Long-term exposure to indoor air pollution and risk of tuberculosis

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Abstract

Indoor air pollution (IAP) is a recognized risk factor for various diseases. This paper examines the role of indoor solid fuel exposure in the risk of mycobacterium tuberculosis (TB) in Delhi Metropolitan, India. Using a cross-sectional design, subjects were screened for a history of active TB and lifelong exposure to IAP sources, such as solid fuel burning and kerosene. The TB prevalence rate in the study area was 1117 per 100 000 population. Every year, increase in solid fuel exposure was associated with a three percent higher likelihood of a history of active TB. Subjects exposed to solid fuel and kerosene use for both heating home and cooking showed significant associations with TB. Age, household expenditure (a proxy of income), lung function, and smoking also showed significant associations with TB. Smokers and solid fuel–exposed subjects were four times more likely to have a history of active TB than non-smoker and unexposed subjects. These finding calls strategies to mitigate solid fuel exposure, such as use of clean cookstove and ventilation, to mitigate the risk of TB which aligns with the United Nations' goal of "End TB by 2030."

1 | INTRODUCTION

Tuberculosis (TB), caused by *mycobacterium tuberculosis* (*M tb*), is the second most prevalent infectious disease[1,2] and accounts for about 1.5 million deaths annually.[3] Low- and middle-income countries (LMIC) bear disproportionately higher burden of TB mortality and morbidity.[4] Among LMIC, India has the highest incidence and prevalence rates of TB in the world.[5] Many factors are shown to increase the risk of activation from latent TB infection to clinically manifested active TB and its severity, including host immunity, exposure to smear-positive pulmonary TB patients, malnutrition, and socioeconomic and environmental exposure and risk behavior (eg, smoking, alcohol consumption, sexual behavior).[6–8]

Among environmental risk factors, air pollution is of particular interest not only because air pollutants, such as particulate matter (PM), can serve as carriers of airborne M.tb but also because it affects lung immunity by inducing oxidative stress and inflammation, and impairs the host's immunity.[9,10] Literature shows epidemiological associations between air pollution exposure and tuberculosis, including in India.[8,11–13] Although the mechanism of TB activation from air pollution is not fully understood,[14] it has been proposed that air pollution affects TB activation through altering lung immunity of the host due to chronic oxidative stress followed by inflammation.[15] Recent literature also shows that air pollution can cause accumulation of carbon in the bronchial tree, which increases the risk of TB by inactivating pulmonary macrophages.[16,17] Although air pollution has long been recognized as a health hazard since the 1952 London Smog,[18,19] LMIC countries account for more than 90% of the air pollution mortality burden, which does not include mortality due to TB.[20]

Given people spend most of their time indoors and a large number of households in LMIC continue to use solid fuel (including, coal, coke or wood, crop residue, and dung cake) for heating and cooking, indoor air pollution (IAP) from these sources is the main contributor of the total air pollution exposure. IAP is implicated in several diseases including cardiovascular disease, respiratory infections, chronic lung diseases, and even death.[21–30] However, the role of IAP in TB disease is inconsistent. For example, Slama et al reviewed 994 articles and only found 6 studies on association between IAP and TB. Only 3 of these 6 showed a positive association between IAP and TB.[31] Likewise, another study found a higher risk of liquid petroleum gas (LPG) exposure in Nepal rather than solid fuel. However, two other studies in Pune (India) and South Africa showed a higher prevalence rate of TB in homes with solid fuel exposure.[32,33] This inconsistency in the epidemiological association between TB risk and IAP is the likely reason that IAP is still not recognized as one of the risk factors for TB by the World Health Organization (WHO).[34] Using a large sample (n = 15 573), this research addresses this gap by quantifying the risk of TB with respect to short and lifelong IAP exposure in a megacity with hazardous levels of air pollution. Our central hypothesis is that current and long-term IAP exposure is associated with a history of active TB.

2 | MATERIALS AND METHODS

2.1 | Study setting

Using a cross-sectional design, data for this study were collected from Delhi Metropolitan, India. The city is home to 16.75 million people[35] and identified one of the most polluted cities in the world. The annual PM_{10} level in the city is as high as 268.6 μg/m,[36] five times higher than the WHO standards.[37] A significant number of homes in the city continue to use solid fuel (wood, crops, dung cake, and charcoal) for heating and cooking, which results in the elevated concentration of fine particulate matter.[38–41]

2.2 | Study definitions

History of TB disease was self-reported, which was cross-validated by the responses to the questions on the clinical assessment of the sputum culture, and other TB-related symptoms, including a history of hemoptysis, prolong cough. Data on latent TB were not collected for this study.

2.2.1 | Obstructive lung disease—Obstructive lung disease (OLD) was defined based on spirometry. A ratio of forced expiratory volume after one second (FEV_1) to forced vital capacity (FVC) < 0.7 was considered as OLD.[42]

2.2.2 | Indoor air pollution—Indoor air pollution (IAP) was defined if households primarily used solid fuel (that included wood, coke, coal, crop residue, and dung cake) or kerosene for cooking and heating purposes. Indoor air pollutants were not monitored in this study, rather pollution sources were used as proxy of exposure. Since the emission types from solid fuel are different from kerosene, both were also examined separately.

2.2.3 | Lifelong exposure—Individual survey module included questions on the history of cooking fuel use (see survey instrument in SOM, question I105 to I110). Using these data, the number of years of exposure to solid fuel and kerosene was computed, separately. Data on other covariates were also collected, such as separate kitchen in the house, exhaust fan in kitchen and its use while cooking, age, smoking, and gender.

