

Assessment of Intra-Household Tuberculosis Transmission: Predictors and Correlates of Risk Factors in India

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Abstract

Household contact tracing is important for tuberculosis (TB) detection to tackle global TB concerns, yet nationally representative evidence remains limited on household-level determinants of TB transmission in India. This study examined the household-level factors like socioeconomic, demographic, behavioural, and environmental predictors of TB burden and transmission in India. Using the NFHS-5 (2018–19) dataset, households were categorised by TB case burden (single case vs. two or more cases), and TB case clustering was used as a proxy for intra-household transmission. Multinomial logistic regression was used, yielding relative risk ratios; ordered logistic regression (partial proportional odds model) was used for sensitivity analysis. A concentration index was used to assess wealth-based inequity in TB distribution. Poverty independently raised TB odds (BPL households, OR 1.114, $p < 0.01$), while wealth (OR 0.773) and higher household-head education (OR 0.527, $p < 0.01$) were protective. Crowding showed the strongest gradient: households of seven or more members had nearly fivefold higher odds of multiple TB cases (OR 4.486, $p < 0.01$; PPOM OR 4.982). Household heads aged ≥ 55 years (OR 2.872), three or more smokers (OR 1.862), and multiple alcohol users (OR 1.278, $p < 0.01$) were associated with elevated risk. Multi-case TB was higher in the Northeast (OR 1.925) and South India (OR 2.576; $p < 0.01$), while aspirational districts paradoxically showed lower single-case odds (OR 0.792), suggesting underdiagnosis. Housing quality (OR 0.847), improved sanitation (OR 0.876), and cleaner cooking fuel (OR 0.622) were protective. Female-headed households had lower single-case odds (OR 0.789, $p < 0.01$), an effect that attenuated for multi-case TB. TB transmission in India reflects intersecting axes of poverty, crowding, age, behavioural risk, geography, and gender, confirming TB as a disease of social inequity. Meeting NSP 2017–2025 targets require shifting from individual case management to household-centric, socially stratified surveillance, alongside structural interventions that address housing, poverty, and behavioural risk.

Introduction

Tuberculosis (TB) continues to be a widespread infectious disease of global importance. Hence, elimination of tuberculosis is considered a prime target (3.3) under the United Nations Sustainable Development Goals (SDGs) by 2030 to ensure healthy lives for all. According to estimates, India bears the highest burden, accounting for a quarter (27%) of global cases (1) despite having only 17% of the world's population. Despite significant advances in its diagnosis and treatment, millions of deaths occur globally every year. In 2024, due to TB, 1.23 million deaths were reported, which was second in the number of deaths after HIV related death tolls (1.50 million deaths) (1). Sensing the gravity of TB disease, the Government of India has implemented Directly Observed Treatment, Short-Course (DOTS), endorsed by the World Health Organisation, to counter TB as part of its revised National Tuberculosis Control Program (RNTCP) in 1997 (2, 3). However, since its inception, this program has experienced fluctuations in its implementation to control TB. Hence, the government of India revised it in 2020 as the National TB Elimination Program (NTEP) to emphasise its aim of eliminating TB by 2025, 5 years earlier than the SDG global targets. This program has a multi-pronged strategy, as emphasised by the National Strategic Plan 2017–2025, under 4 strategic pillars: “Detect-Treat-Prevent-Build” (DTPB), which is based on its actions in active case detection, early diagnosis, free treatment, and digital surveillance systems. Moreover, to improve treatment outcomes and community mobilisation initiatives, it implemented under the “Pradhan Mantri TB Mukh Bharat Abhiyan, 2022,” and nutritional support is being implemented through “Nikshay Poshan Yojana, 2018.” (4). Despite years of sustained interventions, TB remains a major public health challenge in India, which emphasises the need for more substantial efforts to end the TB epidemic (5). It has been underscored that the risks of infection and disease progression are distinct, and a proper understanding of both is essential for planning TB control strategies. (6).

The risk of TB is not solely biological, but the influence of socioeconomic-environmental determinants like poverty, undernutrition, overcrowding, and poor housing that shape vulnerability and transmission at the household level (7–9). Understanding household-level determinants of TB is particularly important, as it is deeply rooted in socially and environmentally disadvantaged households (6, 10, 11). Previous studies reveal that poor households bear manifold more burden of TB compared to affluent households. Poor household environments characterised by overcrowding, poor ventilation, substandard housing, improper garbage disposal, poor drainage, and reliance on solid fuels facilitate the airborne transmission of *Mycobacterium tuberculosis* (8). The geographical location of the place of residence plays a significant role in TB transmission and treatment outcomes, as it poses challenges due to an unstructured health infrastructure. For example, the rural parts of India show significantly higher TB prevalence rates compared to urban areas. Further, the TB treatment success rate is 15–20% lower in rural areas under the Revised National Tuberculosis Control Programme, which contributes one-fourth of the rural-urban disparity in the TB incidence rate (12).

Concurrently, low educational attainment, food insecurity, malnutrition, and barriers to healthcare access contribute to delayed diagnosis, poor treatment adherence, and worse outcomes (13). Following caste-based disparity in the TB burden shows India's structural social hierarchies. Scheduled caste (SCs) and Scheduled tribe (STs) experience an unevenly higher TB burden compared to other social groups (14). These disparities are mediated through multiple interpersonal and behavioural pathways, such as tobacco use and alcohol consumption among household members, which further compound susceptibility to active illness (15). These pieces of evidence suggest a need for a comprehensive assessment of questions such as: what structural, environmental, and behavioural conditions enable TB transmission within a shared living space or at the intra-household level? In this context, the present study aimed to examine the prevalence, pattern, and determinants of TB among patients at the household level. Also, try to assess wealth-related inequality in intra-household TB transmission. Insights derived from this study are critical for refining India's TB elimination strategy and accelerating progress toward a TB-free India.

