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# Spatial disparities in death registration across states and districts of India, 2019-21

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## Abstract

**Background** The persistent issue of incomplete death registration in India, with a significant number of deaths going unrecorded, underscores the critical need for a granular understanding of spatial variations. Given the nation's vast geographic and demographic diversity, this granular understanding, particularly at the district level, is crucial for effective interventions. This analysis, therefore, aims to examine spatial disparities in death registration at both the state and district levels across India.

**Data and methods** Using data from the fifth round of the National Family Health Survey (NFHS-5) conducted in 2019-21, this study analyzed information on 79,449 deaths occurring in the three years preceding the survey, across 707 districts in India. The study explored spatial patterns and identified clusters of death registration using Moran's I and univariate Local Indicators of Spatial Association (LISA) maps. Additionally, spatial regression models were employed to examine the factors influencing death registration at the district level.

**Results** In 2019-21, only 71% of deaths in India were registered, with significant variations across states and districts. The univariate Moran's I value of 0.69 ($p < 0.001$) indicated strong spatial clustering in death registration at the district level. Two notable 'cold spots'—districts with low death registration rates surrounded by other low-registration districts—were identified across 152 districts, primarily in the eastern states of Uttar Pradesh, Jharkhand, Bihar, and the northeastern regions of Arunachal Pradesh, Nagaland, and parts of Manipur. Results from regression models revealed that factors such as the proportion of poor households, rural households, Muslim and Scheduled Tribe (ST) households, and households with at least one uneducated member were negatively associated with death registration at the district level.

**Conclusions** The findings suggest the necessity for region-specific focused interventions to improve death registration in India, taking the social determinants of death registration into consideration and raising societal awareness about it.

**Keywords** Death registration, Spatial patterns, Hotspots, Moran's I, Spatial autocorrelation, NFHS-5

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## Background

The availability of precise and thorough mortality data is paramount for evidence-based public health decisions. Such data empowers governments, healthcare professionals, and policymakers to pinpoint high-risk groups, monitor health trends effectively, and assess the efficacy of health programs [1]. However, despite this critical importance, death registration remains incomplete on a global scale. The World Health Organization (WHO) estimates that two-fifths of deaths worldwide are still not reported [2], posing a substantial impediment to achieving Sustainable Development Goal (SDG) target 17.19.2, which aims for the registration of 80% of deaths and 100% of births by 2030 [3]. A recent WHO report further reveals a stark global disparity: less than 40% of countries– overwhelmingly high-income nations– possess near-complete (≥90%) death registration systems, while many low- and middle-income countries face a critical lack of data or report alarmingly low levels of death registration [4]. This situation underscores the urgent need to strengthen vital statistics systems in a significant portion of the world.

Within this landscape of global challenges in death registration, India, as the world's second most populous nation and responsible for an estimated 17% of global fatalities [5], presents a particularly significant case. The sheer scale of mortality in India underscores the critical importance of reliable and timely data for its central government and state/union territory administrations. Historically, India's civil registration system exhibited varied practices across its states/provinces until the enactment of the Registration of Births and Deaths Act in 1969, which mandated the nationwide registration of births, deaths, and stillbirths [6]. Recognizing the considerable time required for full implementation and system enhancement to produce dependable vital statistics, the Office of the Registrar General of India introduced the Sample Registration System (SRS) in the mid-1960s as a complementary measure [7]. While valuable, the SRS covers only a fraction of the population and does not permit the assessment of vital registration performance at finer administrative scales [8]. Although India's civil registration system has progressed over time, the registration of vital events is still far from universal, marked by substantial socioeconomic and geographic variations [9].

Given the challenges India faces in achieving universal death registration and the substantial variations observed within the country, as outlined above, studying geographic disparities in the coverage and accuracy of death registration at a granular level (district and sub-district) becomes crucial. National and provincial aggregates often mask significant local variations, and such subnational analyses can uncover striking differences in data quality and registration completeness that remain hidden in broader statistics. For example, research in Brazil [10, 11] has demonstrated that national averages in civil registration rates often conceal significant regional deficiencies, while fine-scale spatial examinations in Egypt [12] and Ecuador [13] have demonstrated that even when provincial coverage appears high, substantial gaps may exist at lower administrative levels. Similarly, research in China by [14] and investigations in Nepal [15, 16] emphasize marked provincial and county level variations in registration completeness.

While global research increasingly underscores the importance of granular subnational analysis in understanding death registration patterns, this approach has been notably underutilized in the Indian context, where studies have largely concentrated on state-level variations [8, 9, 17–20]. However, in a nation as immense and diverse as India, relying on national and provincial averages is insufficient, as these aggregates routinely mask critical local differences that are essential for effective intervention. Districts—being the primary units for planning and implementing public health interventions, with nearly 70% hosting populations over one million—could offer a more accurate picture of the challenges at hand [21]. Despite recent progress in death registration practices, India's performance on global vital statistics indices continues to lag [22], suggesting the persistence of deep-rooted systemic problems. Consequently, a detailed, district-level examination is not merely useful but essential to identify local obstacles and develop targeted strategies to enhance the completeness and accuracy of mortality data across the country.

Thus, to address this gap, the present study examines the spatial heterogeneity in death registration across India at both the state and district levels. By mapping the concentration of registered deaths and identifying hotspots, this research provides a detailed picture of local performance that is often concealed in aggregated data. Furthermore, spatial regression models are employed to pinpoint the factors affecting district-level death registration. It is hoped that the results of this investigation could be helpful in developing location-specific interventions and knowledge to enhance the coverage death registration.

## Data and methods

### Data source

This study leverages data from the fifth round of the National Family Health Survey (NFHS-5), conducted between 2019 and 2021, which included 101,839 men (aged 15–54) and 724,115 women (aged 15–49) from 636,699 households across 707 districts within 36 states and union territories (UT) in India [23]. The response rates for men and women responded at rates of 92% and 97%, respectively. For the purposes of this study, the sample was restricted to 79,449 individuals who had died within the three years preceding the survey [23]. More on the sampling and topic covered in NFHS-5 can be found in its national report freely available online at https://dhsprogram.com/pubs/pdf/FR375/FR375.pdf.