2.3 | Data collection

Graduate students from Jawaharlal Nehru University (JNU), Delhi, and physicians with MBBS (Bachelor of Medicine, Bachelor of Surgery) degree were recruited to administer the surveys. Four teams were recruited, and each team consisted of a male and female interviewer, and one physician. All four teams worked simultaneously. All teams were trained to administer the survey, and physicians were trained to perform anthropometric measurement and pulmonary function tests using a handheld portable spirometer (MicroDL, Vyaire, USA). A standard protocol and coding system (SPCS) was developed and enforced. All teams participated in a pilot survey to learn and practice how to enforce the SPCS.

Two rounds of surveys were conducted in the Delhi metropolitan in 2004 and 2009. Households were drawn using a probabilistic sampling design. Details on sampling methodology and sample selection are provided elsewhere.[43] In the first round, 2000 random

points were simulated in the residential areas. The locations were navigated with the aid of a global position system (GPS). If a point was in a multiple housing units building (such as an apartment complex), a list of all households was created and one household was randomly drawn without replacement. Of the 2000 households around the simulated locations, 1576 households consented to participate in the study (a response rate of 78.8%). Location coordinates of the households were recorded. In 2009, 1496 households within 50-m distance of the homes, which participated in 2004, were recruited in order to capture subjects from the same areas.

A total 15 573 subjects participated in the study, and spirometry test and exposure history were restricted to subjects who were 15 years or older. Of the total 11 775 eligible subjects, 5257 (44.6%) consented to participate in the spirometry. The difference in the values of EFV_1 and FVC values (of the healthy subjects) of the handheld spirometer MicroDL and those from the office spirometer (Model #Mir, Spirolab 3) was less than 5%. Participants were paid Rupees 100 (US $1.55) each for their cooperation. The household locations in both rounds were recorded using GPS.

The survey included questions on TB, home environment, types of fuel used for cooking and heating, and life course history of exposure to those fuels. For TB, participants were asked "Has anyone in the household been diagnosed with active Tuberculosis?" If response was "Yes," subject was defined as a case, control otherwise. Follow-up questions concerning the clinical assessment of TB by sputum culture and associated symptoms, such as "coughing blood," were asked for the cross-validation of cases.

Questions concerning other risk factors, such as tobacco smoking and income, were also extracted. The data related to tobacco smoking were self-reported. In case a subject answered "Yes" to a smoking question, follow-up questions about the types and frequency of smoking were asked (see the survey instrument in the supplement online data [SOM]). The lifetime exposure to various types of cooking fuel including types of fuel used at different ages was recorded (see questions I105 through I110). Type of fuel was categorized into (1) solid fuel (coal, coke, dung cake, crop residue, and wood), (2) gas (or liquefied petroleum gas (LPG), (3) electric heater, (4) kerosene, and (5) others. Indoor and outdoor air pollutants were not directly measured. However, outdoor particulate matter 2.5 μm in aerodynamic diameter ($PM_{2.5}$) was estimated using a hybrid approach, which has been used for deriving $PM_{2.5}$ estimates in different parts of the world including Delhi Metropolitan.[44–47] Satellite-based aerosol optical depth (AOD) from MODerate resolution Imaging Spectroradiometer (MODIS) onboard Terra and Aqua satellite at 3-km spatial resolution were acquired from NASA from 2002 to 2009 for the study area.[48] These data were collocated with the meteorological data. An empirical model was developed between in situ monitored $PM_{2.5}$ at the American Embassy in New Delhi and collocated AOD, meteorological conditions, and seasonality. Using the parameter estimated from the empirical model, daily $PM_{2.5}$ was predicted from 2002 to 2009 and aggregated at 1-km spatial resolution (Figure 1). Using the local time-space Kriging, $PM_{2.5}$ was estimated at the location of each household and used in the final analyses.[49]

This study was approved by the Institutional Review Boards of Brown University and the University of Iowa (IRB approval #0810992578 and #IRB00000100, respectively). All methods were performed in accordance with the relevant guidelines and regulations. Informed verbal consent was obtained from each subject before enrollment in study. However, reasons for not participating in the study were not noted.

2.4 | Statistical analysis

Descriptive analyses were conducted to summarize outcome variable and associated risk factors. Univariate analysis was used to compare differences in demographic and clinical variables between subjects with and without a history of active TB. Comparisons were unpaired, and all tests of significance were two-tailed. Continuous variables were compared using Student's t test for normally distributed variables and Wilcoxon's rank-sum test for non-normally distributed variables. Since LPG is considered as a clean fuel, it was used as a reference compared to solid fuel and kerosene exposure. We used a multivariate logistic regression to examine risk of TB with respect to IAP adjusting for individual and household level confounders (logit function in STATA Ver 14.1[50] with cluster option, household being defined as the cluster). Interaction of exposure with smoking was used to assess their synergistic effect. Three models were run separately with all confounding variables. In Model 1, smoking and solid fuel exposure were included independently. In Model 2, smoking, solid fuel exposure, and their interaction were included. In Model 3, only the interaction of smoking and solid fuel exposure was included, as well as long-term outdoor exposure to $PM_{2.5}$. Potential confounders included in all three models were age, gender, lung function, and per capita household expenditure, which served as proxy of household income (see SOM for details and its justification).