Methodology

Data

The present study used the fifth wave of the cross-sectional National Family Health Survey (NFHS-5, 2019-21). This nationally representative survey provides estimates on key indicators related to population, health, and nutrition at the district level for India and each state/Union territory. It employs a multistage stratified sampling design, considering urban and rural areas as natural strata. The survey sampling frame was created using the 2011 census to select Primary Sampling Units (PSUs) - villages in rural areas and Census Enumeration Blocks (CEBs) in urban areas. The selection of PSUs from both strata, rural

and urban, was conducted using the probability proportional to size (PPS) method based on the survey sampling frame. The survey sampled 636,699 households from 653,144 occupied households, yielding a response rate of 98%. The study used the individual file (IAPR7AFL) from this dataset and collapsed it to the household level to obtain a larger number of contextual indicators for comprehensive analysis.

Variables used

Response variables

In the data set, information on self-reported point-prevalence type for Tuberculosis. So, the question was asked of respondents in the household questionnaire: "Does any usual resident of your household, including you, suffer from tuberculosis?" To meet the study objective, the response to this question was initially recorded and converted to a TB count (0 = No TB patient, 1 = 1 TB patient, and 2 = More than 1 TB patient).

A household with more than 1 TB patient is used as a proxy for its TB transmission environment. This scenario is a systematic failure of all four pillars of India's National Strategic Plan, such as 1. "Detect": late detection/diagnosis of the case creates an infectious (transmission) environment for household contacts. 2. "Treat" - incomplete treatment or delayed treatment initiation of the index case permitted ongoing transmission during the infectious period. 3. "Prevent" - failed implementation of TB prevention/isolation measures exposed family members to the TB risk. 4. "Build" - insufficient capacity buildup (such as contact investigation protocols and community health worker training) of the health system weakens the intervention.

Predictor variables

Following conceptualised contextual factors based on previous studies considered for this study are as: sex of the household head (male/female), age of household head (< 15 years, 15–59 years and 60 and above), Household head's educational attainment (no education, up to primary, up to secondary and higher), Overcrowding, Number of dependents, Housing Quality Index (based on material of used for flooring, wall and roof), Wealth quantile, Below Poverty Line status, Number of HH members who smoke, Source of Drinking Water, Toilet Facility, Place of residence (rural/ urban), Type of fuel used for cooking (non- solid and solid), Availability of kitchen (yes/no).

Method: Statistical analysis

As a first step, a descriptive analysis was conducted to examine the prevalence of tuberculosis (TB) across background characteristics, household head, and household-environment risk factors. Thereafter, two complementary regression approaches were conducted to assess prominent factors at the household level for TB transmission that are mentioned below:

1. Multinomial logistic regression: this regression method is the primary method to treat the three-category outcome (0-No; 1-One TB case; 2-Two or more TB cases) at the nominal level. The model estimated relative risk ratios (RRR) comparing each category to the reference (0-No TB), using the specification:

$$\ln[P(Y_i = j)/P(Y_i = 0)] = X_i\beta_j$$

Y_i represents the TB outcome for household i , X_i is the vector of covariates, and β_j denotes the category-specific coefficients.

This approach provides a novel contribution by identifying a prominent factor that shifts risk from 0 to 1 case versus 0 to ≥ 2 TB cases (i.e., determinants of transmission beyond the index case) within households. Further, since the response variable has an ordered nature of household TB burden, the Hauman test is not applicable.

2. Generalised ordered logistic regression: as the response variable has natural ordered categories (grouped from a continuous variable increasing TB burden in the household), we conducted sensitivity analysis using it to validate our multinomial results. This regression model was estimated using the partial proportional odds model (PPOM) framework. The 'gologit2' command with the 'autofit' option was employed to relax the restrictive proportional odds (parallel lines) assumption of the standard ordered logit model by allowing selected covariates to have category-specific effects while constraining others to remain constant across outcome thresholds, allowing for more flexible estimation.

Formally, let Y denote the ordinal outcome with J ordered categories ($j = 1, 2, \dots, J$). The generalised ordered logit model is specified as:

$$\text{logit}[P(Y \leq j)] = q_j + X\beta + Z\gamma_j, j = 1, \dots, J - 1$$

where:

- $P(Y \leq j)$ is the cumulative probability of being in category j or below,
- q_j represents category-specific intercepts (cut-points),
- X is the set of covariates that satisfy the proportional odds assumption (with constant coefficients β),
- Z is the set of covariates that violate the proportional odds assumption, with coefficients γ_j varying across thresholds.

The statistical analysis was conducted in MS Excel and Stata 17 (StataCorp, College Station, Texas).

Results

The bivariate analysis elucidating the household burden of tuberculosis (TB) by socioeconomic factors is presented in Table 1. Households were classified into three categories: those with no TB cases, those with 1 TB case, and those with 2 or more TB cases at the time of the survey. The overall prevalence of TB was found to be 1% among households with one TB case. In contrast, households with multiple TB cases, as a proxy of intra-household transmission of TB, exhibited a prevalence of 0.03%. Among the social determinants, it was observed that Hindu and Muslim households experience a lower burden of TB, with prevalence rates of 0.89% and 0.91%, respectively; in contrast, households of other religion reported a TB prevalence of 1.6%, surpassing the national average and accounting for over one-fifth (21.3%) of the overall TB burden despite constituting only one-tenth of the total household population. Furthermore, intra-household transmission of TB, as indicated by the presence of more than one TB case within a household, shows a higher transmission rate in households of other religions (0.08%) than in Hindu (0.03%) and Muslim (0.02%) households. An increase in the educational attainment of the household head correlates with a decrease in both the prevalence and transmission rates of TB. Similarly, the percentage share, prevalence, and transmission rates of TB were observed to be higher among scheduled castes, scheduled tribes, and rural resident households relative to the other caste and urban counterparts. Upon examining economic factors, it was found that households in the lowest wealth tertile and classified as below the poverty line showed a higher prevalence of TB than their more affluent counterparts, along with a higher share of the TB burden relative to their population share.