### Dependent variable

The key dependent variable was derived from a question posed to respondents who had experienced the loss of a household member, inquiring whether the death was reported to a civil authority. This information was then coded into a binary variable 'death registration', with '0' indicating that the death was not registered and '1' denoting that it was registered with a civil authority.

### Covariates

This study selected key independent variables with the potential to influence death registration. The selection was based on findings from prior research and data availability [19, 20]. These variables included the deceased person's sex and place of residence, the highest educational attainment within the household, household wealth quintile, social group, and the religion of the household head. Table 1 presents a detailed description of these covariates.

### Statistical analysis

To investigate the spatial patterns of death registration in India, our analysis proceeded in several stages. We first calculated the proportion of registered deaths, or the death registration rate, for each state/UT and district across the country. Subsequently, these rates were mapped to visually understand the spatial variation in death registration coverage at both the state/UT and district levels. To explore the relative concentration of death registration at the state level, we employed the Location Quotient (LQ) analysis, which compares the death registration rate in each state/UT to the national death registration rate [24].

Beyond these initial descriptive analyses, we considered the fundamental principle that geographic phenomena often exhibit spatial dependence, characterized by the tendency to cluster in specific locations rather than being randomly distributed. This property, known as spatial autocorrelation (SA), implies that values of a variable at nearby locations tend to be more similar than those at distant locations [25]. Given the spatially varying nature of death registration observed in our initial mapping, it becomes crucial to formally assess the presence and strength of this spatial autocorrelation across the study area. The existence of SA can significantly affect the assumptions and validity of classical statistical analyses that assume independence of observations [25]. Therefore, to assess the overall presence and statistical significance of this spatial clustering in death registration across the entire study region (at the district level), we utilized Moran's I, a widely used global measure of SA. Moran's I provides a single value that estimates the degree of spatial autocorrelation throughout the whole study region [25]. The formula used to calculate it is as follows:

Global Moran's

$$I = \frac{n}{\sum_i^n \sum_j^n w_{ij}} \frac{\sum_i^n \sum_j^n w_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_i^n \left(x_i - \bar{x}\right)^2}$$

Where, n is the number of the spatial features; $x_j$ is the attribute value of feature *j;* $x_i$ is the attribute value of feature *i*, (to be remembered that a variable is also called attribute in the spatial analysis context); $x_j$ denotes the attribute value of feature *j*; $\bar{x}$ is the mean of this attribute; $w_{ij}$ is the spatial weight between feature *i* and *j*; $\sum_i^n \sum_j^n w_{ij}$ is the aggregation of all spatial weights [25]. Moran's I values range from 1 (perfect clustering) to -1 (perfect dispersion). Positive values indicate positive spatial autocorrelation, meaning similar attribute values tend to cluster together on the map. Conversely, negative values suggest negative spatial autocorrelation, where dissimilar attribute values tend to be located near each other (indicating a pattern of high values being surrounded by low values, and vice versa). A Moran's I value close to zero suggests a random or uniform distribution of attribute values across the study area, implying no significant spatial autocorrelation.

Contrary to Global measures such as Moran's I, which merely suggest the existence of general clustering, Local Indicators of Spatial Association (LISA), also referred to as cluster and outlier analysis, are specifically utilized to determine the geographical sites of clusters [26]. This approach permits the visualization of clusters for a particular element, such as death registration within this investigation. LISA maps showcase statistically significant high-high and low-low clusters. High-high clusters

**Table 1** Description of the variables used in the study

| Variables | Description |
|---|---|
| Death registration | % of death registration in a district |
| Male | % of the male deceased in a district |
| No education | % of households with at least one member with no formal education in a district. |
| Residence | % of rural households in a district |
| Poorest households | % of poorest households in a district |
| Muslim | % of Muslim households in a district |
| Scheduled Tribe (ST) | % of ST households in a district |

signify areas (districts in this situation) distinguished by elevated values of a variable and enclosed by other areas with similarly high values. Low-low clusters, in contrast, pinpoint areas with diminished values that are encompassed by other low-value areas. Additionally, LISA is capable of identifying spatial irregularities, categorized as high-low (high-prevalence zones surrounded by low-prevalence zones) and low-high (low-prevalence zones surrounded by high-prevalence zones) [26].

To investigate the factors associated with death registration at the district level in India, with the district as the unit of analysis, we employed a regression modeling approach. Initially, Ordinary Least Squares (OLS) regression was conducted. To assess the presence of spatial autocorrelation in the OLS residuals, we utilized Lagrange Multiplier (LM) and Robust Lagrange Multiplier (RLM) tests. The significance of both LM and RLM test statistics indicated the presence of spatial autocorrelation, suggesting that spatial regression models, specifically the Spatial Lag Model (SLM) and the Spatial Error Model (SEM), would be more appropriate than OLS for this analysis [27]. The choice between the SLM and SEM was guided by the Akaike Information Criterion (AIC). In this study, the SEM exhibited the lowest AIC value and the highest log-likelihood among the three models (OLS, SLM, and SEM), indicating that it provided the best fit to the data while accounting for model complexity.

The SLM, an extension of OLS, incorporates a geographically lagged dependent variable (spatial lag term) as an additional predictor on the right-hand side of the equation. This spatial lag term is calculated as the weighted average of the dependent variable's (death registration) values in neighbouring districts, where the neighbours and their influence are defined by the spatial weights matrix (W). The SLM directly models spatial dependence in the dependent variable [27]. One way to express this model is:

$$y = pWy + Xb + u$$

Wy stands for the spatial lag term (spatially lagged death registration), where $y$ is the dependent variable (death registration), $X$ is the independent variable(s), $b$ is the coefficient associated with $X$, p denotes the coefficient associated with spatially lagged variable $Wy$, and the error term in the model is represented by $u$.

SEM, on the other hand, is employed when it is thought that the errors or residuals from an OLS regression show spatial autocorrelation, or that they are related with errors in nearby places. An equation for SEM is expressed as:

$$y = Xb + u$$

In this case, b is the coefficient related to y, X determines the independent variable or variables, and y refers the dependent variable. With SA, the error word is u. It is defined as $u = \lambda Wu + \varepsilon$, where ε denotes the uncorrelated errors, W is the spatial weights matrix, and λ signifies the spatial autoregressive parameter.