3 | RESULTS

3.1 | Participants

Of the 15 573 subjects, who participated in the study, 174 (1.12%) had a history of active TB, a prevalence rate of 1117 per 100 000 population). Of these 174 cases, 138 (79.31%) also confirmed clinical assessment of their sputum culture. TB prevalence decreased significantly from 1.135% in 2004 to 0.97% in 2009 ($P < .05$). Figure 2 shows the flowchart of the study.

3.2 | Demographics

Subjects with a history of active TB were significantly older than those without TB (mean = 43.8 years ± 18.7 years [95% confidence interval (CI)] and 30.5 years ± 19.3 years; P value < .0001). Although more than half (8126; 52%) of subjects were females, the history of TB prevalence did not vary significantly by gender ($P = .760$).

3.3 | Univariate analysis of association between IAP and TB

The TB prevalence rate was 2.67% among subjects 60 years or older, who were 3.61 times more likely to have a history of active TB than those in the age-group of 15 to 30 years (95% CI: 2.25–5.81; $P < .01$) (Table 1). The probability of the TB risk with respect to duration of exposure to solid fuel among men and women in Delhi is shown in Figure 3. TB

prevalence was higher (n = 94,1.4%) among subjects who lived in homes without an exhaust fan as compared to those in homes with an exhaust fan (n = 79, 0.9%) (OR = 1.5, 95% CI: 1.6–3.48; $P <$ .001). The frequency of TB among those exposed to solid fuel from cooking and heating in their home was 2.1% (n = 36) as compared to 1% among unexposed (n = 137; OR = 2.36; 95% CI 1.6–3.48; $P <$ .0001). TB frequency also varied significantly with respect to household income, measured by household expenditure per capita. For example, frequency of TB was significantly higher among subjects in homes with <2000 Rupees (Rs.) (ie, ~US $30.00)/month per capita expenditure (n = 79, 1.6%) as compared to those with Rs. 2000–5000/month per capita household expenditure (n = 23, 0.56%) (OR = 0.3, 95% CI: 0.18–0.48; $P <$ .0001). The frequency of TB was almost two times higher among subjects exposed to kerosene during lifetime as compared to those unexposed (OR = 1.88, 95% CI 1,10–3.268, $P =$ .026) (Table 1). TB risk among past and current tobacco smokers was 3.27 and 2.88 times higher than among non-smokers, respectively (Table 1). TB was found to be higher in subjects with OLD (n = 11, 3.7%) than those without OLD (n = 91, 1.5%) (Table 1).

3.4 | Univariate analysis for association between IAP and OLD

OLD was found in 297 (4.5%) out of 6554 subjects who were tested with spirometer. There was a significant difference in the age of subjects with OLD in this cohort. 108 (8.9%) were 50 years or older (OR = 2.68, 95% CI: 2.09–3.42, $P <$ .0001). OLD did not differ significantly by gender. 135 (4.7%) and 164 (4.4%) subjects were female in OLD and non-OLD groups, respectively ($P =$ .49). There was no significant difference in the history of tobacco smoking between subjects with and without OLD (75, 4.9% vs. 222, 4.4%, $P =$ .42). However, there was a significant association between IAP exposure and diagnosis of OLD. 191 (5.5%) of subjects with OLD were exposed to IAP as compared to 103 (3.5%) unexposed subjects (OR = 1.61, 95% CI: 1.26–2.05, $P <$ .0001). Duration of solid exposure also showed a significant association active risk of TB. With every year, increase in solid fuel exposure was associated with 3% higher likelihood of a history of active TB (odds ratio: ~1.03, 95% CI: 1.02–1.04; $P <$ .01).

3.5 | Smoking and exposure interaction

Smoking and solid fuel exposure interaction was examined (see Table S2 and Figure S2 in SOM). Interaction of cooking fuel and smoking was insignificant, and interaction of solid fuel exposure and smoking was marginally significant (Figure S1B).

3.6 | Multivariate analysis

Three models were run separately for each cooking and heating exposure (Table 2).

3.6.1 | Cooking related solid fuel exposure—Results of Model 1 suggest that cooking solid fuel–exposed subjects and smokers were 95% and 80% more likely to have a history of active TB than unexposed subjects and non-smokers, respectively. When the interaction term (smoking × exposure) was introduced in Model 2, the odds values further increased for both smokers (odds ratio: 2.03; 95% CI: 1.05 to 3.07; $P <$ .001) and solid fuel exposure (odds ratio: 2.46; 95% CI: 1.24 to 4.79; $P <$ .001). However, their synergistic (or interactive) effect was insignificant as in Model 2. Household expenditure, age, and lung

function showed significant associations with a history of active TB, but it did not vary significantly by gender. Household income is a protective factor, for example, a unit increase in the log (per capita household expenditure (Rs.)) was associated with 30% less likelihood of a history of active TB (odds ratio: 0.73; 95% CI: 0.55–0.96; $P < .05$). In Model 3, the long-term ambient $PM_{2.5}$ exposure did not show a significant association with the history of active TB.