[Table 1 about here]

Demographic factors associated with household TB prevalence and the percentage distribution of households by number of TB patients in India are shown in Table 2. In the classification of households by demographic characteristics, it was found that a substantial majority (83%) are male-headed, with female-headed households comprising a scant 17%. Households with TB patients account for 86% of male-headed households. In contrast, only 14% of households with TB patients are female-headed, indicating a higher prevalence of TB among male-headed households in comparison to their female-headed counterparts. This trend is consistent for both households with a single TB patient and those with multiple TB patients. The age of household heads reported that approximately 47% were headed by younger adults (aged 35 to 45 years), who bear a lower TB burden (44%); conversely, households led by the elderly had a higher proportion of TB cases (approximately 45%). In contrast, households with four or more dependents, while representing a smaller share (9%), carried a greater burden (14%) of all TB cases, with a prevalence rate (1.52%) and transmission rate (0.08% for households with two or more TB cases) that surpassed those of households with fewer than four dependents.

[Table 2 about here]

Household environment and medical risk factors for household TB prevalence, and the percentage distribution of households by number of TB patients in India, 2018-19, are shown in Table 3. Households that rely on smoke-emitting cooking fuels, have substandard housing, lack proper sanitation facilities, include members who smoke or drink alcohol, and have poor water infrastructure face a higher prevalence and spread of TB compared to others. Analysing households by region reveals that those in non-aspirational districts and the northeastern part of India experience a notable TB burden and transmission rates.

[Table 3 about here]

To effectively curb TB transmission in India, it is essential to implement multi-sectoral strategies that promote healthy living conditions, improve socio-economic equity, and ensure risk-free medical practices, as it is observed that a significant portion of Indian households are in non-aspirational districts (85%), have smokers (more than half), belong to the lower wealth tertile (nearly 50%), are situated in rural areas (74%), fall below the poverty line (49%), and are in the poor wealth tertile (45%) (Tables 1, 2, and 3).

Figure 1 illustrates a higher concentration of TB cases among populations in lower-wealth groups. Half of all TB cases occur in just 40% of the population. In contrast, only 10% of the TB burden is associated with the top wealth category, which accounts for one-fifth of the population. This indicates that TB disproportionately affects poorer households.

[Figure 1 about here]

Table 4 presents multinomial odds ratios for risk factors for Household Tuberculosis Outcomes to analyse the key determinants of TB prevalence (households with a single TB case) and intra-household transmission of TB (households with multiple TB cases). Female-headed households show significantly lower odds of TB prevalence compared to male-headed households; however, intra-household TB transmission does not differ significantly between male and female-headed households. In contrast to households led by individuals under 34 years, households headed by those aged 35-54 and those 55 and older are more prone to having a single TB case and possess greater chances of intra-household TB transmission. Social groups and religion are not significantly different in terms of household TB prevalence and transmission among the socio-economic factors. Households with more educated heads, those in aspirational regions, urban settings, and higher wealth tertiles above the poverty line show greater odds of TB prevalence than their counterparts, and as education levels rise, the odds of TB prevalence in these households decrease compared to those with illiterate heads; nevertheless, these social factors do not significantly influence intra-household transmission. In the context of household environment and personal risk factors, larger family sizes, a greater number of dependents (four or more), overcrowded homes, households with alcoholics, and those with smokers show higher chances of having at least one TB case. However, only households with larger family sizes, compared with those with just three members, show significantly higher odds of intra-household TB transmission. Among households with various amenities, better cooking fuels, and sanitation facilities, a high housing quality index is associated with a reduced likelihood of TB and its spread among family members. Households in the Northeast and the South have a higher risk of intra-household TB transmission, with the South showing particularly high odds.

Thus, lower socio-economic status, inadequate household conditions and facilities, and family members engaged in high-risk behaviours increase the likelihood of TB prevalence. Additionally, factors such as the use of high-smoke-emitting cooking fuels, family sizes exceeding three, and residence in the northeast and south regions significantly increase the odds of TB transmission within families.

[Table 4 about here]

To confirm our analysis, ordered logit regression has also been applied, with the results presented in Table 5. Both multinomial and ordered logit regression results reveal comparable findings regarding the factors influencing the prevalence of a single TB case in households. Nonetheless, the increased prevalence of TB within a household as an indicator of intra-household TB transmission highlights that enhanced sanitation, such as using clean fuel, having superior toilet facilities, a better housing quality index, minimal risk factors like non-smokers and non-drinking members, along with a more educated head, significantly contributes to curtailing TB transmission among family members in the household, alongside the factors identified through the multinomial odds ratio.

[Table 5 about here]

Table 1: Socio-economic factors to household TB prevalence and percentage distribution of households by number of TB patients in India, 2018-19										
Socio-economic factors	Households	% share	Total households with TB Patients		No TB Case		1 TB case		Two or more TB cases	
			N	Prevalence (%)	N	Prevalence (%)	N	Prevalence (%)	N	Prevalence (%)
Total	6,36,699	100.00	6,457	100	6,30,242	100.00	6,244	1.00	213	0.03
Wealth Index										
Poor	289924	45.54	3878	60.1	286046	98.66	3747	1.29	131	0.05
Middle	129057	20.27	1212	18.8	127845	99.06	1173	0.91	39	0.03
Richer	217718	34.19	1367	21.2	216351	99.37	1324	0.61	43	0.02
BPL Status										
No	326702	51.31	2739	42.4	323963	99.16	2648	0.81	91	0.03
BPL	309997	48.69	3718	57.6	306279	98.8	3596	1.16	122	0.04
Place of Residence										
Rural	476561	74.85	5187	80.3	471374	98.91	5017	1.05	170	0.04
Urban	160138	25.15	1270	19.7	158868	99.21	1227	0.77	43	0.03
Educational Level of Household Head										
No education	189668	29.79	2559	39.6	187109	98.65	2470	1.3	89	0.05
Primary	117812	18.50	1412	21.9	116400	98.8	1365	1.16	47	0.04
Secondary	269109	42.27	2198	34	266911	99.18	2132	0.79	66	0.02
Higher	60110	9.44	288	4.5	59822	99.52	277	0.46	11	0.02
Household Head Religion										
Hindu	482073	75.71	4403	68.2	477670	99.09	4270	0.89	133	0.03
Muslim	72584	11.40	678	10.5	71906	99.07	662	0.91	16	0.02
Others	82042	12.89	1376	21.3	80666	98.32	1312	1.6	64	0.08
Household Social Group										
SCs/STs	246445	38.71	3246	50.3	243199	98.68	3120	1.27	126	0.05
OBCs	233919	36.74	2018	31.3	231901	99.14	1965	0.84	53	0.02
Others	156335	24.55	1193	18.5	155142	99.24	1159	0.74	34	0.02

