## 1. Introduction

Civil registration and vital statistics (CRVS) systems benefit individuals through establishing legal rights, helping national population service planning and assisting the international community to meet global commitments (1). Effective CRVS is therefore crucial for the promotion of human rights, good governance and development (2). Globally, improved health outcomes are linked to enhanced CRVS performance, and this highlights the urgency of strengthening these systems (3). However, many low- and middle-income countries fail to register vital events with a CRVS system that is supposed to serve their entire population, owing to what has been termed the "scandal of invisibility" (1,2,4).

Gender disparities, particularly among disadvantaged women and children, are evident in the registration of vital events, exacerbating existing inequalities (5). These disparities become especially apparent in death registration, where social and cultural norms, combined with the design of national legal and registration systems, create obstacles that disproportionately affect the registration of female deaths (6). For example, legal systems often require a death certificate for the transfer of property and assets, which are predominantly owned by men. Consequently, female deaths are frequently overlooked in many countries (6).

In India, the Civil Registration System (CRS), managed by the Office of the Registrar General of India (ORGI) under the Ministry of Home Affairs, was established by the Registration of Births and Deaths Act of 1969 (7). To address the long development period required for CRS to become a reliable source of vital statistics, the Indian government introduced the Sample Registration System (SRS) in 1970 as a temporary, population-based data source (8). This initiative was a significant step toward improving the quality and coverage of vital event data.

The growing momentum for a sustainable source of quality information on the occurrence and characteristics of vital events in the first decade of the 21st century (1,9–11) also resonated in India, leading to administrative reforms aimed at improving CRVS systems (12). As a result, birth registration coverage increased from less than 60% in 2001 to over 80% in 2010. Similarly, death registration coverage improved, reaching 69.3% by 2007. However, progress in death registration slowed between 2007 and 2013 (12,13), with coverage only marginally increasing to 70.9% (13). Despite this slowdown, the years 2014 and 2015 marked a revival in death registration efforts in India (13). Nevertheless, significant gender differences persist in death registration, with a 12.9% gap in 2018, where men were more likely to be registered than women (14).

Taking these factors into account, our objectives were centred around three key aspects. First, we aimed to estimate the completeness of death registration for both sexes and the total population in the bigger states of India from 2014 to 2021. Secondly, to estimate the district-level death registration and the gender gap at the district level in India in 2021. Finally, we aimed to compare the total and direct effects of gender on death registration in the years 2015 and 2020, incorporating asset ownership as a mediating factor. Through this approach, we aimed to understand how gender disparities affect death registration and to explore the role of asset ownership in contributing to these differences.

## 2. Materials and Methods

### 2.1 Data

In India, data on registered deaths for both males and females, aggregated at the state level, have been available through the Civil Registration System (CRS) since 2009. The Sample Registration System (SRS) provides age- and sex-specific mortality data for major states. We focus on data from 2014 to 2021, as a new SRS panel based on the 2011 population census was established in 2014. Projected population figures for each five-year age group in India and its major states can be found in reports published by the National Commission on Population (15). To estimate district-level death registration, we utilise data from the National Family Health Survey (NFHS 5). Furthermore, information on asset ownership for larger states is available in the NFHS-4 and NFHS-5 reports, which aids in understanding how gender influences ownership in relation to death registration.

### 2.2 Estimating the Completeness of Death Registration in Major Indian States (2014–2021)

The completeness of death registration in the Civil Registration System (CRS) is defined as the percentage of registered deaths reported by CRS compared to the deaths estimated through the Sample Registration System (SRS) for a given year (13). To estimate the expected deaths from SRS for the years 2014 to 2020, we first interpolated the available projected population percentages for each age group and sex from 2011, 2016, and 2021 for all larger states. Additionally, the age-specific death rates (ASDR) for the age groups 80-84 and 85+ were combined into the 80+ age group to ensure consistency between the projected population age groups and the SRS age groups for each year. We then calculated the total number of expected deaths by summing the products of the SRS ASDR and the population in each age group for both sexes across the states.

