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Tuberculosis and Associated Vulnerabilities Among Rural Residents in Jaipur District, Rajasthan, India: A Community-Based Cross-Sectional Study

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Abstract

Background

Tuberculosis (TB) remains a major public health challenge in India, particularly among rural populations with overlapping biological, behavioural, and occupational vulnerabilities. This study estimated the burden of self-reported TB and examined the independent and cumulative effects of selected vulnerability factors in rural Rajasthan.

Methods

A community-based cross-sectional study was conducted among 13,122 residents from eight villages in Jaipur district, Rajasthan. Socio-demographic characteristics, self-reported TB, and potential vulnerability factors were collected through household surveys. Due to the rarity of TB events, Firth's bias-reduced logistic regression was used to estimate crude and adjusted odds ratios (ORs) with 95% confidence intervals (CIs). A pre-specified sensitivity analysis, Population Attributable Fractions (PAFs), and a composite vulnerability score were used to assess population-level burden and cumulative risk.

Results

The prevalence of self-reported TB was 0.09% (12/13,122) under the primary definition and 0.37% (49/13,122) under the sensitivity definition. Silicosis demonstrated the strongest independent association with TB (adjusted OR 47.38, 95% CI 7.38–304.18; sensitivity model adjusted OR 16.42, 95% CI 4.47–60.33). Under the sensitivity analysis, smoking (adjusted OR 4.14, 95% CI 1.87–9.18), diabetes (adjusted OR 4.40, 95% CI 1.06–18.30), and age > 15 years (adjusted OR 8.73, 95% CI 1.73–44.04) were also independently associated with TB. Although silicosis conferred the highest individual risk, smoking accounted for the largest attributable fraction (≈ 14%). Increasing composite vulnerability scores were associated with progressively higher odds of TB, demonstrating a significant dose–response relationship.

Conclusions

In this rural community, self-reported TB was uncommon but was associated with several biological and behavioural vulnerabilities, particularly silicosis. The observed dose–response relationship between cumulative vulnerabilities and self-reported TB warrants further investigation in larger prospective studies. If confirmed, these findings could inform risk-based approaches for community TB screening in similar high-risk populations.

INTRODUCTION

Tuberculosis (TB) remains the world's leading infectious cause of death, having reclaimed this position from COVID-19 in 2023[1]. According to the WHO Global Tuberculosis Report 2025, an estimated 10.7 million people developed TB and 1.23 million died from the disease in 2024, with the global incidence rate having fallen by only 12% since 2015, far short of the End TB Strategy's 2025 milestone of a 50% reduction [2]. This slow trajectory persists despite record case notifications and expanded diagnostic coverage, underscoring that passive, facility-based detection alone is insufficient to interrupt transmission in high-burden settings [1, 3]. Meeting the 2030 Sustainable Development Goal and End TB targets will require a shift toward proactive, community-based case-finding that can identify undiagnosed TB before further transmission occurs [3, 4]. By systematically targeting populations remote from diagnostic infrastructure or those facing significant material hardship, active case-finding strategies aim to identify these "missing millions" who remain excluded from conventional healthcare pathways [5, 6].

Barriers, including limited healthcare accessibility, delayed care-seeking, stigma, poor awareness, and inadequate surveillance, contribute to the under-detection of disease within these communities. As a result, many individuals remain undiagnosed until advanced stages of illness, sustaining ongoing transmission and limiting the effectiveness of passive case detection strategies. These challenges underscore the need for community-level epidemiological evidence to support targeted screening and prevention initiatives in high-risk populations [7, 8].

The epidemiology of TB is increasingly recognised as being shaped by the interaction of multiple biological, behavioural, occupational, and social determinants rather than by exposure to Mycobacterium tuberculosis alone [9]. Established evidence has consistently demonstrated increased TB risk among individuals with silicosis, occupational silica dust exposure, diabetes mellitus, HIV infection, tobacco use, and prolonged respiratory symptoms such as chronic cough. These factors frequently coexist in vulnerable populations, particularly in rural and occupational settings where poverty, hazardous working conditions, and limited healthcare access further amplify disease susceptibility. While each vulnerability has been independently associated with TB in previous studies, the cumulative effect of multiple coexisting vulnerabilities has received comparatively less attention in community-based populations. Understanding how these factors interact within the same individuals is essential for designing integrated screening strategies capable of identifying those at the greatest risk of developing TB [10, 11].

