Published in final edited form as:
J Expo Sci Environ Epidemiol. 2018 June ; 28(4): 400–410. doi:10.1038/s41370-018-0024-2.

Sources of household air pollution and their association with fine particulate matter in low-income urban homes in India

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Abstract

Introduction—Household air pollution (HAP) is poorly characterized in low-income urban Indian communities.

Materials and Methods—A questionnaire assessing sources of HAP and 24-hour household concentrations of particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) were collected in a sample of low-income homes in Pune, India.

Results—In 166 homes, the median 24-hour average concentration of $PM_{2.5}$ was 167 $\mu g/m^3$ (IQR: 106 – 294). Although kerosene and wood use were highly prevalent (22% and 25% of homes, respectively), primarily as secondary fuel sources, high $PM_{2.5}$ concentrations were also found in 95 (57%) homes reporting LPG use alone (mean 141 $\mu g/m^3$; IQR: 92 – 209). In adjusted linear regression, log $PM_{2.5}$ concentration was positively associated with wood cooking fuel (GMR 1.5, 95% CI: 1.1 – 2.0), mosquito coils (GMR 1.5, 95% CI: 1.1 – 2.1), and winter season (GMR 1.7, 95% CI: 1.4 – 2.2). Households in the highest quartile of exposure were positively associated with wood cooking fuel (OR 1.3, 95% CI: 1.1 – 1.5), incense (OR 1.1, 95% CI: 1.0 – 1.3), mosquito coils (OR 1.3, 95% CI: 1.1 – 1.6), and winter season (OR 1.2, 95% CI: 1.1 – 1.4).

Discussion—We observed high concentrations of $PM_{2.5}$ and identified associated determinants in urban Indian homes.

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Conflict of Interest: None to report.

Keywords

Environmental monitoring; epidemiology; particulate matter; household air pollution; low- and middle income country (LMIC)

Introduction

Household air pollution (HAP) is an established risk factor for respiratory disease in adults and children, and is of particular concern in low- and middle-income countries (LMIC) where biomass fuels are used for cooking and heating. It is estimated that exposure to air pollution led to 6.5 million deaths in 2015, more than 3.2 million of which were from HAP(1). Rural communities largely rely on biomass for cooking, and often do not have access to liquid petroleum gas (LPG) or clean electric sources, either due to availability or financial restrictions. Those living in urban settings often have higher access to these cleaner fuels, however they may still rely on unclean fuels such as wood and kerosene for cooking, heating, and lighting(2).

Detailed information on levels and sources of HAP is required to design well-informed strategies to reduce exposure and subsequent burden of disease(3). Identification of modifiable risk factors is an important first step in improving indoor air quality and lowering exposure to harmful combustion products, such as particulate matter less than 2.5 microns in diameter ($PM_{2.5}$). $PM_{2.5}$ is an important product of combustion that is highly regulated and often associated with negative health outcomes. The vast majority of published literature characterizing HAP exposures, as well as the household conditions in which they occur, is from biomass sources in predominantly rural areas of LMIC(4–10). Characteristics unique to urban settings may play an important role in exposure to HAP and have important health implications, however HAP in densely populated urban environments of LMICs have not been sufficiently characterized to provide strong evidence for effective intervention strategies(11–18).

In the present study, we aim to characterize household concentrations of $PM_{2.5}$ in a sample of low-income urban households in Pune, India. We also explore associations between modifiable risk factors at the household level and concentrations of $PM_{2.5}$ in these homes.

Materials and Methods

Ethics approval for this study was granted from the Institutional Review Boards of the Sassoon Government Hospitals and Byramjee Jeejeebhoy Government Medial College (SGH/BJGMC) in Pune, Maharashtra, India and the Johns Hopkins University School of Medicine in Baltimore, Maryland, USA. All participants provided written informed consent for participation.

Study Population

Pune is a large district located in Maharasthra, a state in the western region of India. The district has a population of nearly 9.5 million, living in both urban (5.7 million) and rural (3.7 million) areas across 15,642 square kilometers (19, 20). Research was conducted in partnership with SGH/BJGMC, Pune, India. SGH/BJGMC is a large Maharashtra Government tertiary care public and teaching hospital, primarily serving the lower socioeconomic communities in Pune and surrounding areas. Participating households in this study were recruited between December 2013 and November 2016 as part of on-going research to assess the association between HAP and tuberculosis (TB), and are populations served by SGH/BJGMC.

Assessment of Household Air Pollution

Concentrations of air pollution from cooking fuels, secondhand tobacco smoke (SHS), and other pollution sources were measured in all participating households using structured questionnaires and objective measures of $PM_{2.5}$.

All questionnaires were translated into Marathi to ensure that subjective questions would be asked in a standardized way, with response options that were clear to the participants, and to ensure that they were true to their intention. Questionnaires were first translated into Marathi and then back-translated into English. Discrepancies were identified, and further edits were made by study team consensus. Questionnaires assessing factors both in the home and outside the home that may affect household $PM_{2.5}$ concentrations were administered to each participant at the baseline visit. Participants were asked about the types of fuel used in the home and typical use of these fuels over the past 7 days. After 24 hours, study staff returned to the home and information was collected on concentration determinants over the previous 24 hours. Information on ventilation was collected by asking participants whether they opened doors or windows when cooking. Additional collected information included trash burning near the home, proximity to neighbors using wood for cooking, exposure to SHS, and/or regular preparation of Mishri (a smokeless tobacco product prepared by burning). Questions regarding neighbors using wood for cooking and the preparation of Mishri were added after data collection began, and thus data exists for only a subsample of participants. Participants also reported the use of mosquito coils, incense, and candles or kerosene for lighting. Details of the housing construction and ventilation were recorded by observation. This included information on household characteristics such as construction materials of the walls, roof, and floor, the presence of a gap between the ceiling and the roof, the presence of a separate kitchen, and the size of the cooking space.