For the years 2015 and 2016, the number of male and female deaths for Gujarat in CRS was not available. We used the proportions of male and female deaths from 2014 and 2017, interpolated the proportions for 2015 and 2016, and distributed the total deaths reported in Gujarat according to these interpolated proportions. Finally, the percentage of completeness of death registration was estimated for the period from 2014 to 2020 for all larger states in India. For states and subcategories where the reported death registration rate exceeded 100 per cent, we capped the registration rate at 100 per cent, assuming that death registration was fully complete in those areas.

### 2.3 Estimating the Completeness of Death Registration at the District Level in India (2021)

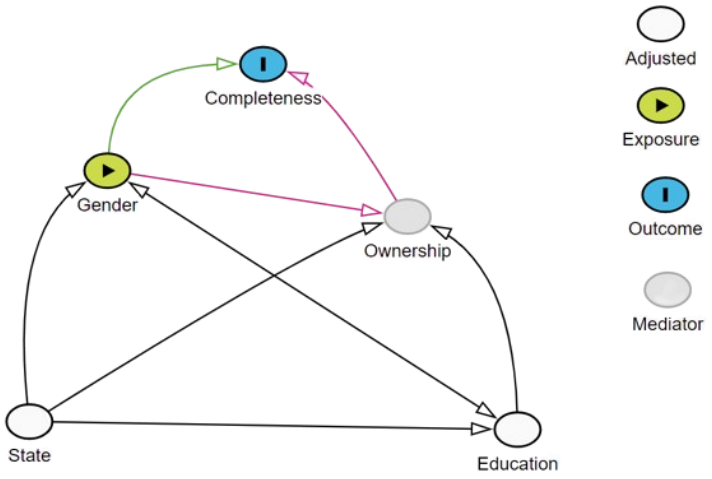
To estimate the completeness of death registration, a Bayesian hierarchical logistic regression model was used, implemented through the *rethinking* package in R. The number of registered deaths was modelled as a binomial outcome with the total number of deaths as the denominator. The log-odds of registration were modelled as a function of gender-specific intercepts, along with district- and state-level random effects of accounting for geographic variation. The model also included fixed effects for household ownership of assets, religious affiliation, economic status, social group, and educational attainment. All parameters were assigned weakly informative normal priors. The model was estimated using four Markov Chain Monte Carlo chains with parallel processing across four cores, and the log-likelihood was retained for model evaluation. Posterior predictive checks were conducted to assess the model's fit by comparing simulated outcomes from the posterior distribution with the observed data.

### 2.4 Exploring Mediators of Gender Disparity in Death Registration in India

#### 2.4.1 Directed Acyclic Graph (DAG)

To examine the causal relationship between gender and the completion of death registration, we utilised a Directed Acyclic Graph (DAG) to visually and analytically represent the potential pathways and confounders in our study (Figure 1). Our primary exposure variable is gender, and the outcome variable is the completion of death registration. In our DAG, ownership of assets by women is considered a mediator, functioning as a “pipe,” one among four elemental confounders (16). Additionally, state and education also act as confounders in this model.

*Figure 1. Directed Acyclic Graph Describing the Gender Effect on Completeness of Death Registration.*




The total effect of gender on the completion of death registration operates through two paths: a direct path from gender to completion and an indirect path mediated by ownership of assets by women. We adjusted for state and education to measure the total effect of gender on the completeness of death registration. To measure the direct effect of gender, we also adjusted for ownership, alongside the other confounders. Both total and direct effects were measured for the years 2015 and 2020.

### 2.4.2 Definition of Variables

The completeness of death registration for both sexes was measured for the bigger states, forming the variable "completeness" in the model. The variable ‘ownership’ is defined as the average of two indicators: the percentage of women who own land (alone or jointly) and the percentage who own a house (alone or jointly), based on data from NFHS-4 (2015–16) and NFHS-5 (2019–21). The variable "education" is measured as the median number of years women attended educational institutions, reported for each state in the NFHS for the respective years.