Most existing studies have examined individual TB risk factors separately or have focused on specific clinical or occupational populations, limiting their applicability to community-based screening programmes [12]. Evidence remains limited regarding the simultaneous evaluation of multiple vulnerabilities within a general rural population, particularly using analytical approaches capable of addressing rare outcomes and sparse-event data. Furthermore, relatively few investigations have attempted to quantify the population-level contribution of individual risk factors or to evaluate whether the accumulation of multiple vulnerabilities produces a graded increase in TB risk. Such evidence is highly relevant for public health programmes because identifying combinations of vulnerabilities may enable more efficient prioritisation of active case finding, resource allocation, and preventive

interventions than reliance on single risk factors alone. Addressing these evidence gaps is increasingly recognised as an important step towards more precise, risk-based approaches to TB control [13, 14].

Rajasthan provides an important setting in which to investigate these relationships. The state contributes substantially to India's TB burden and contains extensive sandstone mining and stone-processing industries that expose large numbers of workers to respirable crystalline silica [15]. Consequently, silicosis remains an important occupational health problem in several districts, frequently coexisting with diabetes, tobacco use, and other recognised determinants of TB. In addition, much of Rajasthan's population resides in rural communities where healthcare access, disease awareness, and early diagnosis remain challenging [15]. These overlapping vulnerabilities create an appropriate setting for examining the combined influence of biological, occupational, and behavioural risk factors on TB and for generating evidence that may support integrated community-based screening strategies in high-risk populations [14].

Against this background, the present study conducted a rapid community-based assessment of self-reported tuberculosis among residents from eight rural villages in Jaipur district, Rajasthan. In addition to estimating the burden of self-reported TB, the study evaluated the independent association of selected biological, occupational, and behavioural vulnerabilities with TB, assessed the population-level contribution of significant risk factors, and examined whether the accumulation of multiple vulnerabilities was associated with a graded increase in TB risk. By integrating these complementary epidemiological approaches, the study aims to provide evidence that may inform more targeted, risk-based community screening and strengthen TB control strategies in vulnerable rural populations.

METHODOLOGY

Study Design and Study Setting

The study follows a community-based cross-sectional study design conducted under the academic and technical supervision of ICMR-NIHR (Indian Council of Medical Research- National Institute of Health Research), Jodhpur, Rajasthan. The rural areas of the Jaipur District were considered under the study. Simple Random Sampling (SRS) was used to select eight villages under two blocks of the Jaipur District.

Sampling Methodology

In the first stage of sample selection, two blocks were randomly selected from the Jaipur District through Simple Random Sampling (SRS). In the second stage, eight villages were selected through SRS under the two blocks. In the third and final stage, the Universal Sampling methodology was followed, which included all the households and their respective family members of each of the selected villages (Fig. 1).

Study Population

The study population primarily included all permanent residents of the villages residing in the households for more than the last three months. All the members of the family were considered in the study irrespective of their age, sex or gender.

Rapid Assessment

The large sample size, along with time and resource constraints, made the process cumbersome to interview everyone in each household. The study followed a self-reporting method of data collection from the respondents of each household as a rapid assessment method. A Respondent was selected from each household who answered the questionnaire on behalf of all the family members. The head of each household was usually identified and selected for the purpose. In the event of their absence or unavailability, the next best individual was selected as per the eligibility criteria from the other family members, or the household was visited again, subject to their availability. The selection criteria of the respondent involved an adult individual (>/=18 years of age), capable of communicating effectively in terms of language and having a healthy cognitive constitution and having a good knowledge of all the members of the family.

Sample Size

All the eligible households in the eight randomly selected villages were surveyed. Upon complete enumeration of the study population, the sample size came to a total of 13,122 sample units.