Real-time household $PM_{2.5}$ concentration was assessed using the Thermo Environmental Instruments pDR-1000 (Thermo Fisher Scientific, Waltham, MA) fitted with a cyclone inlet (BGI, Waltham, MA) and paired with portable constant-flow pumps (SKC Inc, PA). Pumps were pre- and post-calibrated at 4 L/min using a Bios DryCal primary flow calibrator (MesaLabs, Lakewood CO). A pre-weighed Teflon filter was placed downstream in pre-loaded cassettes for gravimetric measurements. The monitoring set-up was placed approximately 1 × 1 meter away from the primary cook stove in each home. In addition to the integrated 24-hr gravimetric filterbased measurement, the pDR-1000 recorded nephelometric-based measurements of $PM_{2.5}$ concentration every minute for the 24-hour period. Filters were post-weighed to assess a 24-hr time-weighted-average (TWA) concentration over the sampling period. The ratio of the TWA nephelometric and the corresponding gravimetric-based TWA concentrations was used as a calibration factor to conver real-time pDR-derived concentrations to gravimetric-equivalent concentrations(21). Blank filters were included for quality control purposes at 10% of the home visits.

Statistical Analysis

For nephelometric measurements less than the limit of detection (0.001 mg/m^3), a correction of the LOD/square root of 2 was applied. Additionally, 15-minute moving averages were calculated for nephelometric data. Households were also categorized into quartiles by 24-hour mean PM$_{2.5}$ concentrations. The number of hours above 75 μg/m^3 PM$_{2.5}$ was also calculated for each home in an effort to understand peak concentrations. This was calculated by summing the number of minutes across the total 24 hours of monitoring where the nephelometric PM$_{2.5}$ concentration was greater than 75 μg/m^3, then converting this total number of minutes into hours. This threshold was chosen as it is an interim target as described by WHO standards for air pollution(22). In addition, the number of hours above 100 μg/m^3, which has been previously reported in the scientific literature (17), was calculated for comparison using this same method.

Median and interquartile range values were calculated for continuous measures of PM$_{2.5}$ concentration. All measures of PM$_{2.5}$ were compared across fuel types (primary and composite) using a global Kruskal-Wallis test. A composite variable for fuel type was calculated to account for the use of multiple fuels, categorizing households as using LPG/electricity only, kerosene but no wood, wood but no kerosene, and both wood and kerosene. Households were also dichotomously categorized as to whether or not they used wood and whether or not they used kerosene.

Linear regression was performed with log-transformed 24-hour average concentrations of PM$_{2.5}$ and our determinants of interest as reported over the past 24 hours to calculate geometric mean ratios (GMR) of association. Additionally, a linear regression was also performed with log-transformed number of hours of PM$_{2.5}$ greater than 75 μg/m^3 as the outcome of interest. A logistic regression model was built to consider the odds ratio of association of reported determinants of interest with those in the highest concentration quartile for mean 24-hour PM$_{2.5}$. Multiviarate regression models for these outcomes of interest were built with fuel variables as the primary concentration determinant of interest, controlling for covariates found to be significant in univariate analysis with p<0.10, or considered to be of epidemiologic importance *a priori*.

Results

A total of 166 households were included in this analysis. Descriptive statistics about cooking fuel are presented in Table 1. The majority of households reported using LPG as their primary fuel source (n=144, 87%), and a lesser proportion reported kerosene (n=19, 11%) and wood (n=4, 2%). Moreover, 35% (n = 58) of homes reported regularly using wood or kerosene as a secondary fuel source (in the past 7 days). Wood was used more often than kerosene as this secondary fuel source (n=38, 23% and n = 20, 12%, respectively). Electricity was used as a secondary fuel source by 20 (12%) of the households. Considering both primary and secondary sources of cooking fuel, 95 (57%) of the households used LPG and/or electricity only, 29 (17%) used kerosene but no wood, 34 (20%) used wood but no kerosene, and 8 (5%) used both kerosene and wood. No households reported biomass use other than wood. Participants reported cooking more frequently and for the longest periods of time in the early morning and at dinner time, although some cooking or heating of food or water was reported during all times of the day. In total, participants reported cooking a median of 120 minutes (IQR: 90 – 165) each day.

All cooking with LPG (n = 145, 100%), and most cooking with kerosene (n = 30, 86%), happened inside of the home as compared to an outside cooking area. While indoor environments predominated as the cooking space for LPG and kerosene, wood fuel was primarily used outside of the home (n=34, 89%). Among all households, 74 (45%) did not have a separate kitchen or room for cooking. When asked about opening windows when cooking, 76 (46%) reported always keeping them open. The remaining (n = 90, 54%) either opened them less than half of the time, never, or did not have windows in their cooking area leading to outside spaces. A larger proportion reported always opening kitchen doors while cooking (n=107, 64%).

Reported sources of other household pollutants are also described in Table 1. Smoking was allowed in 25% of the included homes, and at least weekly burning of trash by the participant or their neighbors was reported by 13 (8%) homes. Incense was used by 130 (78%) participants a median of 15 minutes (IQR: 10 – 20) per day. Mosquito coils, used by 38 (23%) of the participants, were used for much longer periods of time each day (median = 360 minutes; IQR: 60 – 600). In addition to electricity, reported light sources included kerosene (n=15, 9%) and candles (n=117, 70%). A subset of participants was asked about sources of pollutants originating from other households, and 44 (37%) reported smelling others using biomass every day and 21 (17%) reported smelling others prepare mishri in the previous 24 hours.