### 2.4.3 Statistical Analysis

We used a Bayesian hierarchical model for the years 2015 and 2020 separately to evaluate the total effect of gender on the completeness of death registration. The model is defined as follows:

$$O_{i,g} \sim Binomial\left(E_{i,g}, p_{i,g}\right), \qquad i = 1, 2, 3, \ldots \;\; g = 1, 2$$

$$logit(p_{i,g}) = a[g] + b[state] + c * education_{i,g},$$

$$a[g] \sim Normal(abar, sigma),$$

$$abar \sim Normal(0, 1.5),$$

$$sigma \sim Exponential(3),$$

$$b[state] \sim Normal(0, 0.1),$$

$$c \sim Normal(0,0.1)$$

here, the observed number of deaths $O_{i,g}$ for population $i$ and gender $g$ follows a Binomial distribution with parameter $E_{i,g}$ (expected deaths) and $p_{i,g}$ (probability of death registration completeness). The probability $p_{i,g}$ is modelled using the logit function. The parameter $a[g]$ captures the total effect of gender, adjusting for state ($b[state]$) and education ($c$). This hierarchical model allows us to isolate the total effect of gender on death registration completeness while accounting for potential confounding effects from state and education.

To further evaluate the direct effect of gender, we extended the model to include an additional adjustment for ownership. The updated model is defined as:

$$logit(p_{i,g}) = a[g] + b[state] + c * education_{i,g} + d * ownership_{i,g},$$

where $d$ follows a normal distribution with mean 0 and standard deviation 0.05. This adjustment for ownership allows us to estimate the direct effect of gender on the completeness of death registration.

For all models, the contrast, the difference in posterior probability of death registration between males and females, was estimated to understand gender inequities in the completeness of death registration in India for the years 2015 and 2020.

## 3. Results

### 3.1 Trends in the Completeness of Death Registration Across Bigger States (2014–2021)

The overall completion rate of death registration in India increased from 70 percent in 2014 to 89.3 percent in 2021 (Figure 2). Even though the percentage of deaths registered by both men (73.4% to 96%) and women (63.3% to 82.5%) increased throughout this period, the gender disparity extended from 10.1% to 13.5%.

Between 2014 and 2021, among bigger states, Bihar recorded the largest improvement in death registration, with the rate increasing by 2.4 times to reach 57.5%. Despite this progress, the overall level of registration remains relatively low. Uttar Pradesh also showed a substantial increase, with the registration rate rising 1.8 times to 76% in 2021. Madhya Pradesh achieved a registration rate of 94.8%, reflecting a 1.7-fold increase over the period. In 2014, only 4 out of the 21 larger states had a death registration completeness above 90%; by 2020, this number had increased to 11. However, some states reported a decline in registration completeness over time. For example, Jharkhand's rate fell from 64.8% to 52.3%, Himachal Pradesh from 85.5% to 80.2%, Kerala from full coverage to 95%, and Punjab from 100% to 88.1%.