Study Variables

The study variables considered under the study were the comorbidities of the individuals, like Diabetes status, HIV status, people with diagnosed silicosis; risk factors like occupational exposure to silica dust, smoking habits of the individuals; symptoms like individuals having a cough of greater or equal to 2 weeks; and finally, the TB status of the individuals. All the data collected under the study are self-reported in nature and do not have any diagnostic backing, as it completely relies on the health knowledge of the study participants.

Data Collection Method and Tools

Data were collected through house-to-house, face-to-face interviews using a semi-structured questionnaire adapted from a previously published community-based tuberculosis screening tool [16]. The questionnaire captured self-reported information on selected tuberculosis-related vulnerability factors, including comorbidities, behavioural and occupational risk factors, as well as the self-reported tuberculosis status of the participants.

Data Analysis

Data were entered and cleaned using Microsoft Excel 2024 and analysed using R software (version 4.6.1; R Foundation for Statistical Computing, Vienna, Austria). Categorical variables were summarised as frequencies and percentages. Owing to the rarity of self-reported tuberculosis events, Firth's bias-reduced logistic regression was used to estimate crude and adjusted odds ratios (ORs) with 95% confidence intervals (CIs). A pre-specified sensitivity analysis was performed using a broader case definition. Population Attributable Fractions (PAFs) were calculated using Miettinen's case-based formula, and a composite vulnerability score was evaluated using Firth logistic regression to assess the dose–response relationship. Statistical significance was set at $p < 0.05$.

RESULT

A total of 13122 individuals from 8 rural villages located in two administrative blocks of Jaipur district of Rajasthan (India) were included in the study. Participants were predominantly from *Kotputli* Block (72.9%), with the remaining 27.1% residing in *Govind Garh* Block. *Sangted* (19.5%) and Morda (18.9%) contributed the largest proportion of the study population, whereas *Mahar Kalan* accounted for the smallest proportion (0.6%) (Fig. 2).

The sociodemographic characteristics of the study participants are presented in Table 2. Of the 13,122 participants, 52.6% were male, 74.6% were aged > 15 years, 73.6% were not currently employed, and 67.8% belonged to the Other Backward Classes. Among the assessed vulnerability factors, diabetes was the most frequently reported comorbidity (0.46%), followed by current or past smoking (3.09%) and chronic cough lasting > = 2 weeks (1.72%). Self-reported silicosis and occupational silica dust exposure were reported by 0.19% and 0.18% of participants, respectively, while HIV-reactive status was reported by four individuals (0.03%). Using the primary case definition, 12 participants reported tuberculosis, corresponding to a prevalence of 0.09%. Under the sensitivity definition, 49 participants were classified as having self-reported tuberculosis, yielding a prevalence of 0.37% (Table 1).

Table 1
Socio-demographic characteristics, vulnerability factors, and self-reported tuberculosis among the study participants (N = 13,122)

Characteristic	Category	n (%)
Gender	Male	6904 (52.6)
	Female	6217 (47.4)
	Third gender	1 (0.01)
Age group	0–5 years	802 (6.1)
	6–15 years	2538 (19.3)
	> 15 years	9782 (74.6)
Occupation	Agriculture	920 (7.0)
	Unskilled/manual labour	1570 (12.0)
	Skilled/semi-skilled	356 (2.7)
	Professional/business	623 (4.7)
	Not currently employed	9653 (73.6)
Community group	Scheduled Caste	2113 (16.1)
	Scheduled Tribe	1203 (9.2)
	OBC	8898 (67.8)
	General	908 (6.9)
Vulnerability factor	Diabetes	60 (0.46)
	Silicosis	26 (0.19)
	Silica dust exposure	24 (0.18)
	HIV-reactive	4 (0.03)
	Current/past smoker	406 (3.09)
	Chronic cough (≥ 2 weeks)	226 (1.72)
Outcome	Self-reported TB, primary definition	12 (0.09)
	Self-reported TB, sensitivity definition	49 (0.37)

Factors associated with self-reported tuberculosis: univariable and multivariable analysis

Association between participants' characteristics, vulnerability factors, and self-reported tuberculosis are presented in Table 2. Firth's bias-reduced logistic regression was used for both univariable and multivariable analyses because of the small number of tuberculosis events.