Solid fuel use for heating home was significantly associated with TB risk as well, for example, exposed subjects were 88% more likely to have a history of active TB than unexposed subjects (odds ratio: 1.88; 95% CI: 1.13 to 3.11; $P < .05$). Smokers had a 90% greater likelihood to have a history of active TB than non-smokers (odds ratio: 1.90; 95% CI: 1.1 to 3.2; $P < .05$). Introducing the interaction term in Model 2, all three terms (smoking, exposure, and smoking × exposure) were insignificant, suggesting autocollinearity among them canceling out each other's influence (ρ 0.1; P .05). However, when "smoking × exposure" is introduced independently without their main effects, smokers and exposed subjects were 4.1 times more likely to have a history of active TB than non-smokers and unexposed subjects (odd ratio: 4.14; 95% CI: 1.96 to 8.71; $P < .01$). In Model 3, lung function, age, and household expenditure also showed a significant association with the history of active TB. But ambient $PM_{2.5}$ and gender did not show associations with the history of active TB (Table 2).

3.7 | Uncertainty analysis

While 79% of the TB cases were identified based on the culture of their sputum, 21% (36 cases) were not, which can be susceptible to case misclassification. We conducted 100 simulations in which 50% of these non-sputum culture verified cases were randomly misclassified, and analyses were conducted on these misclassified cases and compared to the observed TB cases (Table 3). Although the TB risk of solid fuel exposure was slightly lower in the misclassified data, solid fuel exposure through cooking, heating, and heating and cooking still had a significant association with the history of active TB. For example, in the analysis of solid fuel exposure through cooking, the risk of TB was 66% higher among exposed subjects in the simulated data as compare to 93% in the observed data set. A similar trend was observed for solid fuel exposure through heating (Table 3).

4 | DISCUSSION

Our study shows that 1.12% of participants had a history of TB disease and a majority of them were sputum positive, and IAP exposure is an independent risk factor for TB. The World Health Organization (WHO) reports that almost half of the world's population cook and heat their home with open fire and unsafe stoves using different types of solid fuel, including animal dung, crop residue, wood, and coal.[51] According to WHO, IAP is associated with the risk of pneumonia, stroke, ischemic heart disease, chronic obstructive lung diseases, and lung cancer. However, IAP is not recognized as one of the risk factors of TB.[51]

A few studies evaluated the association between IAP and TB previously. Pokhrel *et al* conducted a hospital-based case-control study on 125 TB subjects compared with 250

matched controls in Nepal. They found that exposure to IAP was 3.4 times more common in TB cases than controls.[52] Slama *et al* reviewed 994 articles on the topics of IAP and TB and conducted a meta-analysis of 6 papers in 2010. Of these six studies, one included only urban area and the rest included both urban and rural areas. Three out of 6 papers showed a significant association between IAP and TB, and the rest did not, concluding insufficient evidence of the association between IAP and TB, and recommended for studies with larger sample size.[31] Of these six studies, one study included national data set on women from the demographic and health survey.[13] Slama's team conclusion was in the line with Hsien *et al* study that conducted another meta-analysis in 2007.[41] Since 2010, a meta-analysis showed a positive association between IAP and TB, which presented a systematic review of 13 papers.[40] In the pooled analysis of the selected 13 studies, this meta-analysis found 30% higher risk of TB for IAP-exposed subjects (OR 1.30 with CI, 1.04–1.62 and *P* value = .02). A recent case-control study from South Africa found that TB was more common in 30% of the homes which used solid fuel.[32] However, a recent study, conducted in Nepal, shows a lower risk of active TB among households using solid fuel as compared to those using LPG.[53] Given this study was conducted based on self-reported data, it is important to use direct measures of different air pollutants to conduct epidemiological studies of the health effects of IAP.[33]

Likewise, a review of literature suggests that there is inconsistency in the association between outdoor air pollution and TB. A literature search by key terms "tuberculosis" and "ambient air pollution" in PubMed yielded 41 articles. Of these 42, five article presented empirical data on the association between tuberculosis and outdoor air pollution (or proximity sources). Two of these five were conducted in the United States (North Carolina and Los Angeles)[8,54] and the remaining three in Asia.[11,55,56] A study in Seoul Metropolitan areas suggested that citywide PM_{10}, O_3, CO, and NO_2 did not show any association with smear-positive TB cases, but inter-quartile range of SO_2 showed a significant association with TB in only males[11] but not in women. However, the study conducted in LA showed no association between proximity to pollution sources (freeways and major arterial roads), but outdoor residential $PM_{2.5}$ exposure showed a significant association with smear-positive TB cases.[54] Study in Beijing and Hong Kong showed associations between seasonal changes in $PM_{2.5}$ smear-positive TB cases.[56] The sample size of most of these studies was small, and most of these studies lacked direct measurements of air pollution. Moreover, outdoor air pollution represented a small fraction of the total air pollution exposure, given people spend 90% of their time indoors. Thus, the possibility of outdoor air pollution exposure misclassification cannot be discounted.

The current study reports a significant association between IAP and TB with some advantages as compared to previous studies. First, a large sample size with a face-to-face interview. Second, adjustment for a few confounding factors, including smoking tobacco, installation of an exhaust fan, and OLD data, that was directly collected during the interviews. Third, to define accurate history of TB and reduce the risk of recall bias, 79% of the TB cases were cross-validated using their response to questions on their sputum exam and history of hemoptysis.

