (32.8) |
| Secondary graduate or less | 70,228 | 14,953 (21.3) | 48,273 | 6546 (13.6) | 20,444 | 8100 (39.6) |
| College or above | 17,961 | 6436 (35.8) | 7450 | 1570 (21.1) | 10,299 | 4830 (46.9) |
| Type of residence | | | | | | |
| Urban    | 38,872 | 11,052 (28.4) | 21,518 | 3798 (17.7) | 16,611 | 7102 (42.8) |
| Rural    | 98,113 | 15,394 (15.7) | 72,845 | 6683 (9.2) | 22,653 | 8354 (46.9) |
| Caste    | | | | | | |
| Scheduled caste | 26,844 | 4531 (16.9) | 20,555 | 2244 (10.9) | 5523 | 2170 (39.3) |
| Scheduled tribe | 23,565 | 2975 (11.2) | 19,489 | 1690 (8.7) | 3358 | 1187 (35.3) |
| Other backward class | 58,461 | 11,371 (19.5) | 38,075 | 3946 (10.4) | 19,007 | 7237 (38.1) |
| Others   | 28,115 | 7569 (26.9) | 16,244 | 2601 (16.0) | 11,376 | 4862 (42.7) |
| Wealth level | | | | | | |
| 1st quintile (poorest) | 25,922 | 1815 (7.0) | 22,203 | 923 (4.2) | 2906 | 812 (27.9) |
| 2nd quintile | 29,082 | 3389 (11.7) | 23,521 | 1825 (7.8) | 4671 | 1463 (31.3) |
| 3rd quintile | 29,232 | 5576 (19.1) | 21,322 | 2731 (12.8) | 7131 | 2708 (38.0) |
| 4th quintile | 27,460 | 7165 (26.1) | 16,718 | 2833 (16.9) | 10,177 | 4201 (41.3) |
| 5th quintile (richest) | 25,289 | 8501 (33.6) | 10,599 | 2169 (20.5) | 14,379 | 6272 (43.6) |
| Paternal education | | | | | | |
| No education | 3006 | 298 (9.9) | 2415 | 133 (5.5) | 466 | 151 (32.4) |
### TABLE 1 (Continued)