The software programs ArcMap version 10.5, GeoDa, and Stata 16 were utilized to analyse data and produce the maps for this study [28].

## Results

### Geographical disparities in death registration across Indian states and union territories (UTs)

Figure 1 illustrates the spatial distribution of death registration rates across India's states and UTs for the period 2019-21. The analysis reveals a significant nationwide challenge of death under-registration, with over 30% of deaths remaining unregistered. Notably, the eastern states of Uttar Pradesh, Bihar, and Jharkhand, along with the northeastern states of Arunachal Pradesh, Meghalaya, Manipur, and Nagaland, exhibited considerably low death registration rates, falling below 60% ('very low' LQ of < 1, see Fig. 2). In contrast, Assam and Odisha showed moderately low registration rates, ranging from 60 to 70%. A substantial portion of states, including the central states of Madhya Pradesh and Chhattisgarh, the eastern state of West Bengal, the western state of Rajasthan, and the northern states/UTs of Uttarakhand, Jammu and Kashmir, and Ladakh, reported death registration rates between 70% and 80% (moderate LQ of 1.00-1.25). High death registration rates (80–90%) were observed in the southern states of Andhra Pradesh and Karnataka, the northeastern state of Mizoram, and the northernwestern state of Haryana. The highest levels of death registration, exceeding 90%, were recorded in the western states of Maharashtra and Goa, the southern states of Kerala and Tamil Nadu, and the northern states of Himachal Pradesh and Punjab (high LQ of > 1.25).

### Geographical disparities in death registration across Indian districts

Figure 3 depicts the spatial heterogeneity of death registration rates across districts in India, revealing significant intra-state variability. Within several states, substantial disparities in registration coverage are evident. For instance, in Madhya Pradesh, a considerable range exists, with districts like Satna, Rewa, and Chhatarpur exhibiting registration rates between 40% and 60%, while Mandsaur, Chhindwara, Shahdol, and Jabalpur demonstrated significantly higher rates, ranging from 85 to 95%. Similar patterns of wide variation within state boundaries are observed in Rajasthan, with higher registration rates in the southern/western districts of Sirohi, Jodhpur, Jaisalmer, Barmer, and Jalore (80–90%) contrasting

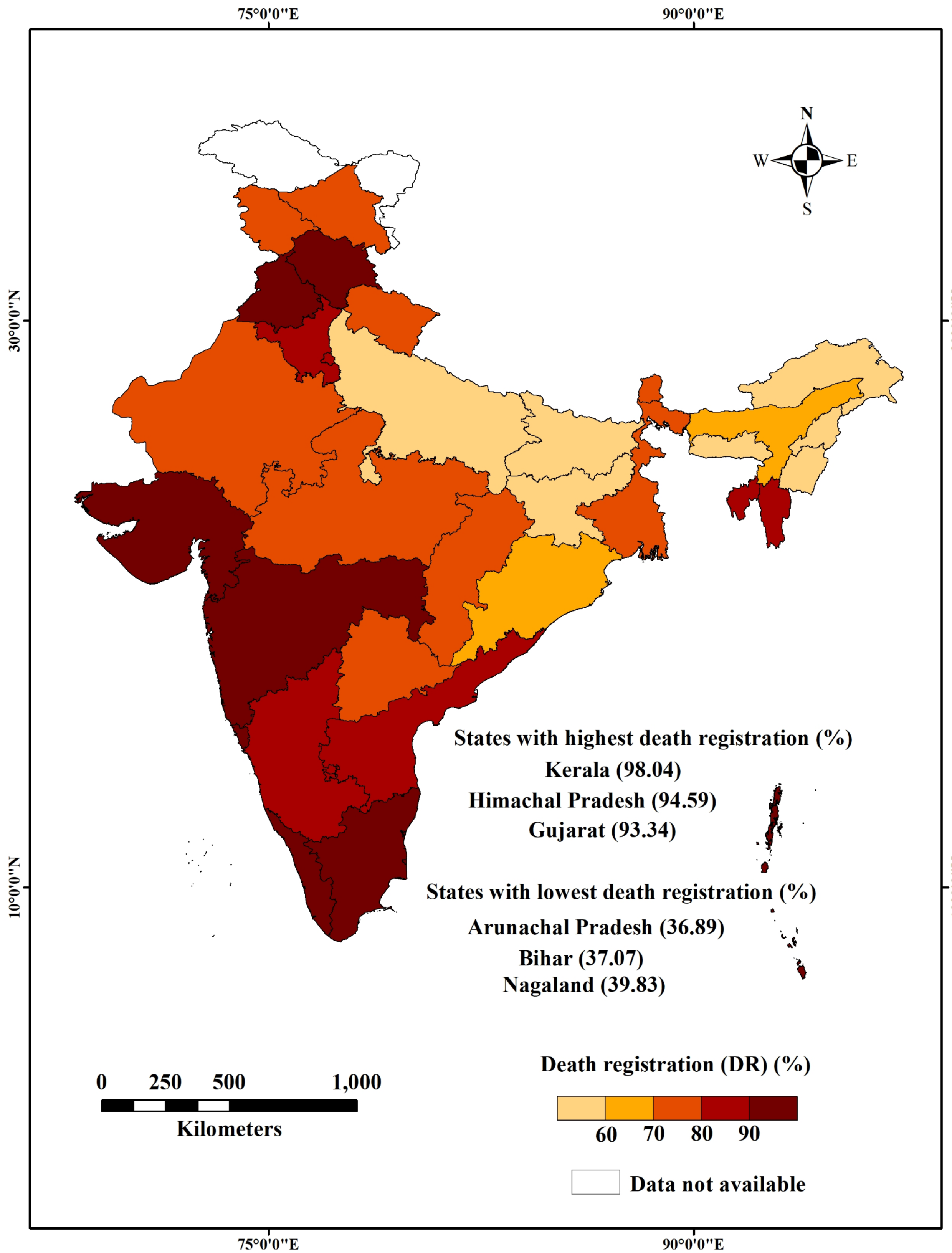


**Fig. 1** Map showing variations in death registration across the states and UTs in India, NFHS-5, 2019-21 (This map was created by the authors. The base layer is a free GIS file downloaded from https://spatialdata.dhsprogram.com/boundaries/#view=table%26;countryId=IA for national and sub-national boundaries)