High concentrations of $PM_{2.5}$ were found in homes, which is summarized in Table 2, Figures 1–2. The overall median 24-hour average concentration of $PM_{2.5}$ was 167 $\mu g/m^3$ (IQR: 106 – 294), more than six times higher than the WHO recommended maximum concentration level of 25 $\mu g/m^3$ over a 24-hour period. The median values of 24-hour TWA $PM_{2.5}$ concentrations were significantly different between the categories of composite cooking fuel, with those using wood or kerosene as a secondary source having a higher average concentration than those using LPG alone. We calculated the number of hours where the concentration of $PM_{2.5}$ was above the WHO interim target of 75 $\mu g/m^3$ as well as 100 $\mu g/m^3$. Overall, households were above the 75 $\mu g/m^3$ threshold for a median of 11.2 hours (IQR: 5.6 – 19.0) each day, and above 100 $\mu g/m^3$ for a median of 8.9 hours (IQR: 3.9 – 15.6) each day. Similar to the 24-hour average values, differences in concentrations were observed by composite fuel variable.

Univariate and multivariate linear regression analyses were conducted to assess the associations of cooking fuel, kitchen characteristics, and other pollutant sources with log-transformed 24-hour TWA $PM_{2.5}$ concentration metrics. Univariate analysis for average 24-hour TWA $PM_{2.5}$ concentration is presented in Table 3. Significant associations were found between wood use and $PM_{2.5}$ (GMR 2.1; 95% CI: 1.4 – 2.9), but not for kerosene use (GMR 1.1; 95% CI: 0.8 – 1.6). Other household characteristics associated with $PM_{2.5}$ included volume of the cooking area (GMR 0.9; 95% CI: 0.8 – 1.0), all concrete or brick construction material of the kitchen (GMR 0.4; 95% CI: 0.3 – 0.6), and presence of a visible gap between the walls and the ceiling (GMR 1.9; 95% CI: 1.3 – 2.7). Households that reported smelling others using biomass daily also had a positive association with 24-hour $PM_{2.5}$ (GMR 1.5; 95% CI: 1.3 – 2.7).

Measurements taken in the winter season were also significantly associated with increased concentrations of $PM_{2.5}$ (GMR 1.6; 95% CI: 1.2 – 2.2). Multivariable adjusted associations between household exposures and $PM_{2.5}$ concentrations are presented in Table 4. In adjusted analysis, wood use (GMR 1.5; 95% CI: 1.1 – 2.0), use of mosquito coils (GMR 1.5; 95% CI: 1.1 – 2.1), and measurements taken in the winter season (GMR 1.7; 95% CI: 1.4 – 2.2) were significantly and positively associated with increasing concentrations of $PM_{2.5}$. As to include only one measure of ventilation in the adjusted model at a time, construction material of the kitchen was included, and the presence of a visible gap between the walls and the ceiling excluded, in the adjusted analysis presented here. A sensitivity analysis was conducted, replacing the construction material variable with the gap variable to assess the association of a visible gap with HAP. In this adjusted analysis, the presense of a visible gap statistically significantly increased the concentration of $PM_{2.5}$ (GMR 1.5; 95% CI: 1.0, 2.2; $p < 0.05$), and tended to increase the odds of being in the highest quartile of exposure (OR 1.3; 95% CI: 0.9, 1.7; $p = 0.13$). Reported smelling of others using biomass daily was also excluded from adjusted analysis as it was only available for a subset of participants.

Figure 3 summarizes the minute-to-minute median of the moving 15-minute average $PM_{2.5}$ concentration by quartile of 24-hour TWA concentrations. Households in the lowest quartile of exposure have median values below WHO’s interim target level for nearly the entirety of the monitoring period. In adjusted logistic regression (Table 5), the use of wood was positively and significantly associated with being in the highest concentration quartile (OR 1.3; 95% CI: 1.1 – 1.5) as compared to being in the bottom three quartiles. Additionally, burning incense (OR 1.1; 95% CI: 1.0 – 1.3) and using mosquito coils (OR 1.3; 95% CI: 1.1 – 1.6) were both associated with the highest concentration quartile, as was measurements taken during the winter season (OR 1.2; 95% CI: 1.1 – 1.4).

We also conducted analysis to assess the association between reported determinants and the number of hours $PM_{2.5}$ concentration was above 75 $\mu g/m^3$. Both increasing the size of cooking area and having a kitchen constructed of concrete and blocks were inversely associated with number of hours above this threshold. Additionally, measurements taken in the winter months were strongly and significantly positively associated with increasing number of hours above the threshold, such that an adjusted analysis was not feasible due to model stability (data not shown).

Discussion

We assessed HAP concentrations of $PM_{2.5}$ over a 24-hour period of time, as well as reported $PM_{2.5}$ sources, in a sample of low-income urban households in Western India. Use of wood for cooking, mosquito coils, and incense were all associated with higher 24-hour TWA $PM_{2.5}$ concentrations. Measurements in the winter months were also associated with higher

24-hour TWA $PM_{2.5}$ concentrations. Larger cooking area volumes and kitchen construction matierals that were concrete or brick tended to be inversely associated with $PM_{2.5}$ TWA concentrations. Infiltration of ambient air pollution into the homes also appeared to play a significant role in increasing household $PM_{2.5}$ concentrations. Additionally, although heterogenous household sources of pollutants were reported, all households had extremely high TWA concentrations of $PM_{2.5}$.

There was significant heterogeneity in types of cooking fuel used among households in our study; although LPG was only used as a primary fuel source, wood and kerosene were used as both primary and secondary fuel sources. The use of wood in our sample appreciably increased the concentration of household $PM_{2.5}$ even though it was primarily used outdoors. Kerosene, however, which was used indoors, was not significantly associated with $PM_{2.5}$ concentrations. $PM_{2.5}$ concentrations produced by the combustion of kerosene are much lower than that of wood, and ultrafine particles (not measured as a part of this study) produced by kerosene combustion may not significantly contribute to mass measurements of $PM_{2.5}$ concentration(23). The heterogeneity of fuel sources used in the communities from which we recruited makes it difficult to compare to other studies, which typically sampled among populations that primarily use wood or other biomass fuels only. In Honduras, type of cooking stove and fuels used in homes were found to explain variability in household $PM_{2.5}$ concentrations, however all included homes used wood-burning stoves (either improved or traditional) (5). Klasen et al. reported fuel types in rural Peru, Nepal, and Kenya, among which 20% of households reported using LPG or kerosene as secondary fuels. As wood was primarily used as cooking fuel in these rural settings, however, concentrations of HAP were much higher than in our study, and ever-use of an LPG stove did not significantly decrease HAP levels in multivariate analysis(10). In low-income urban households in Bangladesh, a setting more similar to ours and one where 64% of households used LPG as their primary cooking fuel, indoor $PM_{2.5}$ concentrations were negatively associated with ventilation of the home, defined by the number of external windows and doors. The study reported that all exposure metrics of $PM_{2.5}$ evaluated were lower in homes with greater number of external windows and doors (17). We did not find opening windows or doors to be associated with $PM_{2.5}$ concentration.