| Variable                        | Overall  |                                  | Public  |                                  | Private |                                  |
|---------------------------------|----------|----------------------------------|---------|----------------------------------|---------|----------------------------------|
|                                 | Total births | Caesarean delivery N (%) | Total births | Caesarean delivery N (%) | Total births | Caesarean delivery N (%) |
| Primary graduate or less        | 2991     | 397 (13.3)                      | 2341     | 196 (8.4)                       | 545     | 192 (35.2)                      |
| Secondary graduate or less      | 13,947   | 2946 (21.1)                     | 9630     | 1330 (13.8)                     | 4002    | 1551 (38.8)                     |
| College or above                | 4032     | 1279 (31.7)                     | 1834     | 301 (16.4)                      | 2149    | 963 (44.8)                      |
| No paternal survey              | 113,009  | 21,526 (19.0)                   | 81,245   | 8885 (11.0)                     | 33,544  | 12,744 (38)                     |
| **Low birthweight (<2500 grams)** |          |                                  |          |                                  |          |                                  |
| Yes                             | 20,636   | 4257 (20.0)                     | 14,169   | 1726 (12.2)                     | 6085    | 2580 (42.4)                     |
| No                              | 106,245  | 21,247 (20.0)                   | 73,412   | 8379 (11.4)                     | 30,566  | 12,415 (40.6)                   |
| Not weighed at birth/don’t know | 10,104   | 942 (9.3)                       | 6782     | 376 (5.5)                       | 2613    | 461 (17.6)                      |
| **Baby size**                   |          |                                  |          |                                  |          |                                  |
| Very large                      | 7700     | 1903 (24.7)                     | 5027     | 750 (14.9)                      | 2454    | 1113 (45.4)                     |
| Larger than average             | 17,981   | 4065 (22.6)                     | 12,014   | 1618 (13.5)                     | 5413    | 2353 (43.5)                     |
| Average                         | 95,810   | 17,613 (18.4)                   | 66,701   | 6964 (10.4)                     | 26,896  | 10,267 (38.2)                   |
| Smaller than average            | 11,900   | 2188 (18.4)                     | 8299     | 909 (11.0)                      | 3368    | 1282 (38.1)                     |
| Very small                      | 3594     | 677 (18.8)                      | 2322     | 240 (10.3)                      | 1133    | 441 (38.9)                      |
| **Mother’s height (cm)**        |          |                                  |          |                                  |          |                                  |
| <145                            | 14,338   | 2911 (20.3)                     | 10,475   | 1271 (12.1)                     | 3371    | 1556 (46.2)                     |
| 145−149                         | 35,195   | 6547 (18.6)                     | 25,382   | 2723 (10.7)                     | 8865    | 3662 (41.3)                     |
| 150−154                         | 47,099   | 8766 (18.6)                     | 32,507   | 3410 (10.5)                     | 13,449  | 5191 (38.6)                     |
| 155−159                         | 28,882   | 5759 (20.0)                     | 19,010   | 2178 (11.5)                     | 9344    | 3506 (37.5)                     |
| ≥160                            | 11,471   | 2463 (21.4)                     | 6989     | 899 (12.9)                      | 4235    | 1541 (36.4)                     |
| **BMI (kg/m²)**                 |          |                                  |          |                                  |          |                                  |
| <16.0                           | 4252     | 513 (12.1)                      | 2050     | 671 (32.7)                      | 2479    | 1429 (57.6)                     |
| 16.0−18.4                       | 25,880   | 3049 (11.8)                     | 9851     | 2154 (21.9)                     | 7705    | 3792 (49.2)                     |
| 18.5−24.9                       | 84,195   | 14,700 (17.5)                   | 59,348   | 6100 (10.3)                     | 22,725  | 8298 (36.5)                     |
| 25.0−29.9                       | 17,913   | 6027 (33.6)                     | 19,898   | 1330 (6.7)                      | 5419    | 1664 (30.7)                     |
| ≥30.0                           | 4745     | 2175 (45.5)                     | 3216     | 226 (7.0)                       | 936     | 273 (29.2)                      |
| **Smoking**                     |          |                                  |          |                                  |          |                                  |
| Yes                             | 1318     | 177 (13.4)                      | 9314     | 876 (9.4)                       | 1861    | 642 (34.5)                      |
| No                              | 135,667  | 26,269 (19.4)                   | 85,049   | 9605 (11.3)                     | 37,403  | 14,814 (39.6)                   |
| **Chewing tobacco**             |          |                                  |          |                                  |          |                                  |
| Yes                             | 8915     | 1306 (14.6)                     | 7045     | 735 (10.4)                      | 1574    | 538 (34.2)                      |
| No                              | 128,070  | 25,140 (19.6)                   | 87,318   | 9746 (11.2)                     | 37,690  | 14,918 (39.6)                   |
| **Drinking alcohol**            |          |                                  |          |                                  |          |                                  |
| Yes                             | 2187     | 336 (15.4)                      | 1768     | 168 (9.5)                       | 340     | 154 (45.3)                      |
| No                              | 134,798  | 25,615 (19.4)                   | 92,595   | 10,313 (11.1)                   | 38,924  | 15,302 (39.3)                   |
| **Miscarriage, abortion or stillbirth** |      |                                  |          |                                  |          |                                  |
| No                              | 14,891   | 3510 (23.6)                     | 9337     | 1258 (13.5)                     | 5166    | 2182 (42.2)                     |
| Yes                             | 122,094  | 22,936 (18.8)                   | 85,026   | 9223 (10.8)                     | 34,098  | 13,274 (38.9)                   |
| **Institutional factors**       |          |                                  |          |                                  |          |                                  |
| Insurance                       |          |                                  |          |                                  |          |                                  |
| Covered                         | 20,958   | 4690 (22.4)                     | 14,877   | 1930 (13.0)                     | 5579    | 2670 (47.9)                     |
| Not covered                     | 116,027  | 21,756 (18.8)                   | 79,486   | 8551 (10.8)                     | 33,685  | 12,786 (38.0)                   |

(Continues)
change in variance (PCV), was calculated at each level, which is our study aim 3. Technical details for VPC and PCV are included in the Supplementary Material.