*Figure 2. Completeness of Death Registration in India by Sex from 2014 to 2021*

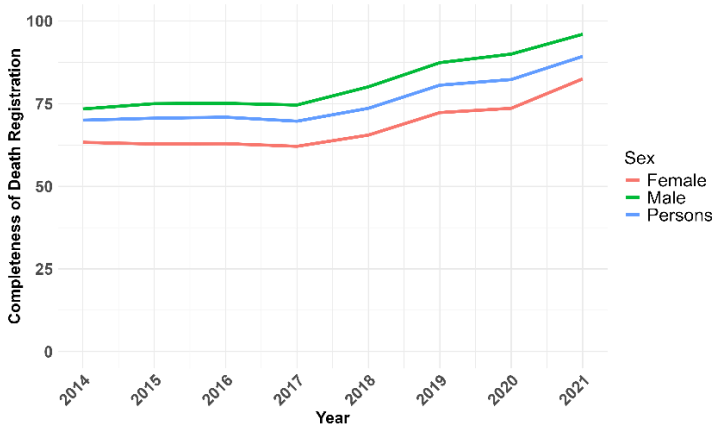
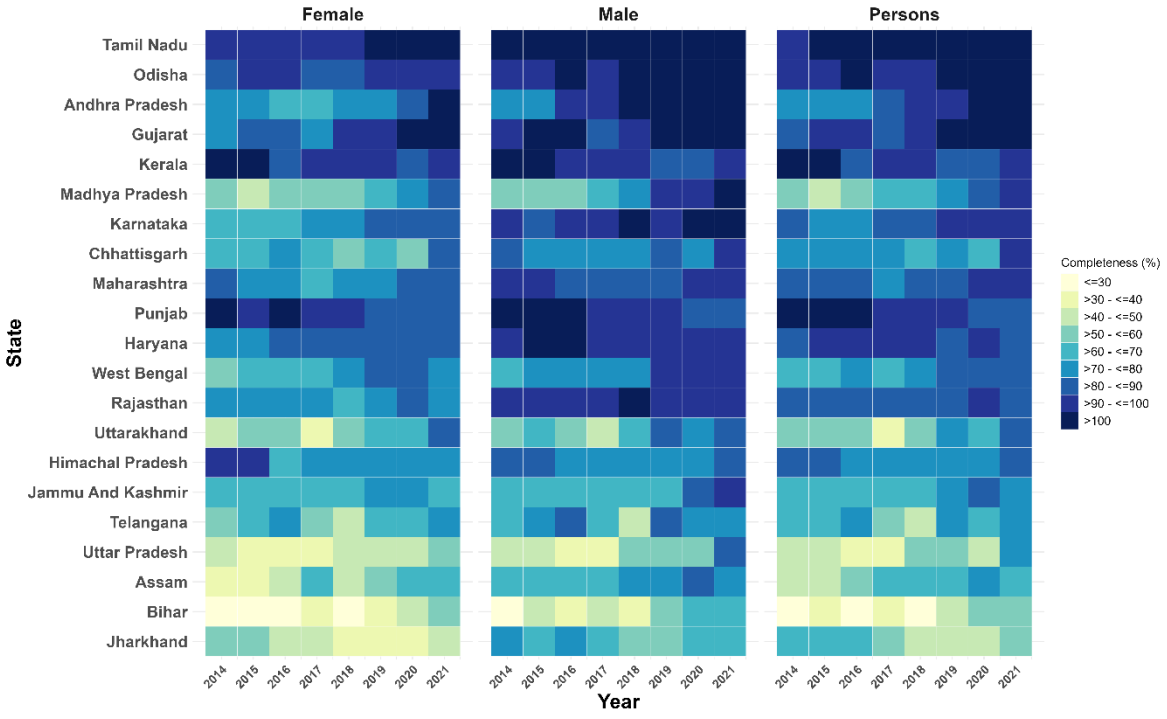



*Figure 3. Completeness of Death Registration by Sex Across Bigger States (2014-2020) in India*



### 3.2 District-Level Gender Gaps in Death Registration Completeness, India (2021)

Based on district-level data from NFHS-5, and after adjusting for education, religion, wealth, caste, and household ownership, India recorded a national gender gap of 7.9 percentage points (95% CI: 7.4–8.3) in death registration completeness in 2021, reflecting a consistent disadvantage in the registration of female deaths. At the state level, several large states reported gaps exceeding 10 percentage points, including Uttar Pradesh (11.6; 95% CI: 10.9 - 12.2), Bihar (11.1; 95% CI: 10.4- 11.8), Jharkhand (11.3; 95% CI: 10.6 - 12.0), and Telangana (10.5; 95% CI: 9.3 - 11.7). In contrast, Kerala (1.0; 95% CI: 0.7 - 1.4) and Goa (0.7; 95% CI: 0.2 - 1.5) showed near parity between male and female registration.