Notably, we observed that the use of mosquito coils was strongly and positively associated with higher concentrations of $PM_{2.5}$. Few studies have investigated the contribution of mosquito coil emissions with household concentrations of $PM_{2.5}$, and most emission analyses have been conducted in the laboratory. In a controlled setting in an Indian home over a period of six hours, the burning of a mosquito coil was found to produce a mean $PM_{2.5}$ concentration of 1031 $\mu g/m^3$ (24). Laboratory studies indicate that the $PM_{2.5}$ mass produced from burning one mosquito coil is equal to that of the burning of 75–137 cigarettes, all the while containing additional dangerous chemical constituents(25). To our knowledge, no other published study has assessed the contribution of mosquito coils to $PM_{2.5}$ concentration due to normal household usage. Households should consider limiting mosquito coil use as they are positively associated with high levels of pollution. The benefit of decreased air pollution concentration, however, should be weighed against the potential for increased exposure to mosquito-borne illness. Future studies should assess the true effectiveness of mosquito coils to prevent against vector-borne diseases, and the alternate scenario of benefit from better air quality.

Infiltration of ambient air pollution indoors is likely a significant contributor to household $PM_{2.5}$ concentrations in these homes. Characteristics of household construction that may impact infiltration were found to be associated with $PM_{2.5}$ concentrations. Having a visible gap between the wall and the roof, which may serve as a point of entry, increased HAP concentrations. Although this may seem contradictory in households that use wood cooking fuel, wood is primarily used outside of the home, and this increased ventilation would likely not serve the purpose of diffusing HAP. Houses constructed of concrete or brick tended to have lower concentrations of HAP, indicating this might be protective by preventing ambient air penetration. Measurements taken in the winter months showed a positive relationship with HAP. Participants also reported neighborhood level factors, such as burning of trash, others using wood for cooking, and other households preparing mishri, which likely contribute to neighborhood ambient levels and infiltrate into homes. Taken with the high concentrations of ambient air pollution in India(26), these conditions suggest an important contribution of outdoor pollutant penetration to HAP.

Few studies assessing HAP have been conducted in low-income urban areas of India or in similar settings. Saksena et al. measured HAP in low-income settlements in Delhi, focusing on communities that primarily used wood for cooking. Among the 80 homes included in their study, both wood and kerosene were found to be used, wood both inside and outside the home, and kerosene primarily inside of the home. Not surprisingly, households using wood had higher concentrations of particulate matter than kerosene households, however those using kerosene and categorized as “low-pollution” communities still had geometric mean levels of particulate matter less than 5 microns in diameter (PM_5) of approximately 600 $\mu g/m^3$ (18). A second study in low-income areas of Dehli attributed high indoor measures of $PM_{2.5}$ to poor ventilation. The authors only presented prevalence of fuel use for LPG and kerosene, although it is mentioned that wood was also used in this population. Nevertheless, indoor levels of $PM_{2.5}$ were also highly elevated, especially in the winter season, with household concentrations of $PM_{2.5}$ averaging 52 $\mu g/m^3$ in the summer, 312 $\mu g/m^3$ in the rainy, and 625 $\mu g/m^3$ in the winter season. Variation of HAP concentration were presented by season and housing characteristics, however variation by fuel use or other pollutant sources were poorly defined(13). In urban homes in Agra, India, 24-hour concentrations of $PM_{2.5}$ were similar to the results we present (average $PM_{2.5}$ 144.5 $\mu g/m^3$), and both indoor and outdoor activities were found to increase concentration, however only a small number of homes were monitored(27). One study measured household concentrations in urban Pune, and report a 24-hour $PM_{2.5}$ concentration of 89.7 $\mu g/m^3$ (SD +/− 43.2) (28). Other urban studies in the region report a wide range of concentrations of household $PM_{2.5}$, ranging from 78 $\mu g/m^3$ in Lucknow, India (29) to 402 $\mu g/m^3$ in Lahore, Pakistan (30). In urban Bangladesh, household $PM_{2.5}$ concentrations were found to be 190 $\mu g/m^3$ (IQR: 170 – 210), similar to the concentration presented in our study (17). Although we did not collect ambient level $PM_{2.5}$ data, the average particulate matter less than ten microns in diameter (PM_{10}) concentration as measured by five government ambient air monitoring stations ranged from 91 $\mu g/m^3$ to 121 $\mu g/m^3$ across the study period (26).

Due to logistic and financial restrictions, we were limited to collecting household measurements at one time point instead of multiple measurements across seasons in each home. Data collection across multiple seasons would have allowed us to account for not only day-to-day variability in the households, but also by season. We did, however, enroll and sample homes throughout the year, and were able to control for seasonal variations in multivariable models. Additionally, our method for controlling for ventilation factors was limited to observable characteristics of the home and reported ventilation activities by the participants. These proxy measures likely do not capture the full variability in ventilation of the included homes, however, they do provide insight into potential modifications at the household level that could alter ventilation. Additionally, we were not able to collect measurements of ambient air pollution at each home, which limits our conclusions about the contributions of infiltration to HAP.