We additionally performed stratified analyses by the type of delivery facility for all these models to examine the difference in VPCs and PCVs between public and private facilities, which is our study aim 4. Lastly, maps were produced to visualize the geographic distribution of caesarean delivery. First, we mapped mean caesarean delivery across 640 districts to visualize unadjusted variation in caesarean use at the district level. Second, we visualized the extent of within-district variation in caesarean delivery by mapping the standard deviations of village-specific residuals within each district. These were estimated by extracting 27,218 village-specific residuals ($u_{ijkl}$) from the fully adjusted model and calculating the standard deviation for each of their corresponding 640 districts. Maps were produced for the entire sample and by type of delivery facility. All models were estimated using MLwiN 3.0 software program. Maps were produced in ArcGIS Pro (version 2.0), and figures, calculations of variance summary metrics, and residuals analyses were performed using the R programming language (version 4).

### 2.6 Missing data

Of 146,713 observations of women who had an institutional delivery for their most recent single-child birth during the 5 years preceding the survey, 4.8% in caste, 1.3% in BMI and 1.3% in maternal height were missing. The main results were based on complete case analyses of 136,985 observations. Since a total 6.6% of the sample were missing, we conducted a sensitivity analysis replicating the methods detailed above utilising multiple imputation. The multiple imputation analysis was based on $m = 20$ imputations and an imputation model that included all dependent and independent variables in the fully adjusted (m1) model.

### 2.7 Ethics approval

Ethics approval from our respective institutions was not required because our study was limited to the publicly available NFHS-4 data set that contained no personally identifiable information.

### 3 RESULTS

#### 3.1 Sample characteristics and prevalence of caesarean delivery

The final analytic sample was composed of 136,985 births nested hierarchically within 27,218 communities, 640 districts and 36 states (Table S1). Of these, 19.3% ($n = 26,446$) were born via caesarean delivery. Most births took place in public facilities ($n = 97,465; 71.2$%) rather than private facilities ($n = 39,520; 28.8$%). However, caesarean deliveries occurred more frequently in private ($n = 15,601; 39.5$%) vs. public facilities ($n = 10,845; 11.1$%) ($p < .001$) (Table 1).

### 3.2 Geographic variation in caesarean delivery prevalence

The lowest prevalence of caesarean delivery was found in Bihar (10.7%) (Table 2). However, the gap between public and private facilities was large (2.8% in public vs. 33.3% in private). On the other hand, Telangana was the highest in caesarean delivery rate (62.1%) and also with a large difference between public (39.7%) and private facilities (74.8%). District-level rate of caesarean delivery also varied considerably from a minimum of 0% to a maximum of 93.3% (Figure 1).

### 3.3 Variance decomposition

Variance estimates from unadjusted and adjusted random intercept models are presented in Table 3. Total variance in caesarean delivery estimated from the unadjusted model (M0) was 4.21 (0.41 at state level, 0.21 at district level, 0.30 at community level and $\pi^2/3 = 3.29$ at individual level). Removing the constant ($\pi^2/3$) yields a total geographic variance of 0.92, which takes into account 22% of the total variance (0.92/4.21). Of the total geographic variance, 44% was attributable to states, 24% to districts and 32% to communities (Figure 2). Results from stratified analyses by the type of delivery facilities showed a greater total geographic variance in caesarean delivery among public facilities than among private facilities (Table 3). For example, a total

### Table 1 (Continued)

| Variable | Overall | Public | Private |
|----------|---------|--------|---------|
|          | Total births | Caesarean delivery N (%) | Total births | Caesarean delivery N (%) | Total births | Caesarean delivery N (%) |
| Antenatal care more than 4 times | 73,403 | 18,546 (25.3) | 47,092 | 7323 (15.6) | 25,611 | 11,144 (43.5) |
| No | 63,582 | 7900 (12.4) | 47,271 | 3158 (6.7) | 13,653 | 4312 (31.6) |