At the regional level, the completeness of death registration and gender disparities vary widely across Indian districts (Figures 4 and 5). Western India reports the strongest outcomes, with 96% of districts recording male completeness above 80% (78.4% above 90%) and 86.5% reaching the same level for females. Gender equality is also relatively high, with 71.6% of districts showing a gap of 5% or less. Southern India follows, with 78.1% of districts exceeding 80% completeness for males and 65.6% for females. While overall levels remain high, gender gaps are more pronounced than in the West, with 17.2% of districts showing a difference between 10 and 15 percentage points.

Northern India shows intermediate performance. Male registration is relatively strong, with 73.5% of districts above 80%, but only 49.3% reach this level for female deaths. In 22.8% of districts, the gender gap exceeds 10–15 percentage points. In contrast, the Northeast, Central, and Eastern regions report persistently low levels of completeness. In the Northeast, 17.3% of districts surpass 80% for male deaths and just 8.7% for females, though most districts show moderate gender gaps (70.2% fall within the 5–10% range). Central India performs similarly, with 23.6% of districts above 80% for males and only 6.8% for females, and 64.9% of districts reporting gaps between 10 and 15 percentage points. Eastern India mirrors this trend, with 21.7% of districts reaching 80% completeness for males and 9.5% for females, and 51.4% showing wide gender gaps in the same range.

At the district level, disparities are even more pronounced. A total of 241 districts recorded gender gaps between 10 and 15 percentage points, reflecting a widespread pattern of male-biased registration. Northern India accounts for a significant share of these districts. In Rajasthan alone, fourteen districts reported high disparities, including Alwar (14.1; 95% CI: 12.1 - 16.0), Dausa (13.8; 95% CI: 11.2 - 16.2), and Karauli (13.5; 95% CI: 11.4 - 15.3). Tehri

Garhwal in Uttarakhand (13.1; 95% CI: 11.0 - 14.9) and Mewat in Haryana (12.1; 95% CI: 10.1, 13.8) show similar gaps.

In Central India, Uttar Pradesh alone contributes sixty-nine districts with gaps above 10 per cent. Among them, Ballia (13.3; 95% CI: 12.2-14.4), Aligarh (13.2; 95% CI: 12.0-14.3), and Bareilly (13.1; 95% CI: 12.1-14.1) report the largest disparities. In Bihar, there were 31 high-gap districts, including Munger (13.0; 95% CI: 12.0, 13.9) and Bhojpur (12.8; 95% CI: 11.7, 13.8). Madhya Pradesh and Chhattisgarh also report several districts with wide gender gaps, such as Chhatarpur (12.7; 95% CI: 11.6-13.7) and Bilaspur (12.5; 95% CI: 10.9-14.0).

In the eastern states, Jharkhand comprises twenty-two districts with large gender gaps, including Purbi Singhbhum (12.9; 95% CI: 12.0-13.8) and Dhanbad (12.7; 95% CI: 11.6-13.7). Puruliya in West Bengal (12.9; 95% CI: 11.6, 14.1) and Mayurbhanj in Odisha (12.3; 95% CI: 11.0 - 13.5) also report high levels of disparity.

Most southern states reported lower levels of gender disparity, with the notable exception of Telangana. The state had nineteen districts with significant gaps, including Jayashankar Bhupalapally (13.6; 95% CI: 11.6-15.4), Karimnagar (12.7; 95% CI: 10.6-14.5), and Medak (12.6; 95% CI: 10.5-14.6). Isolated instances were also observed in Srikakulam and Visakhapatnam in Andhra Pradesh and Raichur in Karnataka.

These spatial patterns reflect persistent gender inequality in India’s death registration system, particularly across the northern, central, and eastern belts. Addressing these disparities will require not only national-level reforms but also district-specific interventions that take into account local administrative practices, infrastructure constraints, and prevailing gender norms.