Findings of this research have important policy implications. First, given that the frequency of TB in our study was 1.12% and considering the population of Delhi as 16.4 million, 183 188 people are likely to have/had active TB in the city, extrapolated an incidence rate to 1117 in 100 000 population. However, if the risk is adjusted to population in age-group 15 years or older, the prevalence of the history of active TB will be 1.48, which will translate to about 242 228 cases of history of active TB. This rate is even higher than the estimated TB cases in India in 1997. Dye and colleagues reported incidence and prevalence rates in India in 1997 as 187 and 505 in 100 000 population, respectively.[57] This is higher than the TB rates of Delhi in 2016 (62 706 cases with an incidence rate of 348 in 100 000 population).[58]

Second, Delhi is the capital of India and many households continue to rely on solid fuel and kerosene for both cooking and heating.[59] We observed a significant decrease in solid fuel use from 2004 to 2009 (34% exposed to IAP in 2004% vs. 23% in 2009). Given that IAP increases the risk for other diseases including cardiovascular diseases, the government should promote the use of cleaner fuels, which would help in reducing IAP-related diseases.[60] Considering that many households are still below the poverty line[61] and cannot afford cleaner fuel for cooking and heating an international collaboration is needed to provide subsidized or low-interest loans for purchasing and installing clean fuel technology. Initiation of an awareness campaign would be an important way to provide information on the risk of solid fuel exposure for different pulmonary and cardiac diseases, including TB. Improving harm reduction measurements and incorporating shear opening windows and doors, or a portable fan facing a window may decrease IAP. In new home designs, the provision of an appropriate exhaust fan in the kitchen and air circulation must be mandatory. Based on the current study findings, we suggest that healthcare professionals in settings similar to India should interrogate cooking- and ventilation-related history for all TB cases, and engage their patients in mitigating their exposure to emission from solid fuel burning. We also suggest that any patient with respiratory symptoms for more than 2–3 weeks and a history of IAP exposure must be screened for TB.

Finally, given the association between solid fuel exposure and TB, mitigation of solid fuel exposure should be considered in strategies aimed at eliminating TB by 2030, as articulated in the UN sustainable development goal.[62]

This study documents the epidemiological association of the risk of TB with long-term solid fuel exposure. However, the findings of the study should be interpreted in light of its limitations. First, due to lack of data availability, results were not adjusted for all comorbidities, including immunological disorders and diabetes, and other risk behaviors, such as alcohol consumption, which are shown to elevate the risk of TB.[63–66] Second, given the nature of the survey data we relied on self-reported measures of TB. The accuracy of self-reported TB was studied before by Hessol and her colleagues.[67] They found that self-reporting of TB disease had 100% accuracy among women with acquired immunodeficiency syndrome (AIDS). The future research is warranted to cross-validate survey-based assessments with the clinical data on TB to determine bias in the self-reported TB in the non-AIDS population. Third, we did not collect data on contact of our subjects with a known TB case and/or history of TB infection among other family members, which can increase the risk of contracting TB. Thus, the results were not adjusted for this risk

factor. Fourth, we did not record reasons for not participating in the study. However, the response rate was 78%, which diminished the probability of non-response bias. In our simulation analysis, we show that even if 50% of the unverified cases are misclassified, solid fuel exposure still showed significant association with the history of active TB. Fifth, we did not measure post-bronchodilator (BD) FEV_1. Therefore, we could not determine the proportion of chronic obstructive lung disease with fixed post-BD obstructions in our study population with OLD. Finally, this research measured exposure to IAP, not the levels of IAP exposure. We did not measure particulate matter size, their type, and concentrations that might be diverse among participants' homes. Therefore, future research should be geared toward (short- and long-term) direct measurements of exposure with respect to different fuel usages, household characteristics, duration, and frequency of household activities that affect IAP. This can help develop precise TB burden associated with indoor exposure, and their associated sources, which can support evidence-based strategies to target the main sources of IAP. The same strategies should be incorporated in the United Nation (UN) and WHO to the reach goal of "End TB by 2030."[68]

In this study, we concluded that IAP was associated with the risk of OLB and TB. Exposure to IAP should be routinely examined in patients with TB in LMIC countries. Clean stove projects[69] that substitute clean with the unsafe fuels should be prompted in LMIC to mitigate the risk of TB.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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DATA AVAILABILITY STATEMENT

Due to IRB restriction, the original data cannot be shared with anyone. But the de-identified original electronic data may be made available to the editor of this journal upon a reasonable request.

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Practical implications

- Indoor solid fuel exposure is a risk factor of TB.

- Efforts must be made to mitigate solid fuel exposure by installing clean cook stove and exhaust fan.

- Clinicians need to screen their patients for the history of solid fuel exposure.