In the univariable analysis, silicosis demonstrated the strongest association with self-reported tuberculosis (OR 66.16, 95% CI 11.21-390.31; *p < 0.05)*. Significant crude associations were also observed for silica dust exposure (OR 21.37, 95% CI 1.16-392.62), HIV-reactive status (OR 116.50, 95% CI 4.24-3201.36). No statistically significant association was observed for female gender, age > 15 years, smoking, or diabetes in the crude analysis. In the primary multivariable model (12 TB cases), silicosis remained independently associated with self-reported tuberculosis (AOR 47.38, 95% CI 7.38-304.18), whereas chronic cough was not statistically significant after adjustment (AOR 4.83, 95%CI 0.78–29.83).

Using the sensitivity definition of self-reported tuberculosis (49 events), silicosis remained significantly associated with tuberculosis (AOR 16.42, 95% CI 4.47–60.33). Significant independent associations were also observed for age > 15 years (AOR 8.73, 95% CI 1.73–44.04), ever smoking (AOR 4.14, 95% CI 1.87–9.18), and diabetes (AOR 4.40, 95% CI 1.06–18.30), whereas female gender and chronic cough were not statistically significant. Silica dust exposure and HIV reactive status were not included in the multivariable models because of collinearity and sparse data, respectively.

Table 2
Univariable and multivariable Firth logistic regression for factors associated with self-reported tuberculosis

Factor	**Crude OR (95% CI)**	**Adjusted OR¹ (95% CI)**	**Adjusted OR² (95% CI)**
Female gender	3.02 (0.89–10.28)	—	1.62 (0.90–2.91)
Age > 15 years	8.55 (0.51–144.47)	—	8.73 (1.73–44.04)*
Ever smoker	1.01 (0.06–17.16)	—	4.14 (1.87–9.18)*
Silicosis	66.16 (11.21–390.31)*	47.38 (7.38–304.18)*	16.42 (4.47–60.33)*
Silica dust exposure	21.37 (1.16–392.62)*	—†	—†
Diabetes	8.61 (0.49–150.42)	—	4.40 (1.06–18.30)*
HIV-reactive	116.50 (4.24–3201.36)*	—‡	—‡
Chronic cough (≥ 2 weeks)	7.45 (1.35–41.21)*	4.83 (0.78–29.83)	2.30 (0.72–7.31)

*Firth (bias-reduced) logistic regression throughout. *p < 0.05. ¹Adjusted OR: multivariable model of silicosis + chronic cough, primary case definition (12 events). ²Adjusted OR: multivariable model of silicosis + chronic cough + diabetes + smoking + age group + gender, sensitivity case definition (49 events). †Excluded*

from multivariable models due to collinearity with silicosis. ‡Excluded from multivariable models given only 4 exposed individuals.

Population attributable fraction

Population attributable fractions (PAFs) were estimated for the principal risk factors significantly associated with self-reported tuberculosis. Under the primary case definition, the estimated PAF was approximately 8% for silicosis and 7% for chronic cough. Using the sensitivity case definition, smoking had the highest estimated PAF (around 14%) followed by silicosis (8%) and diabetes (3%). Although silicosis demonstrated the strongest association with self-reported tuberculosis in the regression analyses. Its estimated population attributable fraction remained modest because of its low prevalence in the study population.

Composite vulnerability score and dose-response relationship

A composite vulnerability score (range 0–4) was constructed by summing four vulnerability factors: silicosis, chronic cough (> = weeks), diabetes, and ever smoking. Silica dust exposure was excluded because of its collinearity with silicosis. Under both primary and sensitivity definitions of self-reported tuberculosis, the prevalence of tuberculosis increased progressively with increasing composite vulnerability score (Table 3). In Firth's penalised logistic regression, each one-point increase in the composite score was associated with nearly threefold higher odds of self-reported tuberculosis under the primary case definition (OR 2.97, 95% CI 1.08-8-16; *p = 0.034*). The association with a more than fourfold increase in the odds of self-reported tuberculosis (OR 4.42, 95% CI 2.90–6.74; *p < 0.001*).