Table 2: Demographic factors to household TB prevalence and percentage distribution of households by number of TB patients in India, 2018-19

Demographic factors	Households	% share	Total households with TB Patients		No TB Case		1 TB case		Two or more TB cases	
			N	Prevalence (%)	N	Prevalence (%)	N	Prevalence (%)	N	Prevalence (%)
Sex of Household Head										
Male	527220	82.8	5538	85.8	521682	99.0	5355	1.02	183	0.03
Female	109479	17.2	919	14.2	108560	99.2	889	0.81	30	0.03
Age of Household Head										
Less than 34 Years	96493	15.2	720	11.2	95773	99.3	703	0.73	17	0.02
35-54 Years	298619	46.9	2860	44.3	295759	99.0	2756	0.92	104	0.03
55+ Years	241587	37.9	2877	44.6	238710	98.8	2785	1.15	92	0.04
Dependent Members in Household										
Nil	180903	28.4	1550	24	179353	99.1	1518	0.84	32	0.02
One	167501	26.3	1663	25.8	165838	99.0	1610	0.96	53	0.03
Two	153004	24.0	1417	21.9	151587	99.1	1365	0.89	52	0.03
Three	79125	12.4	932	14.4	78193	98.8	899	1.14	33	0.04
Four or more	56166	8.8	895	13.9	55271	98.4	852	1.52	43	0.08
Household Size										
0-3 members	211380	33.2	1733	26.8	209647	99.2	1695	0.8	38	0.02
4-6 members	338143	53.1	3376	52.3	334767	99.0	3268	0.97	108	0.03
7+ members	87176	13.7	1348	20.9	85828	98.5	1281	1.47	67	0.08

Table 3: Household environment and medical risk factors to household TB prevalence and percentage distribution of households by number of TB patient:

Household Environment and Medical Risk Factors	Households	% share	Total households with TB Patients		No TB Case		1 TB case		Two TB cases
			N	Prevalence (%)	N	Prevalence (%)	N	Prevalence (%)	N
Overcrowded Household									
No	496095	77.92	4795	74.3	491300	99.03	4641	0.94	154
Yes	140604	22.08	1662	25.7	138942	98.82	1603	1.14	59
Type of Cooking Fuel									
Smoke	302070	47.44	3758	58.2	298312	98.76	3625	1.2	133
Improved	334629	52.56	2699	41.8	331930	99.19	2619	0.78	80
Source of Drinking Water									
Not	287090	45.09	3227	50	283863	98.88	3128	1.09	99
Improve	349609	54.91	3230	50	346379	99.08	3116	0.89	114
Type of Toilet Facility									
No toilet	115137	18.08	1505	23.3	113632	98.69	1450	1.26	55
Improved toilet	521562	81.92	4952	76.7	516610	99.05	4794	0.92	158
Housing Quality Index									
Low	316887	49.77	4085	63.3	312802	98.71	3947	1.25	138
High	319812	50.23	2372	36.7	317440	99.26	2297	0.72	75
Aspirational District Region									
Non aspirational	543244	85.32	5771	89.4	537473	98.94	5577	1.03	194
Aspirational	93455	14.68	686	10.6	92769	99.27	667	0.71	19
NFHS Geographic region									
North	121888	19.14	884	13.7	121004	99.27	860	0.71	24
Central	138812	21.80	1119	17.3	137693	99.19	1095	0.79	24
East	103351	16.23	1346	20.8	102005	98.7	1299	1.26	47
Northeast	94510	14.84	1684	26.1	92826	98.22	1614	1.71	70
West	65543	10.29	483	7.5	65060	99.26	473	0.72	10
South	112595	17.68	941	14.6	111654	99.16	903	0.8	38
Medical risk factors									
Smokers in the household									
None	275842	43.32	1824	28.2	274018	99.34	1770	0.64	54
One	234694	36.86	2408	37.3	232286	98.97	2334	0.99	74
Two	90493	14.21	1453	22.5	89040	98.39	1403	1.55	50
Three or More	35670	5.60	772	12	34898	97.84	737	2.07	35
Alcohol user in the household									
None	436691	68.59	3756	58.2	432935	99.14	3642	0.83	114
One	157822	24.79	1929	29.9	155893	98.78	1863	1.18	66
Two	32366	5.08	543	8.4	31823	98.32	522	1.61	21
Three or More	9820	1.54	229	3.5	9591	97.67	217	2.21	12

Table 4: Multinomial Odds Ratios of Risk Factors for Household Tuberculosis Outcomes in India, 2018-19

Repressors	One TB prevalence in the household	95% CI	> 1 TB prevalence in the household (intra-household transmission proxy)	95% CI
Reference: Non-TB households				
Sex of Household Head				
Male ^R				
Female	0.789***	[0.704 - 0.884]	0.718	[0.365 - 1.413]
Age of Household Head				
Less than 34 Years ^R				
35-54 Years	1.272***	[1.124 - 1.440]	2.239**	[1.115 - 4.496]
55+ Years	1.618***	[1.420 - 1.843]	2.872***	[1.349 - 6.115]
Education level of HH				
No education ^R				
Primary	0.876***	[0.795 - 0.965]	0.679	[0.404 - 1.141]
Secondary	0.730***	[0.666 - 0.800]	0.727	[0.438 - 1.207]
Higher	0.527***	[0.423 - 0.657]	1.287	[0.515 - 3.218]
Dependent Members in Household				
Nil ^R				
One	1.101*	[0.991 - 1.223]	0.963	[0.529 - 1.752]
Two	0.925	[0.818 - 1.045]	0.918	[0.468 - 1.802]
Three	1.084	[0.940 - 1.249]	1.201	[0.616 - 2.343]
Four or more	1.209**	[1.040 - 1.405]	1.397	[0.668 - 2.921]
Overcrowded Household				
No ^R				
Yes	1.247***	[1.144 - 1.359]	1.053	[0.702 - 1.578]
Household size				
1-3 members ^R				
4-6 members	1.123**	[1.007 - 1.253]	2.126**	[1.139 - 3.971]
7+ members	1.380***	[1.187 - 1.604]	4.486***	[2.181 - 9.227]
Religion of the Household Head				
Hindu ^R				
Muslim	1.034	[0.912 - 1.172]	0.802	[0.374 - 1.716]
Others	1.103	[0.946 - 1.287]	1.153	[0.602 - 2.210]
Social Group				
SCs/STs ^R				