*Figure 4. Completeness of Death Registration in India by Gender at District Level (2021)*

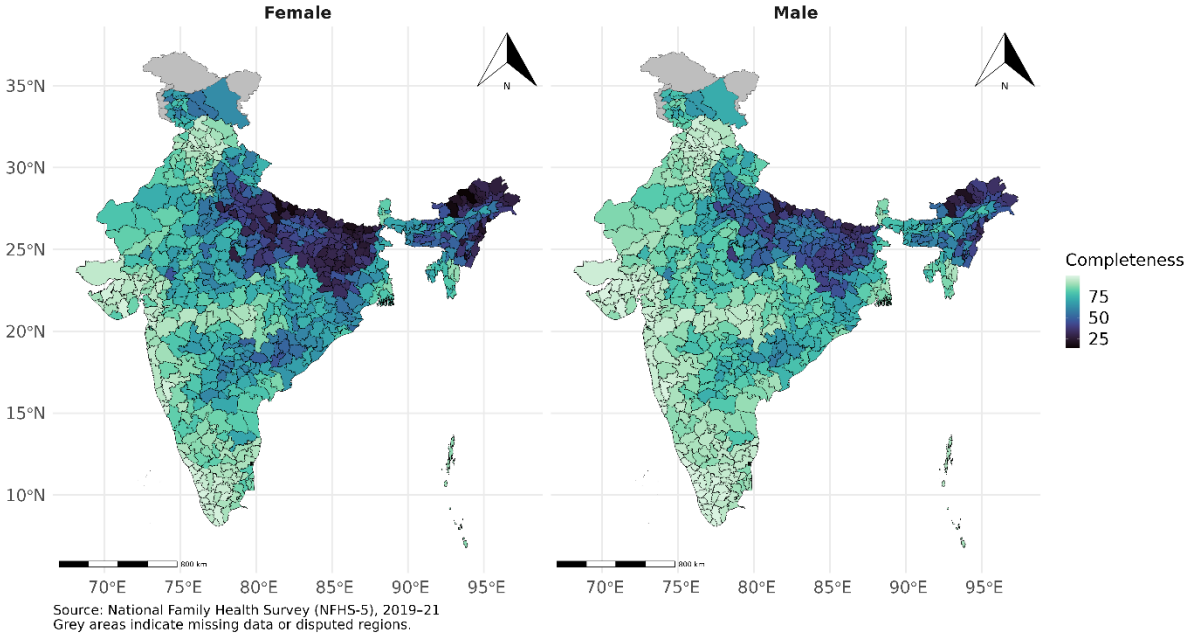
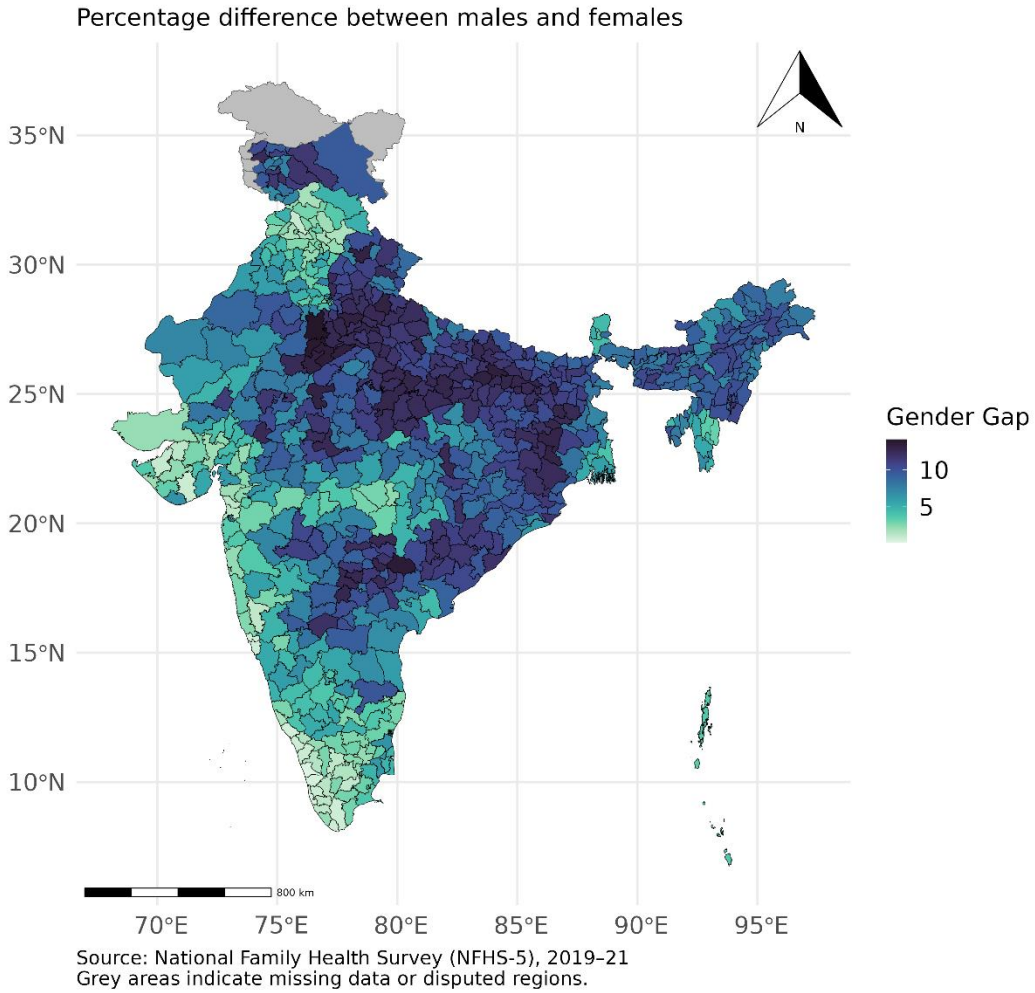