Table 3
Self-reported TB prevalence by composite vulnerability score, showing a dose–response gradient

Vulnerability score	N	TB prevalence, primary (%)	TB prevalence, sensitivity (%)
0 factors	12,221	0.09	0.30
1 factor	660	0.00	0.91
2 factors	56	1.79	7.14
3 factors	5	0.00	20.00

Trend test: Firth logistic regression, score modelled as a continuous predictor.

DISCUSSION

The self-reported TB prevalence of 0.09% observed in this population is markedly lower than the 312 per 100,000 recorded by India's bacteriologically confirmed National TB Prevalence Survey [17]. This difference is unlikely to reflect true epidemiological variation. In that survey, approximately two-thirds of prevalent cases had never sought care, indicating that a large proportion of disease remains undetected regardless of ascertainment method[18]. Self-reported prevalence in Indian populations has consistently been shown to underestimate confirmed disease burden. The prevalence reported here should therefore be interpreted as a minimum estimate, shaped substantially by disclosure and health-seeking behaviour rather than disease occurrence alone. This distinction is central to interpreting all subsequent associations, since misclassification of the outcome affects not only overall prevalence, but the precision of any risk-factor analysis built upon it.

Silicosis showed the strongest and most consistent association with TB across all models, with adjusted odds ratios substantially exceeding the pooled relative risk of approximately four reported in the largest meta-analysis of silicosis and TB [19]. Two explanations are plausible. First, silicosis in this occupationally exposed, nutritionally vulnerable rural population may confer greater risk than in the mixed clinical and mining cohorts that dominate existing literature. Second, and more likely, the small number of TB events (n = 12) limits the precision of odds ratio estimation, even using bias-reduction methods designed for rare outcomes [20]. Both explanations are compatible with the data. The direction and consistency of the association across primary and sensitivity analyses support a genuine effect, in keeping with the established biological pathway linking silica-induced macrophage dysfunction to impaired mycobacterial clearance [3, 4]. The magnitude of the odds ratio, however, should not be generalised beyond this dataset. For screening purposes, the consistency of the association is more informative than its numerical size [21].

Chronic cough followed a different pattern: it was significantly associated with TB in univariable analysis but lost significance after adjustment for silicosis. This attenuation is consistent with confounding by shared occupational exposure rather than an independent effect of cough on TB risk. Chronic cough is common among individuals with silica-related airway disease, independent of TB status, which may explain its reduced specificity as a screening criterion. This aligns with existing evidence questioning the diagnostic value of cough duration alone in TB screening algorithms [22]. In populations with high silica exposure, cough-based symptom screening may therefore misclassify occupational lung disease as tuberculosis risk, reducing its utility unless interpreted alongside occupational history.

Smoking and diabetes were not significantly associated with TB in the primary analysis but reached significance once the case definition was broadened. This pattern is consistent with limited statistical power rather than absence of effect, but literature on both exposures suggests some caution is warranted regardless. A well-adjusted Taiwanese cohort found that current smoking, but not ever-smoking, remained significantly associated with TB after adjustment [23]. A Mendelian randomisation analysis of diabetes and TB reported a pooled odds ratio of approximately 1.2, considerably lower than the 2–4-fold risk typically cited from cross-sectional studies[24]. These findings suggest that true effect sizes for both exposures may be more modest than commonly reported, and that our sensitivity-analysis

estimates should not be interpreted as more definitive than the primary analysis, but as more statistically stable.