OBCs	0.948	[0.872 - 1.030]	0.754	[0.474 - 1.198]
Others	0.927	[0.826 - 1.041]	1.072	[0.603 - 1.904]
Wealth Index				
Poor ^R				
Middle	0.832***	[0.743 - 0.932]	0.968	[0.520 - 1.804]
Richer	0.773***	[0.670 - 0.893]	0.82	[0.384 - 1.749]
BPL status				
No ^R				
BPL	1.114***	[1.033 - 1.202]	0.752	[0.517 - 1.093]
Place of Residence				
Rural ^R				
Urban	1.128**	[1.015 - 1.253]	1.135	[0.656 - 1.964]
Type of Cooking Fuel				
Smoke				
Improved	0.961	[0.876 - 1.053]	0.622*	[0.354 - 1.092]
Source of Drinking Water				
Poor ^R				
Improved	0.959	[0.881 - 1.044]	1.146	[0.720 - 1.825]
Type of Toilet Facility				
No toilet ^R				
Improved toilet	0.876***	[0.801 - 0.958]	0.748	[0.485 - 1.153]
Housing Quality Index				
Low ^R				
High	0.847***	[0.776 - 0.924]	0.679	[0.362 - 1.273]
Smokers in the Household				
None ^R				
One	1.317***	[1.190 - 1.458]	1.138	[0.657 - 1.974]
Two	1.618***	[1.427 - 1.834]	1.526	[0.782 - 2.977]
Three or more	1.862***	[1.600 - 2.166]	1.686	[0.820 - 3.467]
Alcoholic in the Household				
None ^R				
One	1.175***	[1.072 - 1.289]	1.237	[0.780 - 1.960]
Two	1.278***	[1.081 - 1.511]	1.514	[0.790 - 2.901]
Three or more	1.143	[0.884 - 1.477]	2.177	[0.837 - 5.660]
Aspirational District Region				

Non aspirational ^R				
Aspirational region	0.792***	[0.706 - 0.889]	0.909	[0.487 - 1.698]
NFHS Geographic region				
North ^R				
Central	0.799***	[0.707 - 0.904]	0.783	[0.369 - 1.663]
East	1.179**	[1.035 - 1.342]	1.533	[0.768 - 3.058]
Northeast	1.314***	[1.140 - 1.513]	1.925*	[0.936 - 3.958]
West	0.777***	[0.658 - 0.917]	0.447*	[0.192 - 1.041]
South	1.026	[0.891 - 1.182]	2.576***	[1.277 - 5.197]
Constant	0.008***	[0.007 - 0.010]	0.000***	[0.000 - 0.000]
Observations (N)	6,36,699			

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 5: Results of Partial Proportional Odds Model (PPOM) for Household prevalence and intra-household transmission of TB

Comparison						
Co-variables	No TB vs. (1 TB case & ≥2 cases)			(No TB & 1 TB case) vs. ≥2 TB cases		
	OR ₁	95% CI		OR ₂	95% CI	
Sex of Household Head						
Male ^R						
Female	0.787***	[-0.348	-0.130]	0.787***	[-0.348	-0.130]
Age of head of household						
Less than 34 Years ^R						
35-54 Years	1.289***	[0.133	0.375]	1.289***	[0.133	0.375]
55+ Years	1.638***	[0.368	0.619]	1.638***	[0.368	0.619]
Educational Level of Household Head						
No education ^R						
Primary	0.870***	[-0.233	-0.044]	0.870***	[-0.233	-0.044]
Secondary	0.730***	[-0.406	-0.224]	0.730***	[-0.406	-0.224]
Higher	0.543***	[-0.825	-0.395]	1.402	[-0.625	1.301]
Dependents Members in Household						
Nil ^R						
One	1.098*	[-0.011	0.197]	1.098*	[-0.011	0.197]
Two	0.925	[-0.197	0.040]	0.925	[-0.197	0.040]
Three	1.088	[-0.054	0.222]	1.088	[-0.054	0.222]
Four or more	1.215***	[0.049	0.341]	1.215***	[0.049	0.341]
Household size category						
01-03 ^R						
04-06	1.140***	[0.027	0.234]	2.117***	[0.219	1.281]
7+	1.430***	[0.215	0.501]	4.982***	[1.009	2.202]
Household Head Religion						
Hindu ^R						
Muslim	1.026	[-0.095	0.146]	1.026	[-0.095	0.146]
Others	1.104	[-0.049	0.246]	1.104	[-0.049	0.246]
Household Head Social Group						
SCs/STs ^R						
OBCs	0.942	[-0.141	0.021]	0.942	[-0.141	0.021]
Others	0.931	[-0.182	0.039]	0.931	[-0.182	0.039]
Wealth Index						
Poor ^R						
Middle	0.836***	[-0.292	-0.066]	0.836***	[-0.292	-0.066]
Richer	0.774***	[-0.397	-0.115]	0.774***	[-0.397	-0.115]
BPL status						
No ^R						
BPL	1.103***	[0.025	0.171]	1.103***	[0.025	0.171]