*aMother’s perception of baby size at birth.*
geographic variance was 1.11 and 0.67 before and after adjustment, respectively, for the public facility, while it was 0.64 and 0.50, respectively, for the private facility. Of the total geographic variance in caesarean delivery in public facilities, 52%, 23% and 25% were attributable to states, districts and communities, respectively. Similarly, of the total geographic variance in private facilities, 50%, 25% and 25% were attributable to states, districts and communities, respectively (Figure 2).
Proportion in variation attributable to clustering of individual-level risk factors

Of the total geographic variance in caesarean delivery, 44% of the between-state variance, 52% of the between-district variance and 46% of the between-community variance were explained away by the addition of 20 individual-level covariates (Table 3). Of the between-state variance in caesarean delivery in public facilities, 44% was explained by the 19 individual-level factors (excluding the type of facility from 20 covariates), whereas only 20% of the between-state variance was explained by the same set of individual-level factors in private facilities.
variance was accounted for in private facilities. Similarly, adjusting for the 19 individual characteristics explained 38% of the between-district variance and 30% of the between-community variance in public facilities, but only 19% and 24%, respectively, in private facilities. Even though the proportion of variance explained by a set of individual-level risk factors was larger in public facilities, the remaining variation after adjustment was still larger for the public than for the private facilities (Table 3). After adjusting for all the individual-level risk factors, substantial variation remained between-clusters within-district. In maps visualising the post-adjustment standard deviation of cluster-specific residuals in caesarean delivery by districts (Figure 3A-C), larger variation was observed within districts in Southern India. The range of standard deviation of cluster-specific residuals was greater for public facilities compared to private facilities, indicating that the remaining unexplained variation in caesarean delivery at the community level was larger in the public facility.

3.5 | Sensitivity analyses

Results from multiple imputation analyses are provided in Tables S3 and S4 and Figure S1. Both fixed-effects and random-effects estimates were nearly identical for M0 and M1 in imputed and original results.

4 | COMMENT

4.1 | Principal findings

The average rate of caesarean delivery in India (19.3%) obscures considerable within-country variation in caesarean delivery. State-specific prevalence varied from a low of 10.7% in Bihar to a high of 62.1% in Telangana. From the multilevel analysis, more than 20% of the total variation in caesarean delivery was estimated as between-population geographic variability. Of the total geographic variation in caesarean delivery, 44% was attributable to states, followed by communities (32%), and lastly districts (24%). Public facilities showed greater geographic variation in caesarean delivery than private facilities, with total geographic variance estimates of 1.11 and 0.64, respectively. Upon fully accounting for the complete set of 19 individual risk factors, reductions in variance terms were larger for public facilities at all three geographic levels than for private facilities. However, the remaining variation was still greater among public vs. private facilities at all three levels.

4.2 | Strengths of the study

Our study is the first to demonstrate that each geographic level substantially contributes to the shaping of caesarean delivery distribution in India and therefore indicating that single-level studies may provide an incomplete and sometimes misleading understanding of the distribution of caesarean delivery. We also demonstrated that a substantial proportion of between-population variation still existed even after clustering of individual risk factors was comprehensively adjusted for, indicating that contextual factors may contribute to generating between-population variation at the macro- and micro-geographic unit.

4.3 | Limitations of the data

Although our study has many conceptual and methodological strengths, it also includes a few limitations. First, our study variables including caesarean delivery are based on self-report. Although experiencing a surgical procedure is unlikely to be something that someone would forget or incorrectly recount, there are chances of recall bias for other self-report variables (e.g., baby size at birth). However, measurement error associated with these independent variables is likely to be random, such that adjusted models yield conservative estimates of percent explained—which is of greater conceptual importance to the objective of this study—compared with precise fixed-effects estimates. Second, although the multilevel data structure of the present study reflects sampling design of the NFHS-4 data and the contextual reality of multiple units of administrative, geographic and political significance in India, even our four-level model may be at risk of the missing unit problem. For example, subnational administrative units such as division (higher than the district and lower than state), subdistrict (lower than district but higher than community) or geographic units such as zone or region may also have factors shaping the between-population variation in caesarean delivery. Finally, although we tried to control for individual risk factors for caesarean delivery as comprehensively as the NFHS data allowed, it is likely that there are still other important factors missing in NFHS data such as medical factors indicating emergency situation for caesarean surgery.