Population attributable fraction estimates clarify the relationship between individual risk and population-level burden. Silicosis, despite the largest odds ratio, contributed to a comparatively small attributable fraction because of its low prevalence. Smoking, with a smaller odds ratio, contributed a proportionally larger share of the population TB burden due to its higher prevalence. This pattern is not unique to this study. A Kerala-based analysis similarly found that undernutrition and tobacco use contributed more to population TB burden than HIV, despite HIV carrying greater individual risk [25, 26]. A Taiwanese cohort attributed 17% of incident TB cases to smoking, closely matching the attributable fraction observed here [6]. These findings indicate that screening strategies focused solely on high-odds-ratio exposures may overlook exposures responsible for a larger proportion of community TB burden [27, 28].

The composite vulnerability score provides the most direct evidence supporting a shift toward cumulative risk assessment. TB prevalence increased in a graded manner with the number of co-occurring vulnerabilities, a pattern that remained statistically significant across both case definitions. Evidence on cumulative TB vulnerability remains limited. A Brazilian study demonstrated that co-occurring social vulnerabilities interact to worsen TB treatment outcomes [29, 30], and a Kerala programme has used individual-level vulnerability scoring operationally for active case-finding [31, 32]. Neither study, however, demonstrates a dose–response relationship between the number of vulnerabilities and TB prevalence itself in a general community population. This represents an incremental but specific contribution: existing frameworks support the concept of vulnerability accumulation, but empirical dose–response evidence at the population level remains scarce.

These findings support a shift in emphasis for community-based TB screening. Current active case-finding approaches under NTEP typically assess individual risk factors independently. Our results suggest that assessing the accumulation of multiple vulnerabilities within an individual may provide more effective risk stratification than evaluating single exposures in isolation. This approach would not require additional diagnostic infrastructure, only reorganisation of existing screening criteria to prioritise individuals with multiple concurrent vulnerabilities, particularly in occupationally exposed rural populations where several risk factors frequently coexist.

Overall, these findings support cumulative vulnerability assessment as a more informative approach to community TB risk stratification than evaluation of individual risk factors alone, providing a rationale for incorporating composite vulnerability indicators into community-based active case-finding strategies.

Limitations

Several limitations affect the interpretation of these findings. The outcome was self-reported and clinically unconfirmed, which likely underestimates true prevalence and may introduce differential misclassification related to disclosure patterns, particularly by gender. The small number of confirmed TB cases limits precision even with rare-event statistical methods, and findings from eight villages in a

single district may not generalise to other rural Indian settings. These limitations should be considered when interpreting the magnitude, though not necessarily the direction, of the associations reported.

CONCLUSION

This community-based study of 13,122 rural residents in Jaipur district found a low self-reported TB prevalence, with silicosis showing the strongest association with TB across all models. Smoking, diabetes, and chronic cough showed weaker and less consistent associations. Population attributable fraction estimates indicated that silicosis and smoking contributed differently to individual risk versus population-level burden. TB prevalence increased with the number of co-occurring vulnerabilities, suggesting that cumulative vulnerability assessment may offer a useful approach for prioritising community-based TB screening alongside existing single-factor methods.

Abbreviations

TB
Tuberculosis
OR
Odds Ratio
AOR
Adjusted Odds Ratio
CI
Confidence Interval
PAF
Population Attributable Fraction
HIV
Human Immunodeficiency Virus
SRS
Simple Random Sampling
ICMR-NIHR
Indian Council of Medical Research–National Institute of Health Research.

Declarations

Ethics approval and consent to participate:

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and the Indian Council of Medical Research (ICMR) National Ethical Guidelines for Biomedical and Health Research Involving Human Participants (2025). Ethical approval was obtained from the Institutional Ethics Committee of the Indian Council of Medical Research–National Institute of Health Research

(ICMR–NIHR), Jodhpur (File No. IEC-ICMR-NIIRNCD/2021/25/3). Written informed consent was obtained from all participants before their enrolment in the study.

Consent for publication:

Not Applicable

Clinical trial number

Not applicable.

Competing interests:

The authors declare that they have no competing interests.

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Author Contribution

PKA: Literature search, data acquisition, data analysis, and manuscript reviewing. PB: Literature search, data analysis, manuscript preparation, reviewing the manuscript and editing. JKG & GD: Data analysis, reviewing the manuscript, and editing.