Place of Residence						
Rural ^R						
Urban	1.122***	[0.014	0.217]	1.122***	[0.014	0.217]
Aspirational District Region						
Non aspirational ^R						
Aspirational region	0.796***	[-0.335	-0.121]	0.796***	[-0.335	-0.121]
NFHS Geographic region						
North ^R						
Central	0.799***	[-0.341	-0.108]	0.799***	[-0.341	-0.108]
East	1.187***	[0.049	0.294]	1.187***	[0.049	0.294]
Northeast	1.328***	[0.148	0.419]	1.328***	[0.148	0.419]
West	0.770***	[-0.423	-0.099]	0.770***	[-0.423	-0.099]
South	1.059	[-0.075	0.189]	2.245***	[0.317	1.300]
Overcrowded Household						
No ^R						
Yes	1.242***	[0.133	0.300]	1.242***	[0.133	0.300]
Type of Cooking Fuel						
Smoke ^R						
Improved	0.954	[-0.137	0.042]	0.611**	[-0.944	-0.040]
Source of Drinking Water						
No improved ^R						
Improve	0.965	[-0.117	0.046]	0.965	[-0.117	0.046]
Type of Toilet Facility						
No toilet ^R						
Improved toilet	0.875***	[-0.221	-0.046]	0.875***	[-0.221	-0.046]
Housing Quality Index						
Low ^R						
High	0.846***	[-0.254	-0.081]	0.846***	[-0.254	-0.081]
Smokers in the household						
None ^R						
One	1.314***	[0.176	0.370]	1.314***	[0.176	0.370]
Two	1.618***	[0.365	0.598]	1.618***	[0.365	0.598]
Three or More	1.860***	[0.471	0.770]	1.860***	[0.471	0.770]
Alcoholic in the household						
None ^R						
One	1.177***	[0.074	0.251]	1.177***	[0.074	0.251]
Two	1.286***	[0.107	0.397]	1.286***	[0.107	0.397]
Three or More	1.186	[-0.069	0.410]	1.186	[-0.069	0.410]
_cons	0.007***	[-5.108	-4.694]	0.000***	[-9.729	-8.607]
Wald $\chi^2 = 1485.73$, $p < 0.001$						
Pseudo R ² = 0.0340						
Log pseudo-likelihood = -34327.896						

Discussion

The household is one potential context for improving TB infection screening and treatment. Household contact tracing is a pillar of TB disease detection (16). Hence, using a large-scale nationally representative dataset, we aimed to generate comprehensive evidence on household-level tuberculosis (TB) transmission patterns across India, based on different households' socioeconomic and environmental factors. Through a comprehensive analysis, the study identifies five important domains: poverty and socio-economic deprivation; household size and crowding; age-related reluctance in TB detection; substance use behavioural risk; and geographic inequity. All these domains are structured in the discussion below. These study findings closely align with and extend a substantial body of global and Indian evidence on the social determinants of TB.

The concentration of TB cases in the BPL households is the most consistent finding of this study, substantiating previous evidence that economic vulnerability increases every dimension of TB risk, from exposure to diagnostic delay. BPL households' status independently increased TB odds by 11.4% (OR: 1.114, $p < 0.01$; Table 4). This finding is consistent with a previous study that TB incidence follows the social gradient of poverty, mediated through malnutrition, overcrowding, and limited access to healthcare (17). Similarly, another study documented that low income is the single most powerful structural driver of TB burden at the national level (8). Richer households in this study show a substantially lower TB risk (OR: 0.773, $p < 0.01$ for single-case TB; Table 4), reinforcing the concentration index evidence that TB is inequitably distributed toward the economically marginalised. These results call for poverty-sensitive TB interventions aligned with India's NSP 2017–2025, which explicitly acknowledges the need to address the social determinants of TB (4).

Education is highly correlated with wealth, and this correlation also demonstrates a significant protective gradient. The highly educated household heads face dramatically lower odds of TB transmission (OR: 0.527, $p < 0.01$) compared to the uneducated (Table 4), consistent with previous findings that suggest education provides safeguards from TB risk through multiple mechanisms, including health literacy, care-seeking behaviour, and healthier housing (13). Whereas, illiteracy and low educational attainment not only reflect disadvantaged individuals but also structural barriers embedded in India's caste and gender hierarchies (14), particularly relevant for SC/ST households that bear a disproportionate share of the TB burden (50.3% of all TB households, Table 1).

The most striking finding of this study is the exponential increase in the risk of intra-household TB transmission with household size. Households with 7 or more members face an OR of 4.486 ($p < 0.01$) for multi-case TB (Table 4), an effect that strengthens to OR 4.982 in the PPOM sensitivity analysis (Table 5). This finding is consistent with a prior study that found that household contacts of TB-positive individuals have a 25–50% higher infection risk, which is particularly prevalent in crowded households. This TB transmission pattern is expected epidemiologically due to closeness and length of exposure from the index TB case for TB transmission to second TB cases in the household (18). Moreover, empirical evidence suggests that household size operates through multiple pathways for TB transmission, not only at the physical proximity level but also with shared utilities, delayed diagnosis, and index case isolation capacity (19). Rural households, which are more likely to be large, face a TB prevalence of 1.05% compared with 0.77% in urban areas (Table 1), further underscoring this spatial-structural nexus. These findings are also consistent with systematic review evidence by *Dodd et al. (2011)* in the *Bulletin of the World Health Organisation*, who estimated that 5–10% of household contacts of TB cases develop active disease, with higher rates in crowded, low-income settings (20).

Households' heads aged 55 years or older had 2.872-fold higher odds of reporting multiple TB cases (Table 4), suggesting a greater likelihood of clustering of TB cases in the household. It happens because older people often experience immunosenescence (21). Moreover, are reluctant to face a grievous situation. Evidence shows that older adults are more likely to harbour undiagnosed TB and have delayed diagnosis due to limited access to healthcare, social protection or pensions, living in congregate or multi-generational households and poor housing conditions (22). Moreover, if the index TB case is an elderly household head, the transmission of TB risk is more vulnerable because older adults are often diagnosed later due to their clinical manifestations being atypical and overlapping with age-related comorbidities, thereby prolonging the period of infectiousness within households (23, 24). This finding is particularly important in the Indian context, where 37.9% of household heads in the present sample were aged ≥ 55 years (Table 2), underscoring the need to prioritise elderly-headed households for active case finding, systematic household contact investigation, and early diagnosis under India's National Tuberculosis Elimination Programme.