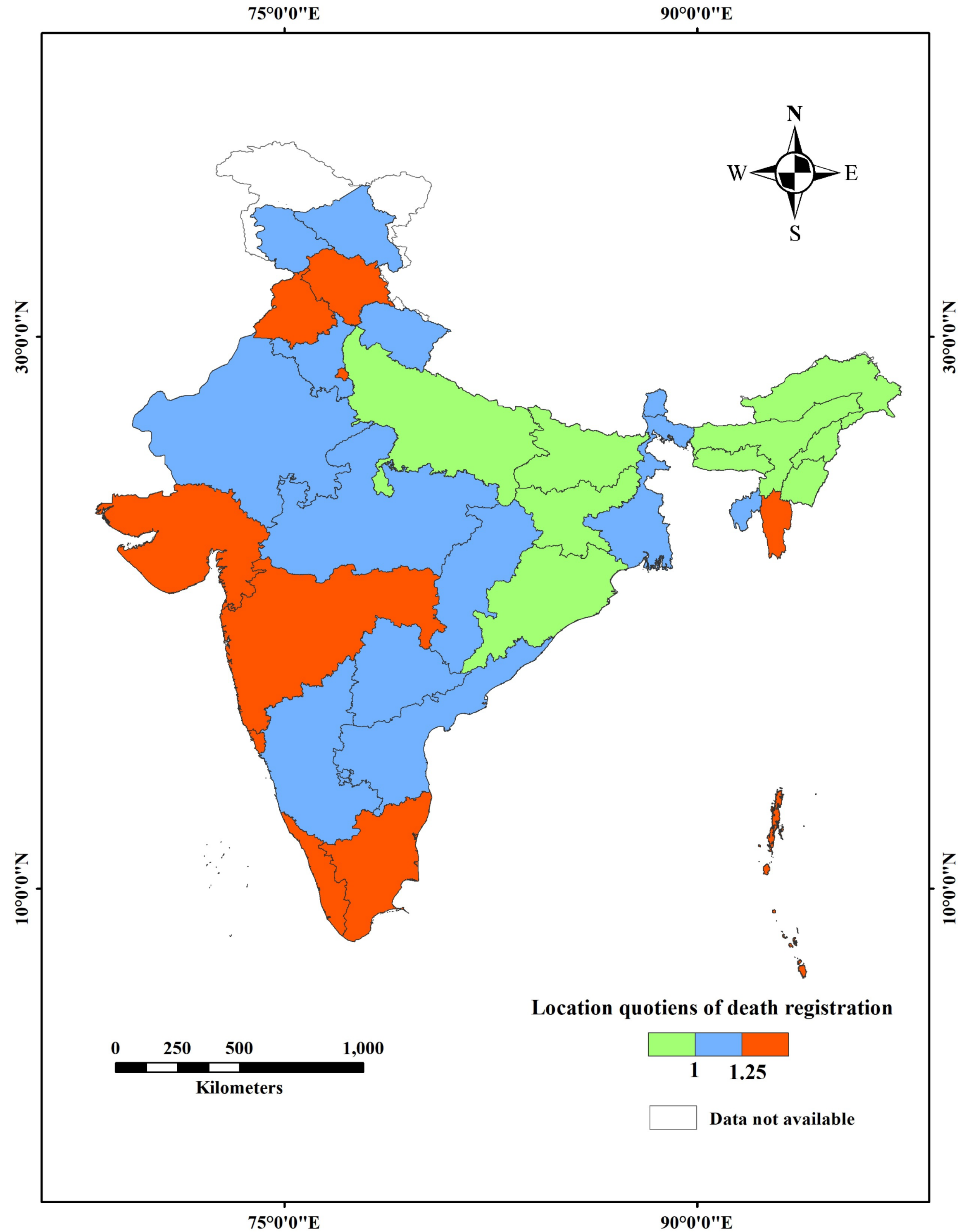


**Fig. 2** Location quotient map of death registration for Indian states and UTs, NFHS-5, 2019-21 (This map was created by the authors. The base layer is a free GIS file taken from https://spatialdata.dhsprogram.com/boundaries/#view=table%26;countryId=IA for national and sub-national boundaries)