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Data Availability

The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

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Figures

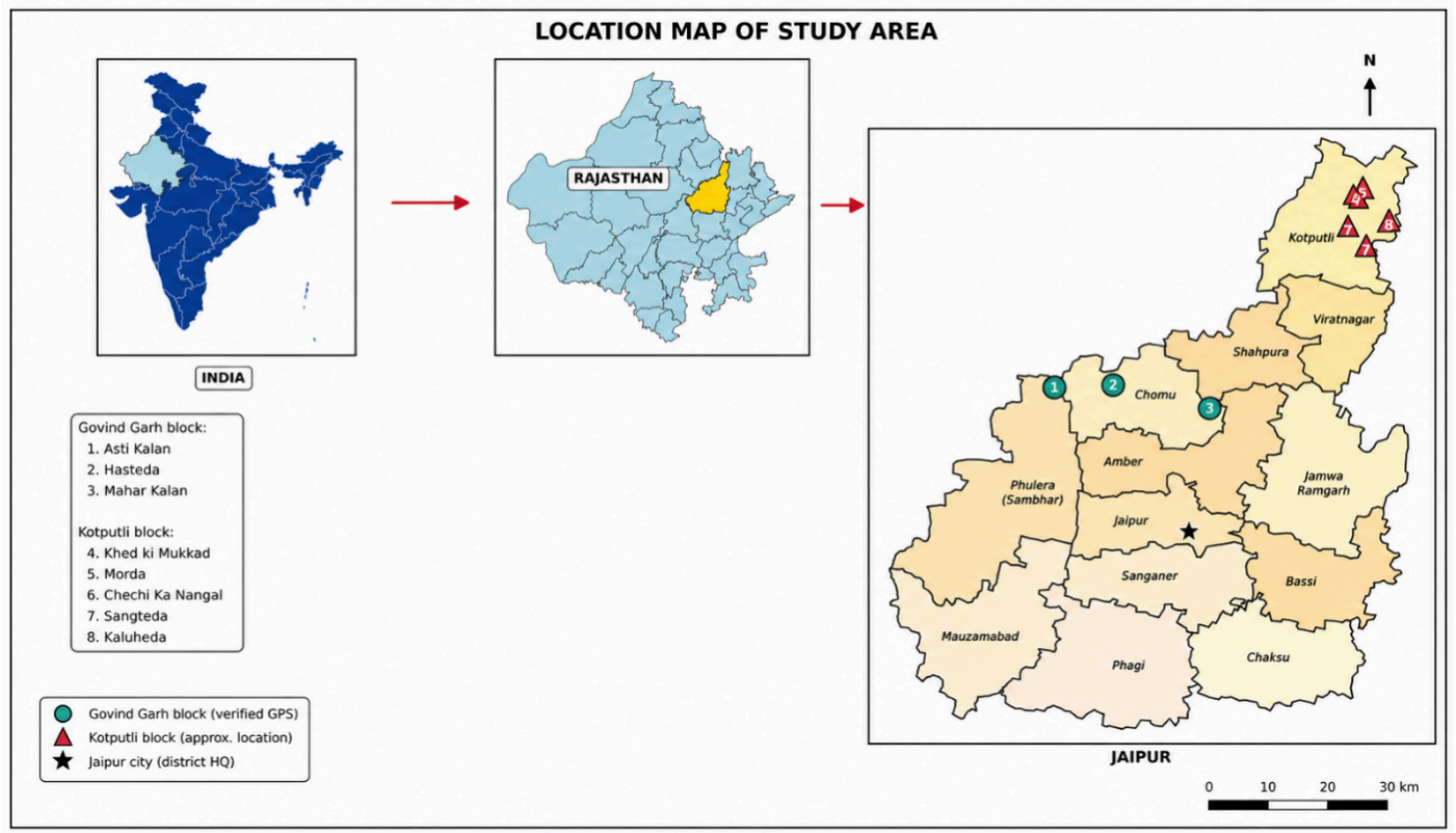


Figure 1. Location map of the study area