In conclusion, we observed alarmingly high concentrations of $PM_{2.5}$ in a sample of urban homes in Western India. Household pollutant concentrations were over six times the WHO upper limit of 25 μg/m^3, even among those only using LPG for cooking. We identified several contributing factors to HAP, including wood, mosquito coils, incense, and noted seasonal variation. Additional research on contributions from ambient air pollution and kerosene use is needed to better inform strategies for HAP reduction. Interventions to address these high levels of HAP in Indian urban communities will likely require both household and neighborhood level interventions to reduce the burden of exposure in these densely populated communities.

Acknowledgments

The authors would like to thank the study participants and their families for volunteering their time and opening their homes to us. Research reported in this manuscript was supported by the National Institute of Allergy and Infectious Diseases of the National Institutes of Health under award number R01AI097494, and by the Fogarty International Center, Office of AIDS Research, National Cancer Center, National Heart, Blood, and Lung Institute, and the NIH office of Research for Women’s Health through the Fogarty Global Health Fellows Program Consortium comprised of the University of North Carolina, Johns Hopkins, Morehouse and Tulane under award number R25TW009340. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. Data in this manuscript were also collected as part of the Regional Prospective Observational Research for Tuberculosis (RePORT) India Consortium. This project has been funded in whole or in part with Federal funds from the Government of India’s (GOI) Department of Biotechnology (DBT), the Indian Council of Medical Research (ICMR), the United States National Institutes of Health (NIH), National Institute of Allergy and Infectious Diseases (NIAID), Office of AIDS Research (OAR), and distributed in part by CRDF Global. The contents of this publication are solely the responsibility of the authors and do not represent the official views of the DBT, the ICMR, the NIH, or CRDF Global. Any mention of trade names, commercial projects, or organizations does not imply endorsement by any of the sponsoring organizations. Research reported in this manuscript was also supported by the Ujala Foundation and the Gilead Foundation. Dr. Aarti Kinikar was supported by the Fogarty International Center BJGMC JHU HIV TB Program D43TW009574.

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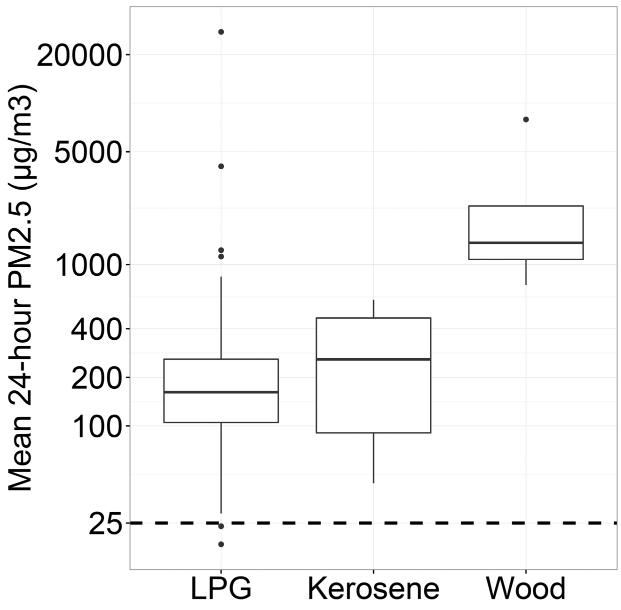
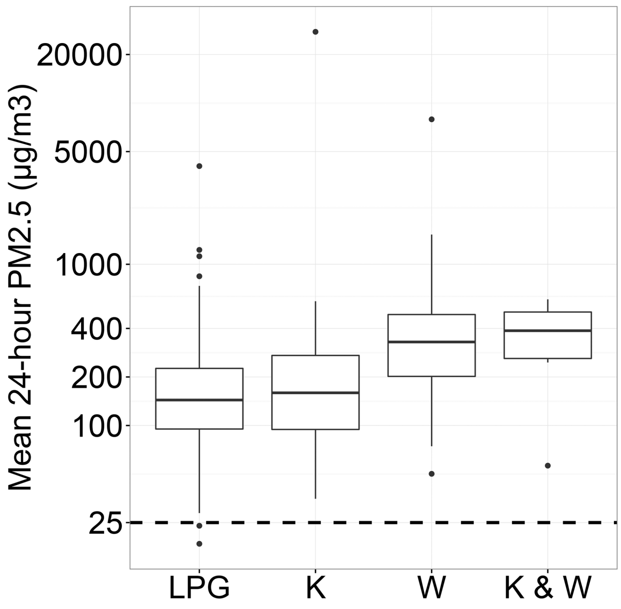


a) Primary Cooking Fuel



b) All Cooking Fuels

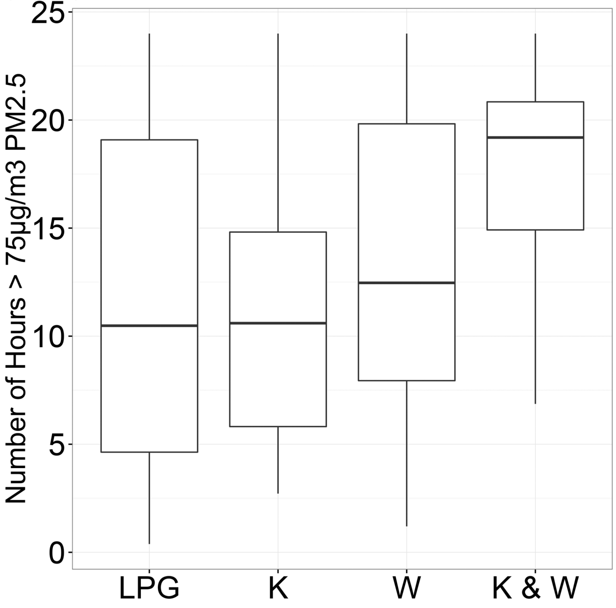
Figure 1.

Distribution of the mean 24-hour time-weighted-average $PM_{2.5}$ concentration ($\mu g/m^3$) as compared to the WHO 24-hour standard of 25 $\mu g/m^3$ (dashed line) by type of a) primary cooking fuel and b) all cooking fuels in low-income urban homes in Pune, India (n = 166).