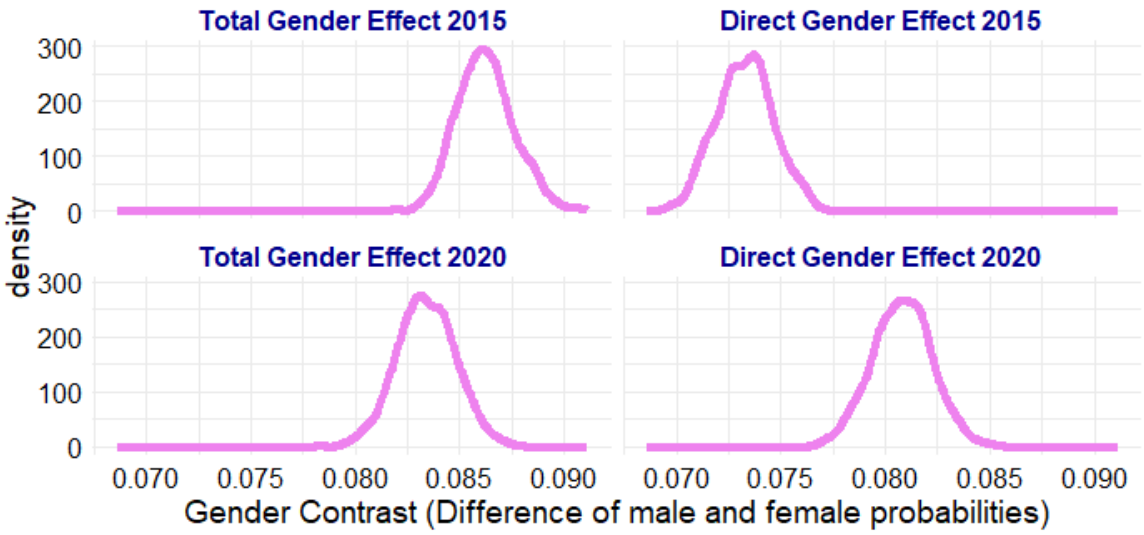

*Figure 5. District-Level Gender Gap in Death Registration Completeness in India (2021)*