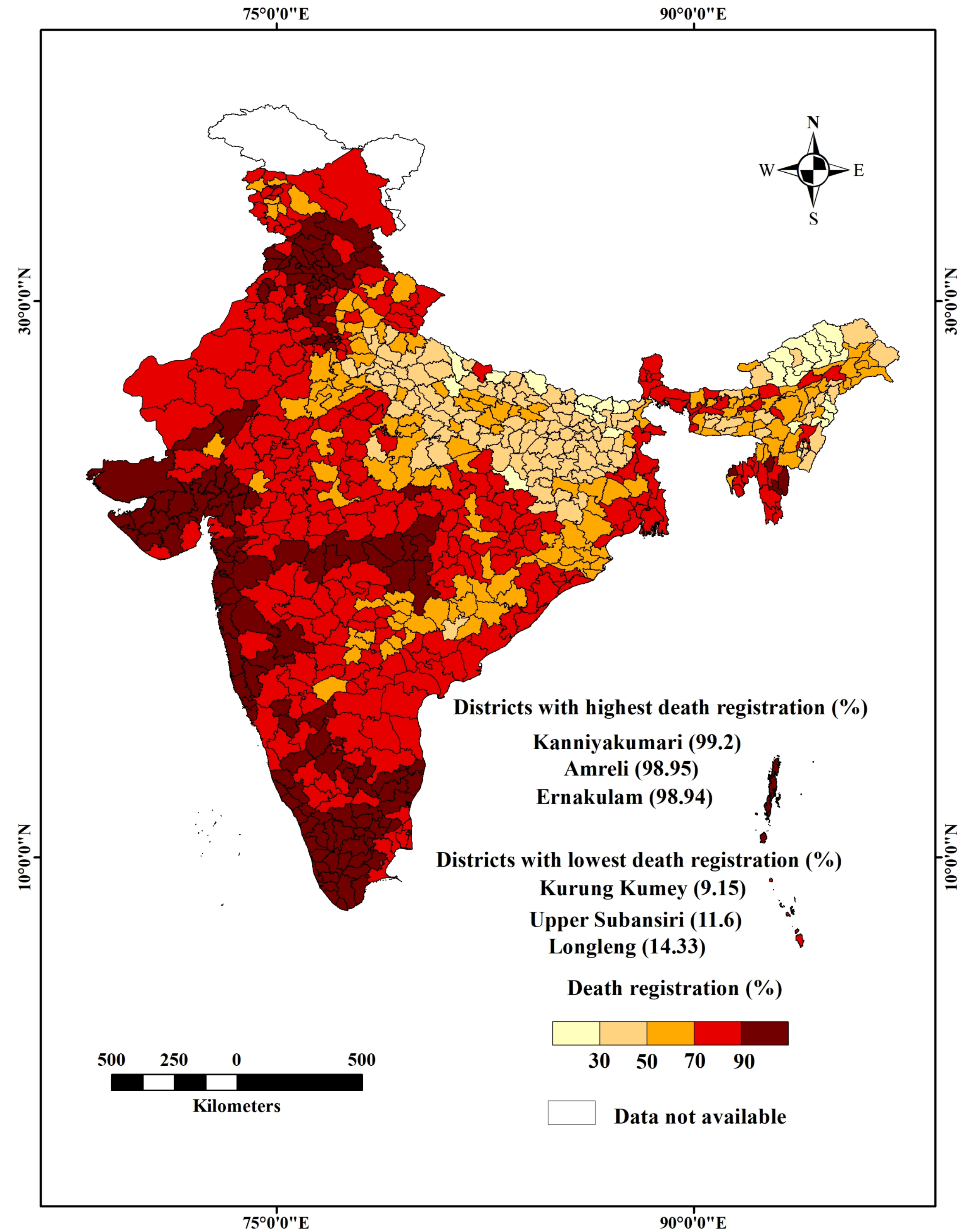


**Fig. 3** Map showing variations in death registration across the 707 districts in India, NFHS-5, 2019-21 (This map was created by the authors. The base layer is a free GIS file downloaded from https://spatialdata.dhsprogram.com/boundaries/#view=table%26;countryId=IA for national and sub-national boundaries)

sharply with lower rates in the northeastern districts of Baran, Sawai Madhopur, Karauli, Bharatpur, and Alwar (55–65%). Analogous intra-state disparities are also noticeable in Maharashtra (between coastal and interior districts), Karnataka (northeastern versus southern districts), and Odisha (coastal versus interior districts), underscoring the localized nature of factors influencing death registration.

Twenty-six districts reported alarmingly low death registration rates of less than 30%, with the lowest rates observed in Kurung Kumey (9.15%) and Upper Subansiri (11.60%) of Arunachal Pradesh, and Longleng (14.33%) of Nagaland. Further, 116 districts had death registration between 30 and 50%. Most of these districts with low registration were concentrated in a few states: Uttar Pradesh, Bihar, Jharkhand, Nagaland, Meghalaya, Arunachal Pradesh, and other northeastern states. Out of the 707 districts, 135 were found to have death registration rates between 50 and 70%, while high death registration rates (70-90%) were reported in 266 districts. On the other hand, highest deaths were registered (> 90%) in 162 districts, sprawling over mostly western states of Maharashtra, Goa, and Gujarat and the southern states such as Tamil Nadu, Kerala, and Karnataka. Districts with highest registration were recorded in the districts Kanyakumari (99.20%), Amreli (98.95%) and Ernakulam (98.94%) of Tamil Nadu, Gujarat, and Kerala respectively.

### Spatial autocorrelation in death registration and covariates at the district level

Table 2 presents the univariate Moran's I statistic, assessing the degree of spatial autocorrelation for death registration and the selected covariates across the 707 districts of India. The Moran's I value for death registration was 0.69 ($p < 0.01$), indicating a significant positive spatial autocorrelation, suggesting that districts with similar death registration rates tend to cluster geographically. Significant positive spatial autocorrelation was also observed for several covariates: proportion of rural population (Moran's I = 0.70), proportion of Muslim households (Moran's I = 0.74), proportion of poorest households (Moran's I = 0.60), proportion of household members with no education (Moran's I = 0.54), and proportion of Scheduled Tribe (ST) households (Moran's I = 0.51), all with $p < 0.01$. The proportion of male deceased individuals showed a weaker positive spatial autocorrelation (Moran's I = 0.21, $p < 0.01$).

**Table 2** Univariate Moran's I statistic showing Spatial autocorrelation of death registration and different variables across 707 districts of India, NFHS-5, 2019-21

| Variables (district level) | Univariate Moran's I |
|---|---|
| Death registration (%) | 0.69 |
| Male (%) | 0.21 |
| No education (%) | 0.54 |
| Rural (%) | 0.70 |
| Poorest households (%) | 0.60 |
| Muslim (%) | 0.74 |
| Scheduled Tribe (%) | 0.51 |

Note: The *p*-value for all Moran's I values provided in the table above was less than 0.01

### Spatial clustering of death registration across Indian districts: LISA analysis

Figure 4 visually depicts the spatial clustering of death registration rates across districts in India. Two prominent low-low clusters, or "cold spots," were identified—these are areas where districts with below-average death registration rates are contiguous with other similarly low-performing districts. These cold spots encompass 152 districts, primarily concentrated in two regions: one cluster in the northeastern states of Arunachal Pradesh, Nagaland, and parts of Manipur; and another cluster in eastern India, notably in Jharkhand, Bihar, and Uttar Pradesh. Conversely, 170 districts were found to form high-high clusters, or "hotspots," where districts with above-average death registration rates are surrounded by similarly performing districts. These hotspots are predominantly located in three regions: southern India (including districts in Tamil Nadu, Andhra Pradesh, and Kerala), western India (comprising districts in Maharashtra and Gujarat), and northern India (encompassing Punjab, Haryana, and parts of Himachal Pradesh). Distribution of proportions of the covariates at district-level have been mapped and added in on a map as a Supplementary File (A) for the reader to understand the distribution of these attributes at the district level.