Figure 1

Geographical location of the study area in Jaipur district, Rajasthan, India

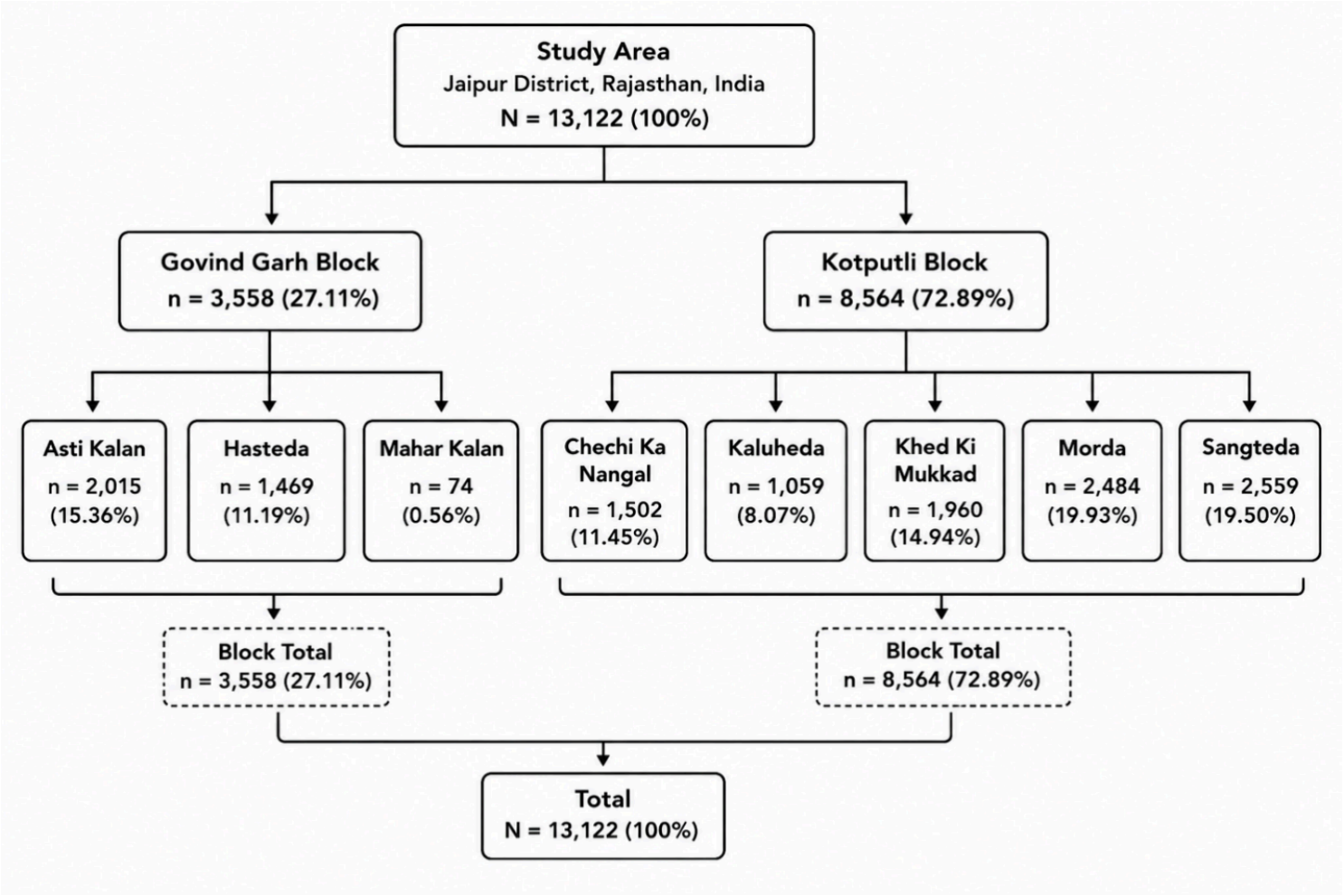


Figure 2

Flow diagram showing the distribution of study participants across the selected villages in Jaipur district, Rajasthan, India.