K: Kerosene but no wood; W: Wood but no kerose;

K & W: Both kerosene and wood

a) 75 µg/m^3



b) 100 µg/m^3

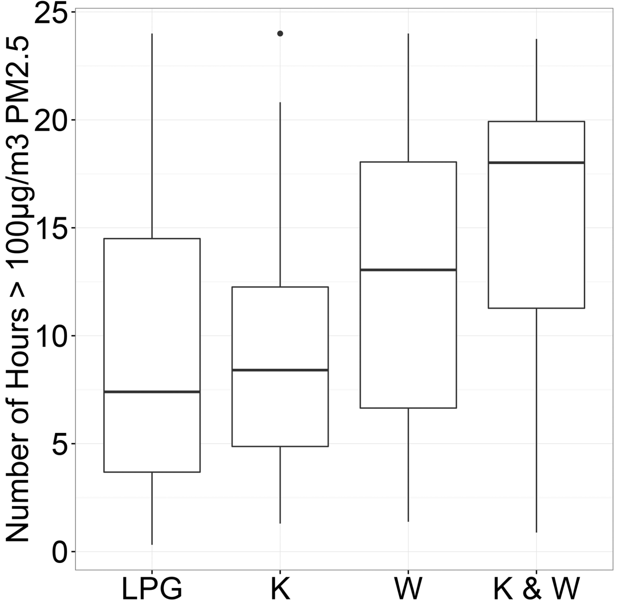


Figure 2.

Distribution of the number of hours of $PM_{2.5}$ above 75 µg/m^3 and above 100 µg/m^3 by types of cooking fuel used in the home in low-income urban homes in Pune, India (n = 166).

K: Kerosene but no wood; W: Wood but no kerose;

K & W: Both kerosene and wood

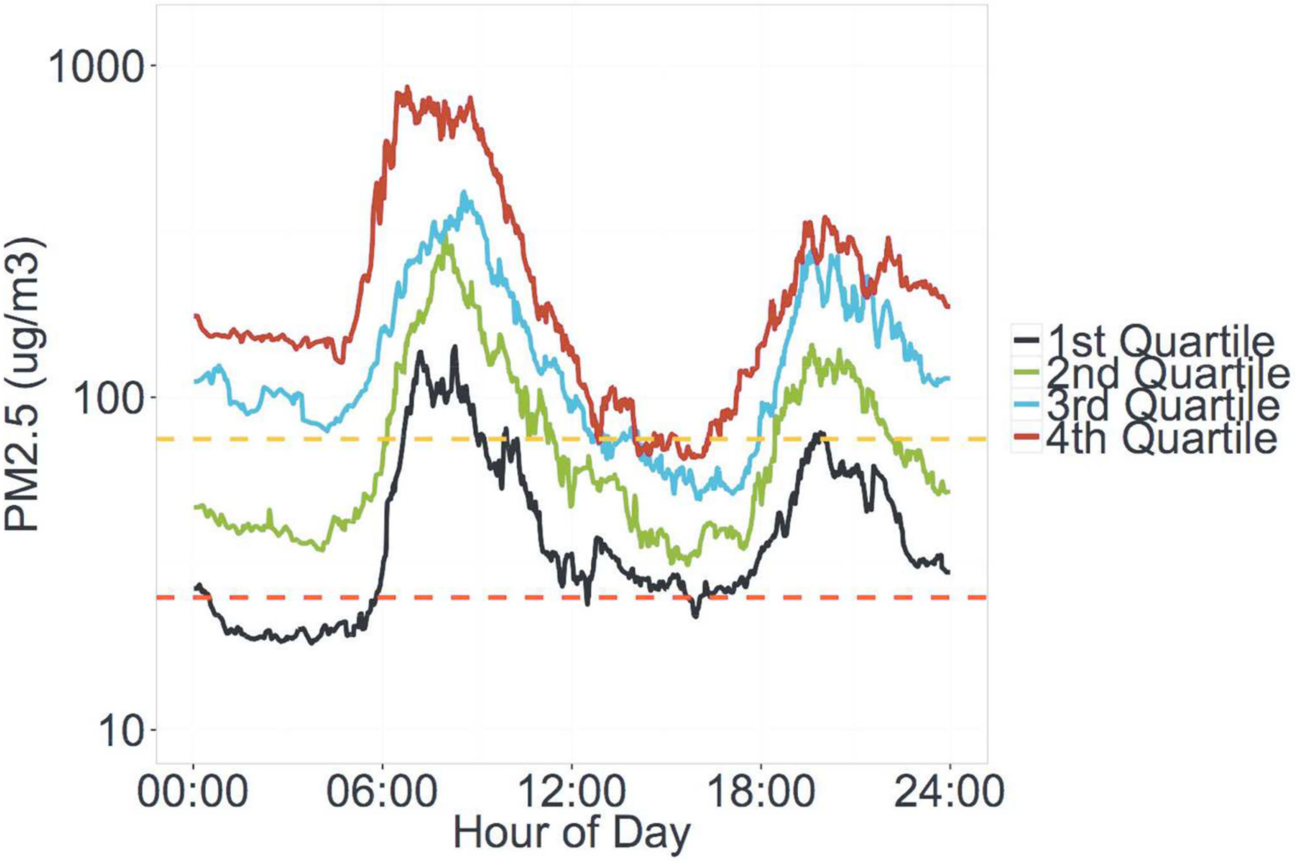


Figure 3.

Minute by minute median of the moving 15 minute average $PM_{2.5}$ ($\mu g/m^3$), by quartile of 24-hour average $PM_{2.5}$ concentration among 166 low-income urban homes in Pune, India.

Table 1

Reported sources of household air pollution in low-income urban homes in Pune, India (n = 166).