### Results of spatial regression models

#### *Descriptive statistics of the variables*

Table 3 presents the descriptive statistics for the variables used in this study. The average death registration rate is 70.35% (SD = 20.86), ranging from 9.15 to 99.20%. The mean percentage of male deceased individuals is 82.83% (SD = 7.08), with values spanning from 20.77 to 98.32%. On average, 29.32% (SD = 11.66) of households have at least one member with no formal education, with proportions varying between 1.04% and 65.29%. Rural households constitute an average of 73.66% (SD = 19.56) of the sample, ranging from 0.17 to 98.52%. The percentage of households in the poorest quintile averages 22.61% (SD = 19.28), with a range from 0.11 to 79.65%. Additionally, the mean percentage of Muslim households is 11.39% (SD = 17.18), varying from 0.07 to 99.82%, and the mean percentage ofST households is 14.34% (SD = 25.93), ranging from 0.08 to 99.88%.

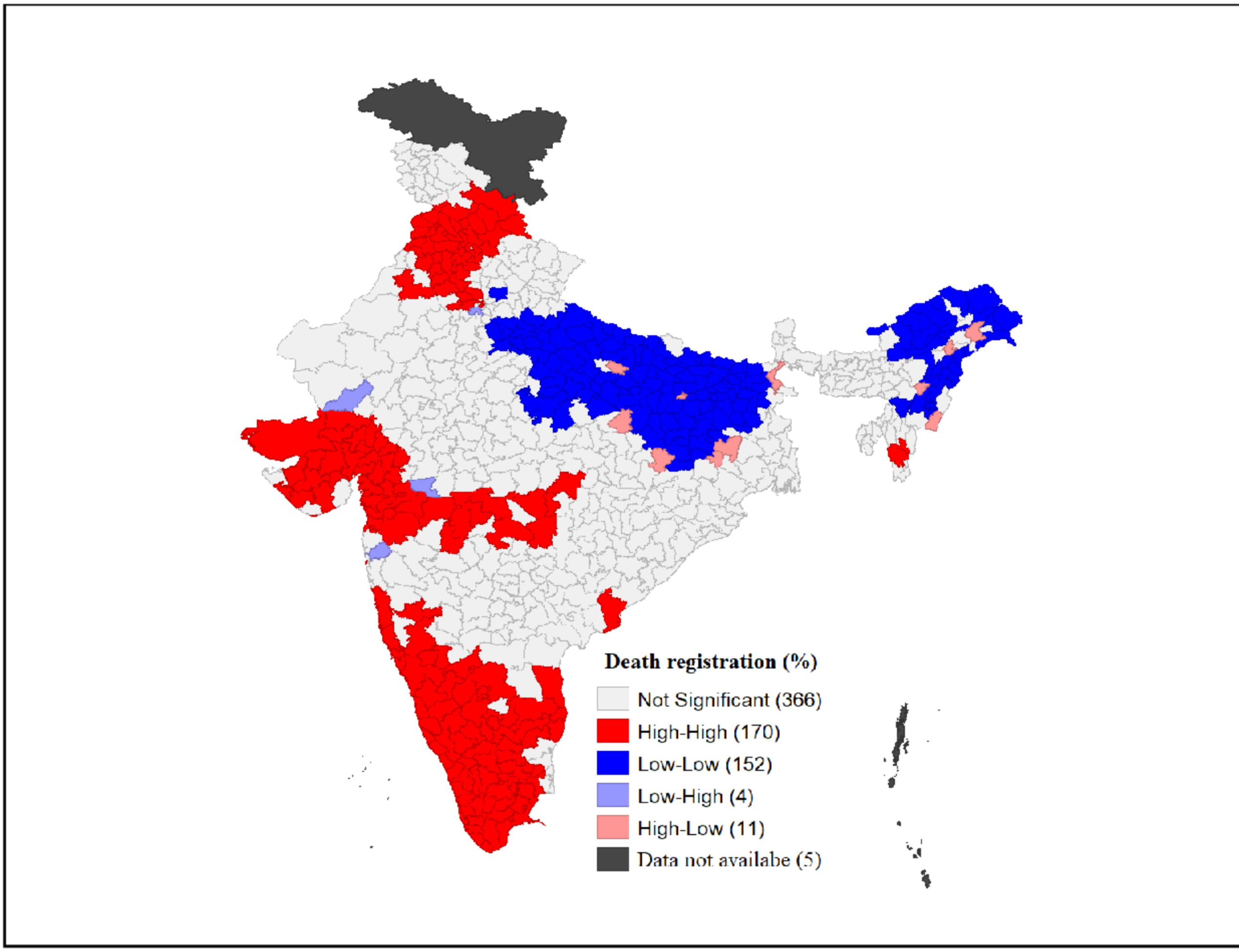


**Fig. 4** Univariate LISA map showing the spatial clustering of death registration across the 707 districts in India, NFHS-5, 2019-21 (Map was created by the authors. The base layer is a free GIS file from https://spatialdata.dhsprogram.com/boundaries/#view=table%26;countryId=IA for national and sub-national boundaries)

**Table 3** Descriptive statistics of the variables, India, NFHS-5, 2019–2021

| Variables | Mean (%) | SD | Minimum (%) | Maximum (%) |
|---|---|---|---|---|
| Death registration (%) | 70.35 | 20.86 | 9.15 | 99.20 |
| Male (%) | 82.83 | 7.08 | 20.77 | 98.32 |
| No education (%) | 29.32 | 11.66 | 1.04 | 65.29 |
| Rural (%) | 73.66 | 19.56 | 0.17 | 98.52 |
| Poorest households (%) | 22.61 | 19.28 | 0.11 | 79.65 |
| Muslim (%) | 11.39 | 17.18 | 0.07 | 99.82 |
| ST (%) | 14.34 | 25.93 | 0.08 | 99.88 |

***Estimates from the spatial error model***

Table 4 presents the estimates from the SEM, illustrating the spatial association between death registration and its covariates. Based on the lowest Akaike Information Criterion (AIC) value (5539.72, $p<0.001$), the SEM was identified as the best-fitting model among the three considered (OLS, SLM, and SEM). The detailed results for the other two spatial regression models (OLS and SLM) have been included as Supplementary File (B). The SEM results indicated significant associations between several covariates and death registration at the district level. Specifically, higher percentages of households with at least one uneducated member, Muslim households, and Scheduled Tribe (ST) households were statistically significantly associated with lower death registration rates. Similarly, districts with a higher proportion of poor and rural households also exhibited significantly lower death registration. The sex of the deceased emerged to be an important determinant. A