The relationship between the number of household smokers and TB transmission represents a crucial behavioural finding of this study. Households with three or more smokers face an OR of 1.862 ($p < 0.01$) for single-case TB and a non-significant but elevated OR of 1.686 for multi-case TB (Table 4). This is consistent with the large evidence base linking tobacco smoking to TB susceptibility, which the study estimated smokers face a 2-3-fold increase in TB risk, with passive smoking also elevating household secondary attack rates (15). Therefore, *Slama et al., (2007)* argued that household smoking should be considered a community-level intervention target in national TB programs, not merely an individual lifestyle factor. India's current NSP does not adequately integrate tobacco cessation as a TB prevention strategy, a gap that this study's findings clearly reflected.

Alcohol use within the household similarly shows a graded association, with households reporting two alcohol users facing an OR of 1.278 ($p < 0.01$) for single-case TB (Table 4). In this context, a previous study identified alcohol use disorder as one of the top three risk factors for TB globally, mediating risk through immunosuppression, nutritional deficits, and reduced treatment adherence (26). In India, where alcohol use is socially linked to poverty and masculine gender identity, family alcohol use is a target for integrated TB-alcohol interventions.

The strikingly high multi-case TB odds in the Northeast (OR: 1.925, $p < 0.1$; Table 4) and South India (OR: 2.576, $p < 0.01$; Table 4) deserve particular policy attention. The Northeast finding is consistent with documented challenges of health system infrastructure, higher HIV co-infection rates, and ethno-tribal social structures that may delay care-seeking in this region. This finding is consistent with a previous study that indicates sub-national variation in TB case

notification rates across India, identifying the Northeast and Eastern regions as areas with persistently high disease burden (27). The South India finding is perhaps more counterintuitive, given that Southern states generally rank higher on human development indicators. However, the South's urban concentration, high HIV prevalence in Andhra Pradesh and Telangana, and relatively older age structure may contribute to higher intra-household transmission. This aligns with documented evidence that reveals TB transmission risk in urban South Indian settings is amplified by factors including slum density and TB-HIV co-infection (28). Moreover, the aspirational district designation, which reflects underdeveloped regions, is associated with lower odds of single-case TB (OR: 0.792, $p < 0.01$; Table 4). This apparent paradox likely reflects underdiagnosis rather than true lower burden. This phenomenon is documented with the help of estimated figures of TB notification gap in India, which is largest in precisely the most marginalised and geographically remote regions, where health system reach is weakest (29).

High housing quality independently reduces TB odds by 15.3% (OR: 0.847, $p < 0.01$; Table 4), consistent with the established evidence base on the built environment and TB. The empirical finding shows that poor housing quality, including a lack of ventilation, damp walls, and inadequate lighting, sustains airborne *M. tuberculosis* transmission by increasing aerosol concentration (30, 31). Access to improved toilet facilities is similarly protective (OR: 0.876, $p < 0.01$; Table 4), likely reflecting broader sanitation and hygiene behaviours that reduce infection risk. Previous studies found that poor sanitation was independently associated with TB incidence in India, even after controlling for crowding and poverty (32). The protective effect of improved cooking fuel approaches significance for multi-case households (OR: 0.622, $p < 0.1$; Table 4), reflecting the growing recognition that household air pollution from solid fuel combustion impairs lung immunity. A previous study estimated that exposure to biomass smoke doubles the odds of pulmonary TB, primarily through oxidative stress-induced impairment of alveolar macrophages (33).

Female-headed households show significantly lower odds of single-case TB (OR: 0.789, $p < 0.01$; Table 4), whereas the multi-case (transmission) coefficient is non-significant (OR: 0.718; Table 4). This gender differential may reflect lower rates of behavioural risk factors (smoking, alcohol) in female-headed households, earlier health-seeking behaviour, or differential household composition. However, it must be interpreted cautiously, as female household heads may themselves be at higher risk of diagnostic delay and underreporting due to gender-related stigma. The gender lens is further illustrated by the disproportionate presence of SC/ST households in the TB-affected population (50.3% of all TB cases, Table 1), a community in which women face compounded intersectional vulnerabilities. *Krishnan et al. (2014)* documented that Indian women with TB face significant stigma-driven delays in care-seeking, potentially masking their actual disease burden (14, 34). Hence, TB programs must adopt gender-transformative strategies to simultaneously address TB risk and gender-based barriers to care, a perspective directly aligned with India's NSP's call for gender-sensitive service delivery.

Conclusion

This study provides a nationally representative, household-level analysis of determinants of TB transmission in India. The dependent variable, categorised as households with a single TB case versus those with two or more cases, also serves as a proxy for intra-household transmission. Our multinomial logistic regression and partial proportional odds model consistently identify large household size, poverty, older household head age, and tobacco and alcohol use within the household as independent risk amplifiers for both TB occurrence and intra-household TB spread. Strikingly, households with 7 or more members face nearly a fivefold elevated risk of multiple TB cases. The related finding has direct operational significance for India's household contact investigation protocol.

The geographic heterogeneity documented in this study, with the Northeast and South disproportionately bearing the burden of intra-household transmission, suggests that India's TB program response must be spatially differentiated and context-sensitive. The concentration of TB in poor, BPL, SC/ST, and low-education households confirms that TB in India is fundamentally a disease of social inequity, and that biomedical interventions alone, without structural reforms addressing poverty, housing, and behavioural risk factors, will be insufficient to achieve the NSP 2017–2025 goal of reducing TB incidence by 80% and TB deaths by 90% by 2025.

Our findings call for a paradigm shift in India's TB program from individual case management to household-centred, socially-stratified risk surveillance. The NFHS-5 data, while cross-sectional, offer unparalleled representativeness and richness for such analysis, and our framework can serve as a replicable model for sub-national TB monitoring and equity assessment.

Limitations

This study has several important limitations that must be acknowledged when interpreting its findings. First, the NFHS-5 data are cross-sectional in design, precluding causal inference. Second, TB status in NFHS-5 is based on self-reports from household members, not on laboratory-confirmed diagnoses. This introduces the possibility of misclassification bias in both directions, i.e., under-reporting and over-reporting. Third, the operationalisation of intra-household transmission using the ≥ 2 -case threshold, while epidemiologically justifiable and consistent with the published literature, cannot fully distinguish between shared-source exposure (e.g., all household members exposed to the same extra-household source) and sequential within-household transmission. Molecular genotyping data, unavailable in NFHS-5, would be required to confirm transmission chains definitively. Finally, while the PPOM sensitivity analysis supports the main multinomial logistic regression findings for most covariates, the proportionality violations for some variables (notably cooking fuel and geographic region) suggest that their associations with TB outcomes may be threshold-dependent and should be interpreted with appropriate caution.