	7-day	24hour
Primary Fuel Types, n(%)		
LPG or electric	145 (87)	144 (87)
Kerosene	17 (10)	19 (11)
Wood	4 (2)	4 (2)
Secondary Fuel Types, n(%)		
None	88 (53)	99 (60)
Electricity	20 (12)	17 (10)
LPG	0 (--)	0 (--)
Kerosene	20 (12)	19 (11)
Wood	38 (23)	31 (19)
Combined Fuel Types, n(%)		
LPG/electricity only	95 (57)	104 (63)
Kerosene (no biomass)	29 (17)	28 (17)
Wood (no kerosene)	34 (20)	27 (16)
Both kerosene and wood	8 (5)	7 (4)
Time using LPG		
None	21 (13)	22 (13)
< 1 hour	3 (2)	0 (--)
≥ 1 hour	142 (86)	144 (87)
Time using Kerosene		
None	131 (79)	132 (79)
< 1 hour	14 (8)	14 (8)
≥ 1 hour	21 (13)	22 (13)
Time using Wood		
None	126 (76)	132 (80)
< 1 hour	13 (8)	11 (7)
≥ 1 hour	27 (16)	23 (14)
Fuel Used Inside the Home, n(%)		
LPG/Electricity	145 (100)	--
Kerosene	30 (86)	--
Wood	4 (11)	--
No separate kitchen for cooking, n(%)	74 (45)	--
Times of day usually cook, n(%)		
Early morning	163 (98)	163 (98)
Between morning and lunchtime	98 (59)	109 (66)

	7-day	24hour
Lunchtime	88 (53)	65 (39)
Between lunch and dinner	116 (70)	120 (72)
Dinner	163 (98)	152 (92)
Late evening	29 (17)	23 (14)
Use of secondary cook fuel > 30 minutes per day, n(%)	59 (36)	52 (31)
Windows always open while cooking, n(%)	76 (46)	--
Doors always open while cooking, n(%)	107 (64)	--
Construction material of the kitchen		
All corrugated metal	32 (19)	--
Roof or walls corrugated metal	44 (27)	--
All concrete or brick	90 (54)	--
Visible gap between the roof and the top of the walls, n(%)	34 (20)	--
What type of road does the house lie on, n(%)		
Small	143 (87)	--
Medium or large	22 (13)	--
Self or neighbors burn trash daily, n(%)	13 (8)	17 (10)
Burning incense, n(%)	130 (78)	94 (57)
Minutes per day burning incense given burn incense, median (IQR)	15 (10 – 20)	15 (10 – 20)
Use mosquito coils, n(%)	38 (23)	20 (12)
Minutes per day burning mosquito coils given burn mosquito coils, median (IQR)	360 (60 – 600)	360 (15 – 480)
Light source: Kerosene, n(%)	15 (9)	5 (3)
Minutes per day using kerosene, median (IQR)	10 (0 – 600)	0 (0 – 10)
Light source: Candles, n(%)	117 (70)	32 (19)
Minutes per day using candles, median (IQR)	0 (0 – 30)	0 (0 – 20)
Smell others using biomass daily (among those asked[1]), n(%)	44 (37)	37 (30)
Smell others preparing mishri daily (among those asked[1]), n(%)	10 (8)	21 (17)
Household smoking rules		
Not allowed	125 (76)	--
Sometimes allowed or no rules	40 (24)	--

[1] Among n = 119 households.

Table 2

Concentrations of markers of household air pollution by composite cooking fuel in low-income urban homes in Pune, India (n = 166).

	Total n=166	**LPG/Electricity Only n=95**	**Kerosene (no wood) n=29**	**Wood (no kerosene) n=34**	**Both Wood and kerosene n = 8**	**p-value[1]**
24-hour mean PM2.5 (μg/m^3), median (IQR)	167 (106 – 294)	**141 (92 – 209)**	**172 (113 – 273)**	**249 (128 – 453)**	**442 (268 – 538)**	**0.001**
Hours > 75 μg/m3 PM2.5 (μg/m^3), median (IQR)	11.2 (5.6 – 19.0)	10.5 (4.6 – 19.1)	10.6 (5.8 – 14.8)	12.5 (7.9 – 19.8)	19.2 (14.9 – 20.8)	0.14
Hours > 100 μg/m3 PM2.5 (μg/m^3), median (IQR)	8.9 (3.9 – 15.6)	**6.9 (3.6 – 14.9)**	**8.0 (5.2 – 11.3)**	**10.4 (5.6 – 17.7)**	**17.4 (12.8 – 19.4)**	**0.03**

[1] Bolded values statistically significant at $p < 0.05$ for a global Kruskal-Wallis test comparing concentrations of $PM_{2.5}$ across composite cooking fuel categories.

Table 3

Univariate linear regression for continuous log 24-hour average $PM_{2.5}$ ($\mu g/m^3$) concentrations across cooking fuel, cooking fuel behaviors, and other sources of HAP among households in low-income urban homes in Pune, India (n = 166).

	Univariable GMR (95% CI)	**p-value**[1]
Kerosene Use	1.1 (0.8 – 1.6)	0.55
Wood Use	**2.1 (1.4 – 2.9)**	**0.0001**
Combined Fuel Types		
LPG/electricity only	REF	
Kerosene (no biomass)	1.2 (0.8 – 1.8)	0.41
Wood (no kerosene)	**2.2 (1.4 – 3.2)**	**0.0002**
Both kerosene and wood	2.0 (1.0 – 4.2)	0.06
Time using LPG		
None	REF	
< 1 hour	--	--
≥ 1 hour	0.6 (0.4 – 0.9)	0.01
Time using Kerosene		
None	REF	
< 1 hour	1.1 (0.6 – 1.9)	0.77
≥ 1 hour	1.1 (0.7 – 1.8)	0.59
Time using Wood		
None	REF	
< 1 hour	1.6 (0.9 – 2.8)	0.14
≥ 1 hour	**2.4 (1.5 – 3.6)**	**0.0001**
Log volume of cooking area	**0.9 (0.8 – 1.0)**	**0.004**
Door always open while cooking	1.2 (0.9 – 1.7)	0.24
Windows always open while cooking	0.8 (0.6 – 1.1)	0.10
Construction material of the kitchen		
All corrugated metal	REF	
Roof or walls corrugated metal	0.7 (0.5 – 1.1)	0.14
All concrete or brick	**0.4 (0.3 – 0.6)**	**< 0.0001**
Construction material of kitchen (continuous)	**0.6 (0.5 – 0.7)**	**< 0.0001**
Visible gap between the roof and the top of the walls	**1.9 (1.3 – 2.7)**	**0.001**
What type of road does the house lie on		
Small	REF	