### 3.3 Total and Direct Effects of Gender on Completeness of Death Registration in India

This analysis draws on data from major Indian states, as district-level comparisons were not possible, as the completeness of death registration was not captured in NFHS-4 at the district level. In 2015, across these states, men had an average 8.62 percentage point higher likelihood of having their deaths registered compared to women (Credible Interval: 8.37–8.91), indicating a substantial gender disparity (Figure 6). By 2020, this total effect declined slightly to 8.34 percentage points (CI: 8.05–8.61), suggesting limited progress toward gender equity in death registration practices. In 2015, 15.0% of the total effect was mediated through household ownership of assets, with the remaining 7.33 percentage points (CI: 7.07–7.60) representing the direct effect of gender. By 2020, the mediated share had decreased to just 3.12%, while the direct effect increased to 8.08 percentage points (CI: 7.79–8.36). This shift suggests that material factors such as asset ownership played a diminishing role in explaining the gender gap over time, with more of the disparity persisting independently of household wealth.

*Figure 6. Total and Direct Effects of Gender on Completeness of Death Registration in India*




### Discussion

The findings of this study highlight a significant improvement in the overall completeness of death registration in India from 2014 to 2021. However, they also expose a persistent and growing gender disparity. Despite increases in death registration rates for both men and women, the gap between them widened, with men consistently more likely to have their deaths registered than women. Although the total effect of gender on death registration decreased

slightly from 2015 to 2020, it remains almost constant, indicating that gender biases still affect the registration process. Interestingly, while asset ownership contributed to this disparity in 2015, its impact lessened by 2020, suggesting a shift in the factors driving gender differences in death registration.

While the overall completeness of death registration in India has improved, it remains below 90%, indicating that the CRS is not yet a fully reliable primary data source for mortality information in India. The reliance on temporary measures like surveys, such as the SRS, highlights the need for strengthening permanent mechanisms. In regions where death registration completeness exceeds 100%, the CRS appears to perform better than the SRS, suggesting that it could be a viable source of mortality data in those areas. Furthermore, evidence indicates that the CRS may be more reliable than the SRS for measuring adult mortality in several states in India (17). However, the quality of cause-of-death information from registered deaths still lags, pointing out the need for significant improvements in this area (14).

Additionally, the widening gender gap suggests that, despite overall improvements, systemic issues continue to disadvantage women in the death registration process. The reduction in the mediating effect of asset ownership on gender differences between 2015 and 2020, along with the nearly constant total gender effect on death registration, indicates the need to explore other factors exacerbating gender disparities in death registration. Furthermore, the revitalisation of the Pradhan Mantri Awas Yojana (Prime Minister's Housing Plan) in 2015, which mandates house ownership in the name of women or jointly in the name of women, may have contributed to increased asset ownership among women (18). This shift, as seen in the differences between NFHS-4 and NFHS-5 (19,20), could be one reason for the decline in the mediating effect of asset ownership on gender disparities in death registration. Also, the decline in the mediating effect of asset ownership suggests that policies targeting property rights may not be sufficient on their own to close the gender gap in death registration.

While previous research has highlighted significant spatial disparities in death registration across Indian districts—particularly in eastern and northeastern states—driven by factors such as poverty, rurality, and educational disadvantage (21), our findings suggest that gender disparities in death registration are an additional contributor to these spatial patterns. The geographic clustering of high gender gaps in Northern, Central, and Eastern India aligns with

many of the low-registration districts identified in earlier studies, indicating that gender inequality in death registration may partially explain the regional heterogeneity.

Overall, while the efforts to improve death registration in India have yielded positive results, particularly in increasing the completeness of registrations, the persistent and widening gender gap underscores the need for more targeted interventions. The diminishing role of asset ownership in mediating gender disparities suggests that addressing these inequalities will require a multifaceted approach that goes beyond property rights and includes broader systemic changes. Future research should focus on identifying and addressing other socio-cultural and economic factors that contribute to the gender gap in death registration, ensuring that all deaths are equally recognised and recorded. Strengthening the CRS system to address these disparities is essential for improving the accuracy and inclusiveness of vital statistics in India.

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