- Indoor air pollution must be incorporated in the strategies to end TB, such as the UN goal to End TB.
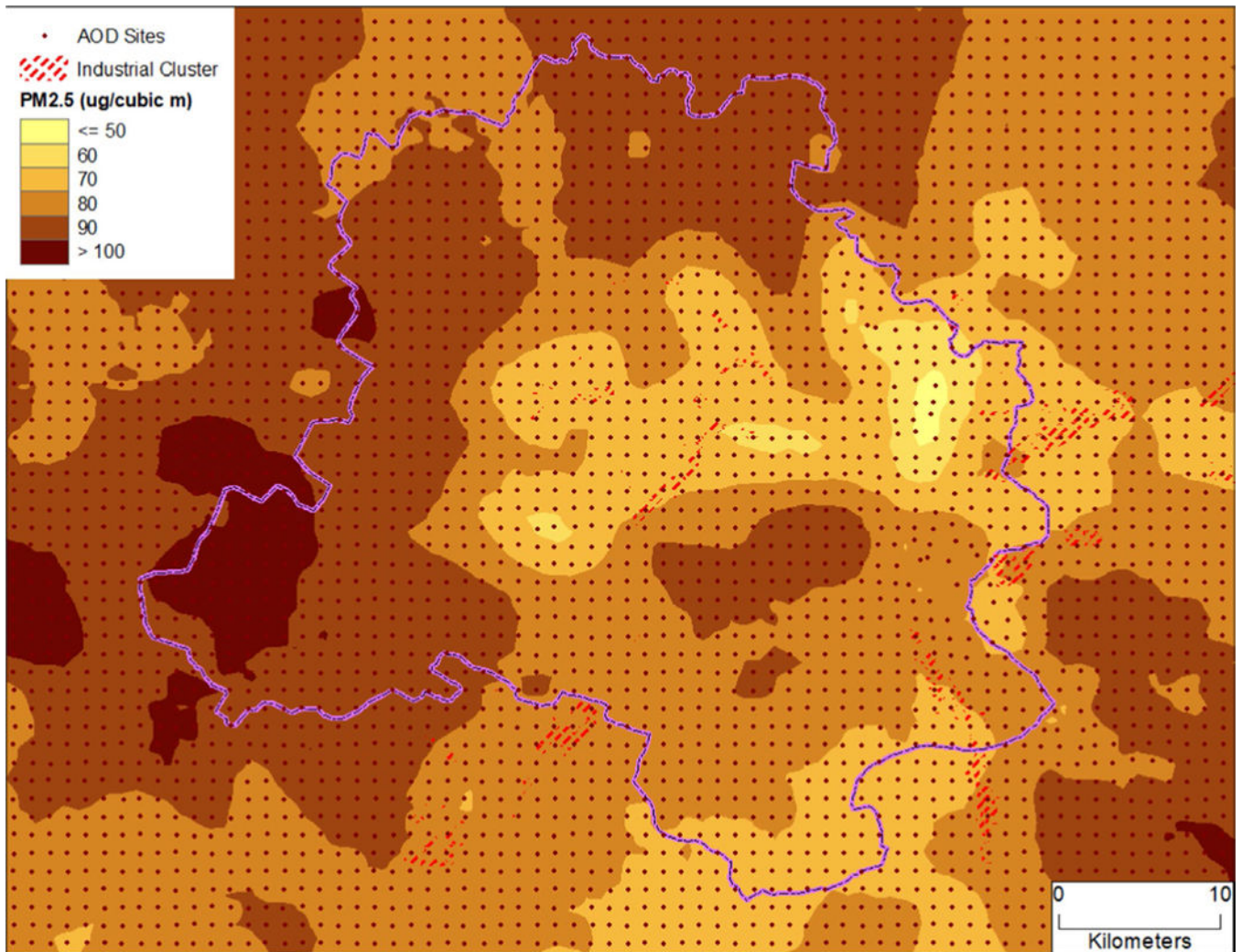
FIGURE 1.

Ambient $PM_{2.5}$ (μg/m^3) concentration in and around Delhi Metropolitan from 2002 to 2009 estimated using a hybrid approach (see Sinha and Kumar[44] for details)

Total Participants
n (%)

15,399 (100)

2004
n (%)

8,233 (53)

2009
n (%)

7,340 (47)

Unexposed
6,981 (84.4)

Exposed
1,282 (15.6)

Unexposed
6,867 (94.2)

Exposed
420 (5.8)

Active TB
77 (1.1)

Active TB
26 (2.0)

Active TB
61 (0.9)

Active TB
10 (2.4)

Total Active TB
174 (1.1)