	Univariable GMR (95% CI)	**p-value[1]**
Medium or large	0.9 (0.6 – 1.5)	0.78
Smell others using biomass daily	**1.5 (1.0 – 2.2)**	**0.03**
Smell others using mishri daily	1.1 (0.7 – 1.8)	0.56
Self or neighbors burn trash daily	0.9 (0.5 – 1.4)	0.60
Burning incense	1.0 (0.7 – 1.3)	0.79
Use mosquito coils	1.2 (0.7 – 1.8)	0.53
Light source: Kerosene	2.0 (0.8 – 4.9)	0.12
Light source: Candles	1.0 (0.6 – 1.4)	0.81
Winter Season	**1.6 (1.2 – 2.2)**	**0.002**

[1] Bolded values statistically significant at $p < 0.05$

Table 4

Multivariate linear regression for continuous log 24-hour average $PM_{2.5}$ ($\mu g/m^3$) concentration controlling for kerosene and wood, ventilation, and other sources of HAP among households in low-income urban homes in Pune, India (n = 163).

	Total	**Univariate GMR (95% CI)**	**p-value**[1]	**Multivariate GMR (95% CI)**	**p-value**[1]
Kerosene Use					
No	129 (79)	REF		REF	
Yes	34 (21)	1.0 (0.7 – 1.4)	0.90	1.2 (0.9 – 1.5)	0.25
Wood Use					
No	130 (80)	REF		REF	
Yes	33 (20)	**2.0 (1.5 – 2.7)**	**0.0001**	**1.5 (1.1 – 2.0)**	**0.004**
Log volume of cooking area	6.1 (5.3 – 6.7)	**0.9 (0.8 – 0.9)**	**0.0001**	**0.9 (0.87 – 0.99)**	**0.04**
Window always open while cooking					
No	88 (54)	REF		REF	
Yes	75 (46)	0.8 (0.6 – 1.0)	0.10	0.8 (0.6 – 1.1)	0.12
Door always open while cooking					
No	59 (36)	REF		REF	
Yes	104 (64)	1.1 (0.8 – 1.4)	0.58	0.9 (0.7 – 1.1)	0.30
Construction material of the kitchen					
All corrugated metal	30 (18)	REF		REF	
Roof or walls corrugated metal	43 (26)	0.8 (0.6 – 1.2)	0.35	1.1 (0.8 – 1.6)	0.58
All concrete or brick	90 (55)	**0.5 (0.4 – 0.7)**	**< 0.0001**	0.8 (0.5 – 1.1)	0.13
Burning incense					
No	69 (42)	REF		REF	
Yes	94 (58)	1.1 (0.9 – 1.5)	0.32	1.2 (0.98 – 1.5)	0.07
Use mosquito coils					
No	143 (88)	REF		REF	
Yes	20 (12)	1.3 (0.9 – 1.9)	0.24	**1.5 (1.1 – 2.1)**	**0.01**

	Total	Univariate GMR (95% CI)	p-value[1]	Multivariate GMR (95% CI)	p-value[1]
Winter					
No	104 (64)	REF		REF	
Yes	59 (36)	**1.8 (1.4 – 2.4)**	**< 0.0001**	**1.7 (1.4 – 2.2)**	**< 0.0001**

[1] Bolded values are statistically significant at $p < 0.05$

Table 5

Logistic regression for odds of being in the top quartile for average $PM_{2.5}$ ($\mu g/m^3$) controlling for kerosene and wood, cooking fuel behaviors, and other sources of HAP among households in low-income urban homes in Pune, India (n = 163).

	Univariate OR (95% CI)	p-value[1]	Adjusted OR (95% CI)	p-value[1]
Kerosene Use				
No	REF		REF	
Yes	1.1 (0.9 – 1.3)	0.42	1.1 (0.9 – 2.0)	0.48
Wood Use				
No	REF		REF	
Yes	**1.3 (1.1 – 1.5)**	**0.0002**	**1.3 (1.1 – 1.5)**	**0.005**
Log volume of cooking area	**0.95 (0.92 – 0.99)**	**0.01**	0.97 (0.94 – 1.0)	0.16
Window always open while cooking				
No	REF		REF	
Yes	**0.9 (0.7 – 0.97)**	**0.02**	0.9 (0.8 – 1.0)	0.054
Door always open while cooking				
No	REF		REF	
Yes	1.0 (0.9 – 1.1)	0.95	0.9 (0.8 – 1.0)	0.16
Construction material of the kitchen				
All corrugated metal	REF		REF	
Roof or walls corrugated metal	0.9 (0.7 – 1.8)	0.21	1.0 (0.8 – 1.3)	0.79
All concrete or brick	**0.7 (0.6 – 0.9)**	**0.0002**	0.9 (0.7 – 1.1)	0.14
Burning incense				
No	REF		REF	
Yes	**1.2 (1.02 – 1.4)**	**0.03**	**1.1 (1.0 – 1.3)**	**0.03**
Use mosquito coils				
No	REF		REF	
Yes	**1.2 (1.1 – 1.4)**	**0.01**	**1.3 (1.1 – 1.6)**	**0.003**
Winter				
No	REF		REF	
Yes	**1.2 (1.1 – 1.4)**	**0.002**	**1.2 (1.1 – 1.4)**	**0.004**

[1] Bolded values are statistically significant at $p < 0.05$