4.4 | Interpretation

The findings presented herein are highly relevant to the current policy discussions regarding caesarean delivery in India and globally. Prevalence of caesarean delivery at the district and state level was
considerably heterogeneous, indicating that the overall rate masks the variation across multiple geographic levels within India.

Results from unadjusted and adjusted multilevel models demonstrate that differing contexts respond differently to individual determinants of caesarean delivery. For example, despite between-state differences accounting for the greatest proportion of overall variation in caesarean delivery, they were the least amenable to explanation via individual characteristics, while districts accounted for the least amount of total variation but were most explainable by the aforementioned risk factors. A substantial

FIGURE 3  Distribution of standard deviation of cluster-specific residuals by 640 districts: overall (A), public (B) and private (C)
level of variation in caesarean delivery still remained unexplained even after full adjustment of all individual risks in all levels, indicating that structural attributes missing in our model would likely shape between-population variation in caesarean delivery. For example, at the community level, different social norms and cultures formulated within a community, different forms and quality of community health workers’ activities, or geographic accessibility to the facilities having surgical capacity would affect the caesarean delivery rate within a community. At the district or state level, health policies such as payment to providers or service delivery mechanisms could affect the caesarean delivery.

The proportion of the variation in caesarean delivery explained by the individual characteristics was smaller in the private facility, indicating that structural factors drive geographic variation in caesarean delivery more strongly among the private facility than among the public facility. The public-private partnership (PPP) programmes performed as a state initiative, for example the Chiranjeevi Yojana in Gujarat or Ayushmati Scheme in West Bengal, can be one example of those structural factors.26–28 As mentioned previously, the state only funds services provided by public providers in India. However, through the PPP, the state pays private obstetricians to tackle the problem of the lack of obstetricians in public facilities so that pregnant mothers can give birth at private facilities without concerns about the cost. However, due to higher reimbursement to providers for caesarean delivery than vaginal delivery, caesarean delivery disproportionally increased among private facilities during the programme, which led some states to modify the programme to pay a fixed sum for a specific unit of deliveries regardless of the type of the deliveries, acting as an embedded disincentive for unnecessary caesarean delivery.26–28 This led to a decrease again in caesarean delivery. These state-level policies may shape the between-state variation in caesarean delivery.

The high degree of variation in caesarean delivery presented in this study suggests that rates in some locales may be too high and too low in others. That is, high caesarean prevalence observed in some states may be to some degree composed of medically unnecessary caesarean deliveries, which may not only adversely affect health outcomes for individual mothers and babies, but also occupy resources that could have been utilised elsewhere with possibly greater medical need. On the other hand, low caesarean prevalence observed in other states may indicate unmet need for medically necessary caesarean deliveries, thus contributing to avoidable morbidity and mortality. Therefore, it may be useful to identify optimal caesarean delivery rates appropriate for the context of multiple geographic levels, and monitor them appropriately.

5 | CONCLUSIONS

Our study results highlight the importance of understanding geographic variation at multiple levels as illustrated through a comprehensive accounting of the variations in caesarean delivery in India. Tailored contextual interventions may reduce between-population variations in caesarean access and utilisation, beyond those targeting individual characteristics alone. Specific policy recommendations are beyond the scope of this paper. Future studies should investigate the potential of specific interventions by identifying more diverse contextual factors driving between-population variations. Such studies will require more extensive data including detailed clinical, administrative and sociocultural information.

CONFLICT OF INTEREST

All authors declare no conflict of interest.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the Demographic and Health Survey program at https://dhsprogram.com/data/dataset/India_Standard-DHS_2015.cfm?flag=0

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SUPPORTING INFORMATION
Additional supporting information may be found online in the Supporting Information section.