Policy Implications

The findings of this study have several direct and actionable implications for India's National Strategic Plan for Tuberculosis Elimination (NSP 2017–2025) and for the broader development policy agenda. Household Size as a Contact Investigation Risk Stratifier: Large household size emerges as a transmission risk elevator from the study. Hence, it should be formally incorporated into India's Revised National TB Control Programme (RNTCP) contact investigation risk stratification algorithm. Elderly-headed households further serve as a risk multiplier, indicating that community-based screening should be more focused on

them, particularly in high-burden districts. In this context, mobile TB diagnostic units should be deployed to senior citizen centres, rural health camps, and gram sabhas to reduce diagnostic delay in this vulnerable group. Findings confirm geographical disparities in TB Transmission Hotspots, so grey regions need to incorporate a geographic risk map to intensify the penetration of household TB management efforts for preventive therapy among household contacts. Further, paradoxically, a similar pattern is observed in aspirational districts, with lower odds of TB, which likely reflects a diagnostic gap rather than a true lower burden. Hence, there is an urgent need to verify and validate reporting data.

Declarations

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Author Contribution

The project was conceived by **AKY**, who conceptualised the study, contributed to the design of the methodology, and led the writing and critical revision of the manuscript **NSD** contributed to data curation, analysis, and interpretation of the results, and assisted in drafting sections of the manuscript. **VY** contributed to the literature review, validation of findings, and critical review and editing of the manuscript for important intellectual content. The final manuscript was read and approved by all writers.

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Data availability

The data used in this study are derived from the National Family Health Survey (NFHS-5), which operates under the Ministry of Family and Health Affairs, New Delhi, India. The data collection is conducted by the International Institute for Population Sciences, Mumbai. These data are publicly available upon request from the Demographic and Health Surveys (DHS) programme website (<https://dhsprogram.com>).

Ethics approval

This study is based on secondary analysis of publicly available, de-identified data from the National Family Health Survey (NFHS-5), which operates under the Ministry of Family and Health Affairs, New Delhi, India. The data collection is conducted by the International Institute for Population Sciences, Mumbai. As the study utilizes pre-existing, de-identified secondary data with no direct involvement of human participants, formal institutional ethical review and clearance were exempt/not required.

Consent to participate

Informed consent was obtained from all participants by the NFHS implementing agencies prior to data collection. The authors had no direct contact with survey participants.

Consent to publish

Not applicable, as the data is publicly available and does not include any identifiable individual data.

Competing interests

The authors declare no competing interests.

Clinical trial number: Not applicable.

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Figures

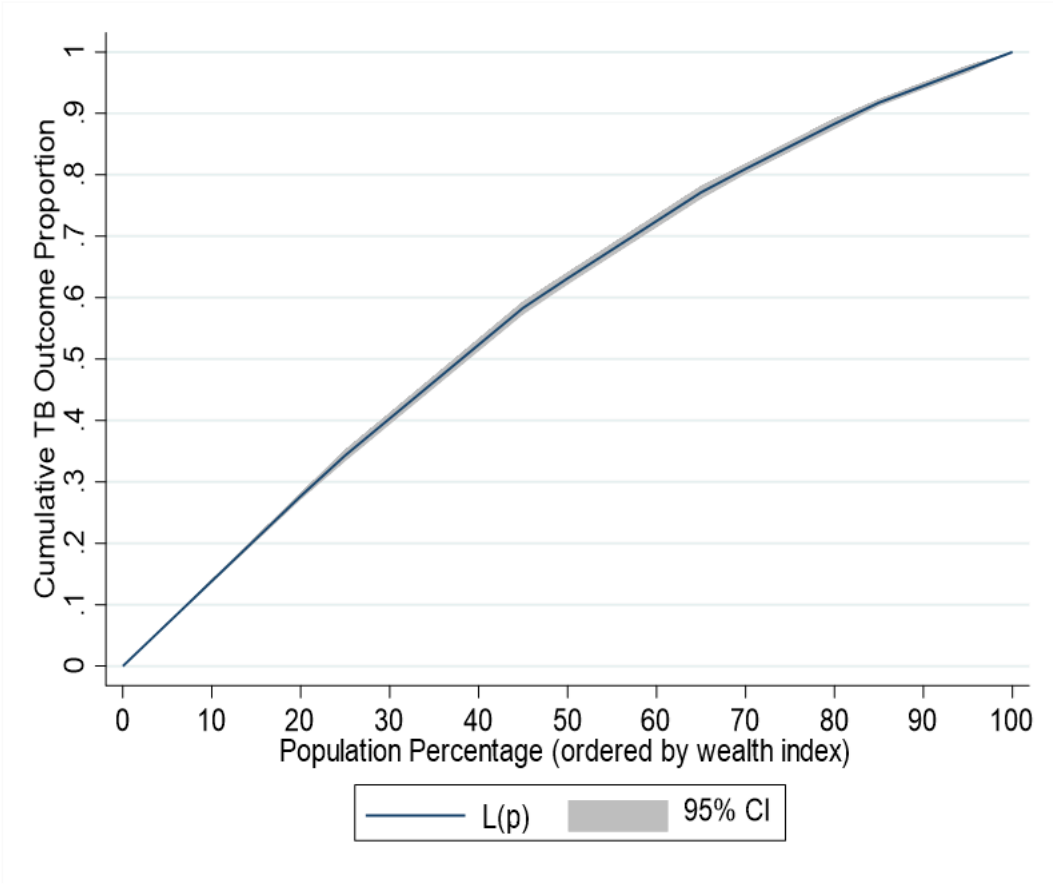


Figure 1

Concentration Curve Showing the Distribution of Tuberculosis Cases by Household Wealth Status"

"Concentration Curve of Tuberculosis Case Distribution Across Wealth Quintiles"