FIGURE 2.
The flowchart of participants by TB and solid fuel exposure status

FIGURE 3.
Probability of the history of active TB with respect to duration of exposure to solid fuel among men and women in Delhi, 2004–2009
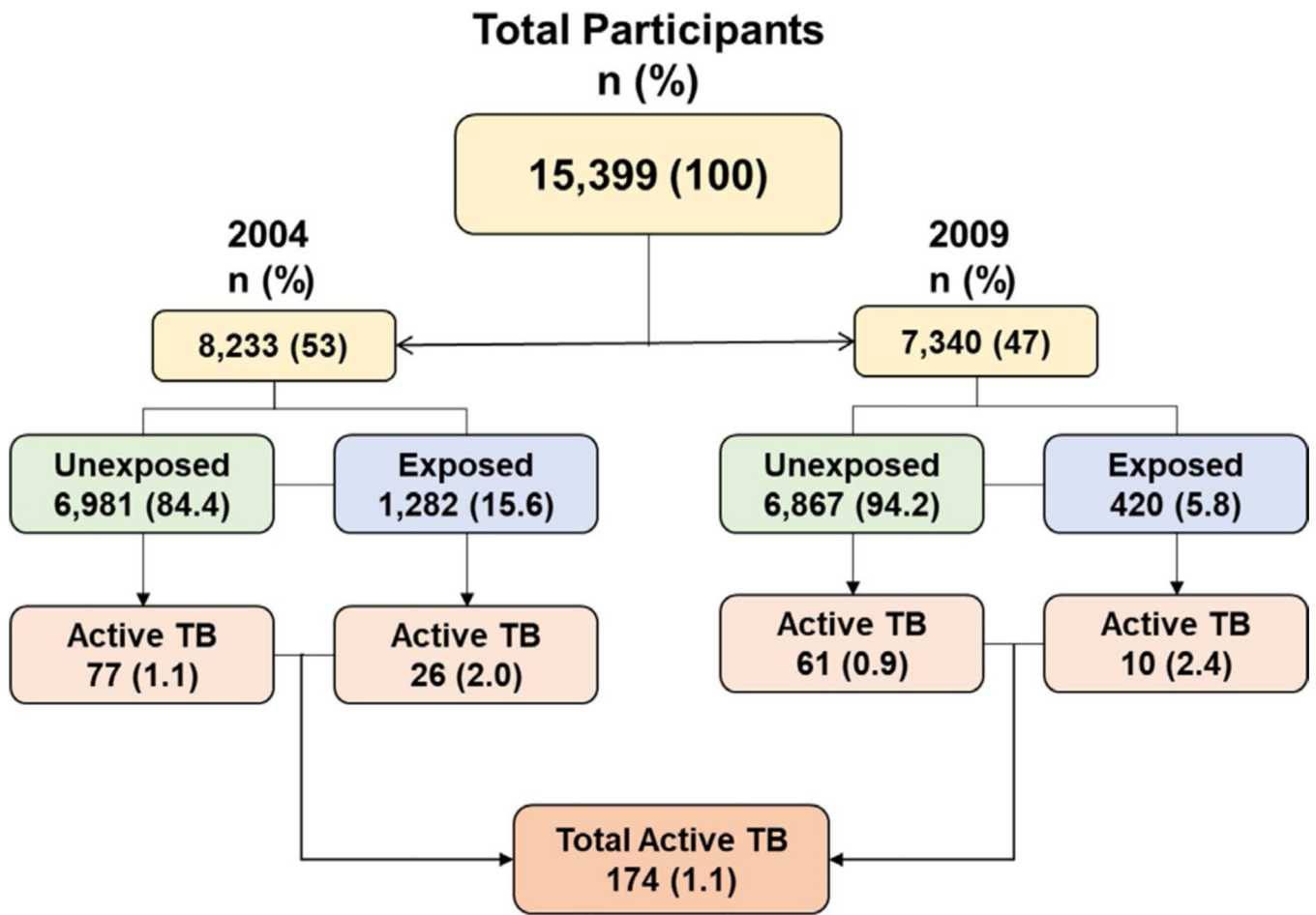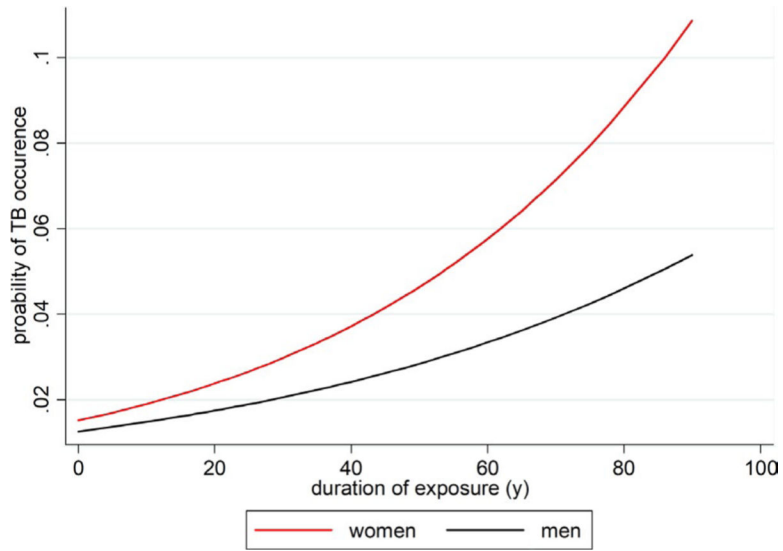
TABLE 1

TB status with respect to the selected demographic and household variables, Delhi 2004–2009

Variables	% TB+ (n)	Odds Ratio	95% CI
Year			
2004 (base)	1.25 (8233)	1	
2009	0.97 (7340)	0.73	0.53–0.99
Gender			
Female (base)	1.14 (8126)	1	
Male	1.09 (7447)	0.90	0.66–1.22
Age (y)			
15–30 (base)	0.74 (5106)	1	
31–45	1.59 (3325)	2.14 ***	1.39–3.27
46–60	1.88 (2236)	2.52 ***	1.61–3.95
>60	2.67 (1275)	3.61 ***	2.25–5.81
Exhaust fan in house			
Yes(base)	0.89 (8571)	1	
No	1.40 (6729)	1.50 ***	1.11–2.03
Solid fuel use for heating house			
No (base)	0.99 (13 818)	1	
Yes	2.12 (1702)	2.36 ***	1.60–3.48
Smoking status			
No (base)	1.30 (5916)	1	
Past smoker	4.10 (242)	3.27 ***	1.67–6.40
Current smoker	3.66 (465)	2.88 ***	1.68–4.91
Cooking fuel			
LPG (base)	1.02 (14 254)	1	
Solid fuel	2.06 (1018)	2.32 ***	1.44–3.74
Kerosene	2.71 (221)	2.83 ***	1.14–7.02
Household expenditure per capita			
<1000 (base)	1.60 (4945)	1	
1000–2000	1.09 (6025)	0.61 ***	0.44–0.86
2000–5000	0.56 (4074)	0.30 ***	0.18–0.48
5000	0.85 (472)	0.43 ***	0.16–1.19
Lung function (100 x (FEV1/FVC))			
90 to 100	1.28 (4522)	1	
80 to 90	1.90 (1313)	1.40	0.86–2.27
70 to 80	1.91 (419)	1.49	0.71–3.16
<70 (or OLD)	3.67 (300)	2.86 ***	1.49–5.57
Solid fuel exposure duration during life course (year)			
No exposure (base)	1.00 (3664)	1	