**Table 4** Estimates from Spatial Error Model (SEM) showing the association between death registration and key sociodemographic variables, India, NFHS-5, 2019-21

| Independent variables | Coefficient (*p*-value) | Lower CI | Upper CI |
|---|---|---|---|
| Male (%) | 0.035 (0.049) | -0.119 | 0.191 |
| No education (%) | -0.327 (0.000) | -0.452 | -0.223 |
| Rural (%) | -0.046 (0.050) | -0.097 | 0.004 |
| Poorest households (%) | -0.182 (0.000) | -0.180 | -0.024 |
| Muslim (%) | -0.034 (0.000) | -0.101 | 0.032 |
| ST (%) | -0.114 (0.000) | -0.163 | -0.066 |
| N | 707 | | |
| Lag coefficient (λ) | 0.767 (0.000) | | |
| AIC | 5539.72 | | |
| R-squared | 0.716 | | |

Note: CI-Confidence Interval, AIC- Akaike Information Criterion, ST- Scheduled Tribe, N- Number of districts

10% increase in deaths of males corresponded with a 0.3% increase in death registration, indicating that male deaths were recorded at a relatively higher rate than those of females. The impact of education levels was further demonstrated by the fact that a 10-point increase in the percentage of household members without any education was linked to a 3.2-point decline in death registration. Death registration was correlated with the percentage of rural households. For every 10-point increase in rural households, there was a corresponding 0.4% decrease in death registration. Household wealth was observed to be crucial since death registration decreased by 1.8% for every 10% increase in the poorest households. In case of religion, a 0.3% decrease in death registration was attributed to a 10% increase in Muslim household heads. A 10-point rise in the proportion of ST household heads was associated with a 1.1-point reduction in death registration.

## Discussion

This study examines death registration patterns across India using data from the fifth round of the National Family Health Survey (NFHS-5) conducted in 2019-21 at both state and district levels. The findings reveal that three out of ten deaths are not reported nationally, highlighting a significant challenge. Furthermore, the study identifies considerable spatial heterogeneity in death registration coverage, with substantial disparities observed across both state and district levels. A clear regional gradient emerges, with the eastern and northeastern states consistently exhibiting lower rates of death registration, while the western and southern states generally demonstrate higher rates. The study further reveals significant intra-state variations, highlighting the localized nature of under-registration within broader regional trends. Despite these localized differences, death registration at the district level displays significant spatial autocorrelation. This is evidenced by the identification of distinct "cold spots"– clusters of districts with low registration– predominantly concentrated in the northeast and eastern India. Conversely, "hotspots"– clusters of districts exhibiting high registration– are predominantly located in the southern, western, and northern regions of India. Furthermore, this study explored the socio-demographic factors associated with the observed spatial disparities in death registration through spatial regression analysis. Our findings revealed significant district-level associations between death registration coverage and several key variables: proportion of male deaths, proportion of households in poorest quintile, proportion of Muslim households, proportion of ST households, proportion of deceased's household members with limited educational attainment, and proportion of rural residents.

Consistent with previous literature on vital statistics in India, the pronounced geographical divide, with eastern and northeastern states consistently exhibiting alarmingly low death registration rates compared to their western and southern counterparts, underscores deep-seated regional inequalities [9, 18, 19]. This pattern likely reflects the cumulative impact of varying levels of socio-economic development, historical investments in public health infrastructure, and the strength of local governance mechanisms. For instance, limited access to and education and healthcare facilities prevalent in many eastern and northeastern states may directly correlate with lower awareness and utilization of death registration services [22]. Furthermore, historical patterns of social exclusion and marginalization in these regions could also contribute to lower engagement with formal registration processes [29]. This persistent divide necessitates targeted policy interventions that acknowledge and address these underlying systemic factors rather than relying on generalized national strategies.

The substantial within-state variations observed at the district level underscore the limitations of relying solely on state-level averages and emphasize the localized complexities of death registration. This granularity reveals that even within states with relatively high overall registration rates, significant pockets of under-registration persist, often concentrated in more remote or underserved areas. This highlights the critical role of local administrative capacity, the accessibility of registration centres, and community-level awareness initiatives in determining registration completeness [22]. Addressing these intra-state disparities requires a more localized and context-specific approach, potentially involving strengthening local governance mechanisms, enhancing targeted outreach programs, and leveraging community health workers to facilitate registration in underserved populations.

The identification of distinct spatial clusters of low ("cold spots") and high ("hotspots") death registration at the district level provides a valuable lens for targeted interventions. The clustering of low-performing districts in the Northeast and eastern India suggests the presence of shared regional challenges that hinder registration, potentially including difficult geography, limited accessibility and connectivity, and socio-cultural factors that de-prioritize formal death recording [22]. Conversely, the "hotspots" in the South, West, and North likely benefit from a confluence of factors such as higher literacy, better infrastructure, and a greater societal emphasis on formal documentation [30]. Understanding the specific factors that contribute to the success in these high-performing clusters could provide valuable lessons for improving registration in the low-performing regions.

Our spatial regression analysis revealed statistically significant district-level associations, illuminating socio-demographic determinants of death registration. Notably, higher male mortality was linked to higher death registration coverage, a finding consistent with studies in India and elsewhere [18, 29–32]. This likely reflects the influence of inheritance practices and access to pension benefits. Broader scientific literature offers several interconnected explanations for the more frequent registration of male deaths. These include the importance of documenting male lineage in patrilineal societies for inheritance, the immediate financial needs arising from the death of male primary earners (such as pension and insurance claims), societal norms assigning legal and administrative responsibilities to men, and potential barriers faced by women in accessing registration services due to autonomy or mobility restrictions [3, 4]. Furthermore, gender-based disparities in education and awareness can indirectly contribute to the under-registration of female deaths.

A key finding of this study is the statistically significant negative association between the proportion of Muslim and ST households in a district and the rate of death registration. These results are consistent with extant literature [19, 29]. It is crucial to acknowledge that these district-level correlations are subject to the ecological fallacy and do not permit definitive conclusions about individual household registration practices within these communities. These district-level associations could be influenced by a variety of factors, including historical marginalization potentially fostering lower levels of engagement with formal administrative systems, prevailing socio-economic vulnerabilities such as poverty and limited educational attainment which may impede awareness and access to registration procedures, and community-specific cultural norms that may not prioritize or fully appreciate the benefits of official death recording.