Variables	% TB+ (n)	Odds Ratio	95% CI
<20	2.00 (1506)	2.05 ***	1.26–3.33
20–40	2.50 (1284)	2.57 ***	1.59–4.17
40+	3.55 (169)	3.71 ***	1.53–8.94
Kerosene exposure during life course			
No exposure (base)	1.47 (6071)	1	
<20	2.76 (326)	1.91 *	0.95–3.82
20–40	2.61 (115)	1.80	0.56–5.78
40+	2.70 (111)	1.86	0.58–5.99

Note: No of of years of exposure was computed based on data from lifetime cooking matrix of the individual module of the survey instrument (question i105 to i110).

*
$P < .1$.

**
$P < .05$.

***
$P < .1$.

TABLE 2

Odds ratio of TB with respect to the use of solid fuel in comparison with clean fuel (ie, liquid petroleum gas) for heating home and cooking in Delhi, 2004–2009

Covariate	Solid fuel use for cooking			Solid fuel use for heating		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
ln (household expenditure per capita (Rs.))	0.73** (0.55–0.96)	0.73** (0.56–0.97)	0.65*** (0.49–0.85)	0.72** (0.54–0.95)	0.72** (0.54–0.95)	0.68*** (0.51–0.91)
Age (y)	1.02*** (1.00–1.03)	1.02*** (1.00–1.03)	1.02*** (1.01–1.03)	1.01** (1.00–1.03)	1.01** (1.00–1.03)	1.01** (1.00–1.03)
Gender (0 = female, 1 = male)	0.87 (0.56–1.36)	0.88 (0.56–1.37)	0.71* (0.48–1.06)	0.9 (0.58–1.42)	0.91 (0.58–1.43)	0.82 (0.54–1.23)
Lung function (%)	0.98** (0.97–1.00)	0.98** (0.97–1.00)	0.98** (0.97–1.00)	0.98** (0.97–1.00)	0.98** (0.97–1.00)	0.98** (0.97–1.00)
Smoking (1 = Yes, 0 = No)	1.80** (1.07–3.02)	2.04** (1.18–3.52)		1.90** (1.14–3.18)	1.54 (0.85–2.79)	
Exposure (1 = Yes, 0 = No)	1.95** (1.06–3.61)	2.46*** (1.26–4.80)		1.88** (1.13–3.11)	1.39 (0.71–2.72)	
Smoking × Exposure		0.47 (0.14–1.59)	1.59 (0.55–4.60)		2.36 (0.81–6.90)	4.15*** (1.95–8.79)
Ambient PM$_{2.5}$ exposure (μg/m³)		0.99 (0.96–1.03)	1 (0.96–1.03)		0.99 (0.96–1.03)	1 (0.96–1.03)
Constant	0.4 (0.04–3.71)	0.53 (0.02–12.04)	1.49 (0.07–31.58)	0.41 (0.04–4.39)	0.61 (0.02–14.98)	0.96 (0.04–21.68)
Observations	5187	5187	5187	5166	5166	5166

*
P < .1 (95% confidence interval in parenthesis).

**
P < .05.

***
P < .01.

TABLE 3

Odds ratio of observed and 100 simulations of randomly misclassified 50% (ie, 18 cases) of the non-sputum culture verified TB cases with respect to different solid fuel exposures and confounders

Variables	Observed			With 50% randomly cases misclassified		
	Cooking	Heating	Cooking and heating	Cooking	Heating	Cooking and heating
ln (household expenditure per capita (Rs.))	0.70 (0.516–0.957)	0.68 (0.500–0.933)	0.75 (0.544–1.021)	0.65 (0.64–0.66)	0.64 (0.63–0.64)	0.69 (0.68–0.70)
Age (y)	1.03 (1.016–1.038)	1.03 (1.015–1.037)	1.03 (1.016–1.038)	1.03 (1.03–1.03)	1.03 (1.03–1.03)	1.03 (1.03–1.03)
Gender (0 = female, 1 = male)	0.87 (0.572–1.328)	0.90 (0.586–1.371)	0.87 (0.571–1.327)	0.90 (0.89–0.92)	0.93 (0.92–0.94)	0.90 (0.89–0.91)
Lung function (%)	0.99 (0.970–1.003)	0.99 (0.971–1.004)	0.99 (0.970–1.003)	0.99 (0.99–0.99)	0.99 (0.99–0.99)	0.99 (0.99–0.99)
Smoking (1 = Yes, 0 = No)	1.70 (0.952–3.053)	1.77 (0.986–3.182)	1.66 (0.924–2.977)	1.54 (1.50–1.59)	1.60 (1.55–1.64)	1.50 (1.46–1.54)
Exposure (1 = Yes, 0 = No)	1.93 (1.065–3.480)	1.75 (1.038–2.948)	1.99 (1.229–3.219)	1.66 (1.62–1.71)	1.57 (1.54–1.61)	1.78 (1.75–1.82)
Observations	6544	6521	6544	6544	6521	6544

Note: Odds ratios and 95% confidence interval in parenthesis.