The finding that districts with a higher percentage of household members of the deceased with little to no education tend to have lower death registration rates underscores the importance of education in the death registration process. This aligns with the understanding that knowledge is a key factor in increasing social awareness [31, 32]. Our study also indicates that districts with a higher percentage of poor households tend to record deaths at lower rates, which may be attributed to the financial burden associated with hospital charges and the costs of the death registration procedure, including the issuance of death certificates, as suggested by previous research [19, 29]. Furthermore, the deceased's residence was found to be connected to death registration at the district level, with districts having a higher proportion of rural households exhibiting lower rates. This is likely due to a combination of factors, including the higher prevalence of poverty and engagement in cultivation and agricultural activities in rural areas, potentially leading to limited awareness of government benefits like pensions, and reduced access to death registration services [19]. While our study offers insight into the potential factors driving spatial variation in death registration at the district level, further investigation is needed to understand these dynamics more thoroughly. Future research could include in-depth qualitative studies within contrasting clusters of high and low registration coverage to uncover the underlying drivers and barriers to registration. Longitudinal studies that track changes in registration rates in response to targeted interventions could also provide valuable insights.

Although India has a national framework for civil registration under the Registration of Births and Deaths Act of 1969, the implementation, development, and functioning of the civil registration system (CRS) vary significantly across the country [22]. While states like Kerala, Tamil Nadu, Maharashtra, and Goa have established efficient and well-functioning registration systems [30], other regions—particularly in the eastern and northeastern states, which face geographic isolation, difficult terrain, and low accessibility—encounter considerable challenges. These states struggle with inadequate registration infrastructure and human resources, difficulties in digitizing records—especially at the grassroots level in blocks and villages—lack of effective personnel training, limited public awareness campaigns, and weak enforcement of penalties for non-compliance [22, 33]. Additionally, the involvement of multiple government departments in the registration process, coupled with the infrequent convening of Inter-Departmental Coordination Committees, leads to poor coordination, incomplete and delayed data submission, and hampers the formulation of effective improvement strategies [22]. To address these challenges, it is crucial to streamline coordination, improve infrastructure, enhance training programs, and introduce stronger enforcement mechanisms. Furthermore, sustained public awareness campaigns and the adoption of digital solutions at the local level could significantly improve registration rates and ensure a more equitable system across these regions.

To further enhance death registration rates across the states, a comprehensive and multi-faceted approach could be considered. Simplifying the death certification process, for example, might reduce procedural barriers and improve accessibility [4]. Additionally, lowering late registration fees could alleviate some of the financial burdens that disproportionately affect marginalized communities, particularly women [29]. It may also be beneficial to address systemic barriers faced by these groups, such as lack of awareness, limited access to registration services, or cultural norms that hinder engagement with formal documentation processes. Strengthening the enforcement of penalties for non-registration, as outlined in the RBD Act, could potentially improve compliance and enhance the overall reliability of the system [34]. However, it is equally important to pair such measures with educational initiatives that raise awareness about the importance and benefits of registration, particularly in underserved areas [33]. One promising strategy could involve adopting a community-based approach to death registration. Empowering community health workers, especially women, to play an active role in notifying authorities of deaths might not only improve registration rates but also help reduce gender biases in the reporting process [35]. This approach could be especially effective in rural and remote areas where access to formal registration centres may be limited. Additionally, fostering greater community trust and participation through such initiatives could lead to more inclusive and equitable registration practices across the country.

This study has several limitations. First, the NFHS-5 relied on self-reported data, as interviewers did not verify death registration through death certificates. This reliance on respondent-provided information may introduce inaccuracies, as self-reported data can be subject to recall bias and reporting errors. As a result, the actual number of deaths registered may be either overestimated or underestimated. Second, it is important to acknowledge that some of the estimated death registration rates, particularly at finer geographical levels, may be associated with large confidence intervals, potentially affecting the robustness of those specific estimates. This inherent uncertainty needs to be taken into account when interpreting the findings. Third, the cross-sectional design of the study limits the ability to establish causal relationships between death registration and the independent variables examined. Lastly, the analysis was restricted to the variables available in the NFHS-5 dataset, potentially excluding other important predictors of death registration that were not captured in the survey.

## Conclusions

The study revealed substantial spatial disparities in death registration across the states and districts of India, with eastern and northeastern regions exhibiting persistently low registration levels, in contrast to higher rates observed in northwestern, southern and western states. Socio-demographic determinants—particularly gender, household wealth, educational attainment, and social group—play a pivotal role in shaping these patterns. Marginalized communities continue to face systemic barriers to registration, underlining the need for equity-oriented policy responses. To address these challenges, region-specific interventions are essential, including gender-sensitive strategies that prioritize improved access for women, especially in rural and underserved areas. Strengthening community outreach, enhancing awareness, and simplifying procedural barriers can further improve registration rates among vulnerable populations. A comprehensive, inclusive approach to death registration will not only ensure more complete and accurate vital statistics but also support more responsive and equitable public health planning across India.

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-22707-2.

Supplementary Material 1

Supplementary Material 2

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### Author contributions

AS: Conceived and designed the study; extracted and analysed the raw data; supervised the study; wrote the original draft; reviewed and edited the manuscript. AK: Extracted and analysed the raw data; wrote the original draft; reviewed and edited the manuscript. SR: Conceived and designed the study; reviewed and edited the manuscript. RC: Supervised the study; reviewed and edited the manuscript. AT: Created figures and map; reviewed the manuscript. SS: Wrote the original draft; reviewed and edited the manuscript. VK: Reviewed and edited the manuscript.

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**Data availability**
The data used in this study can be obtained for free by submitting an online request to the Demographic and Health Surveys (DHS) repository https://dhsprogram.com/data/available-datasets.cfm The base layer for the maps was downloaded as a free GIS file from https://spatialdata.dhsprogram.com/boundaries/#view=table%26;countryId=IA for national and sub-national boundaries).

## Declarations

**Ethics approval and consent to participate**
The study was based on secondary dataset with no identifiable information on the survey participants. The dataset is freely available in the public domain for research use. Therefore, no ethical clearance and consent for participation was required.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

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