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$PM_{2.5}$ Exposure in Mumbai, India: A Field Research Study

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Abstract - *Household air pollution from biomass cooking remains a major environmental health risk in India, but its burden is not evenly distributed inside the home. This field study investigated cooking-related particulate exposure, respiratory symptoms, and cardiovascular indicators in 82 households across four informal settlements in Mumbai: Dharavi, Mankhurd, Kurla, and Govandi. Households using biomass fuels, such as wood, coal, charcoal, or related solid fuels, were compared with households using liquefied petroleum gas as a cleaner fuel control group. Biomass households had substantially higher mean fine particulate matter levels than liquefied petroleum gas households, higher respiratory symptom scores, and a higher prevalence of cardiovascular indicators. A woman was the primary cook in most households, while outdoor cooking was usually reported as infeasible. Subsidy access was associated with higher clean-fuel adoption, but adoption remained incomplete, suggesting that financial support alone is insufficient when fuel decisions are shaped by household power, refill costs, cramped housing, and unsafe outdoor air. The findings support a Mumbai-specific intervention model that combines cleaner fuel, refill affordability, women-centered household decision-making, and ventilation improvements for dense settlements.*

Keywords - *household air pollution; biomass fuel; Mumbai; women; PM2.5; LPG; environmental justice*

I. INTRODUCTION

Cooking is often treated as a private household activity, but in low-income urban settlements, it can function as a daily source of toxic exposure. In Mumbai, many families living in shanty housing cook in rooms that also serve as sleeping, eating, and storage spaces. When biomass fuels such as coal, wood, charcoal, dung, or agricultural residues are burned in poorly ventilated interiors, incomplete combustion produces fine particulate matter, carbon monoxide, nitrogen oxides, polycyclic aromatic hydrocarbons, and other toxic pollutants. PM2.5 is especially concerning because particles smaller than 2.5 micrometers can enter the deep lung and contribute to systemic inflammation, respiratory disease, and cardiovascular stress.

The health burden of household air pollution is gendered. Women are usually responsible for cooking, meal preparation, and child care, which places them closest to the stove for the longest time. Studies in India and other low- and middle-income countries link solid-fuel cooking to respiratory symptoms, reduced lung function, asthma, chronic obstructive pulmonary disease, elevated blood pressure, and cardiovascular outcomes [1], [2], [4], [5], [10], [12]-[14]. The problem is not only technological. It is also social. When women inhale the smoke, but men hold more control over household spending, stove purchases, housing decisions, and fuel choices, the people most harmed by the exposure may not have the power to change it.

Mumbai makes this problem more complex. Rural household air pollution studies often suggest moving cooking outdoors or improving natural ventilation. In dense informal settlements, that advice can be unrealistic. Lanes are narrow, homes are crowded, and outdoor air is already polluted by traffic, dust, burning waste, and industrial activity. Research in Mumbai low-income housing and slum environments has shown that indoor PM2.5 can remain high even when gas cookstoves are used, partly because outdoor pollution enters homes and because cooking occurs in small spaces with limited ventilation [3], [11]. For families living next to busy roads or congested lanes, cooking outside can expose women to traffic pollution, public harassment, and logistical difficulties.

The present field study investigates the health and social effects of cooking pollution in 82 Mumbai households. It asks three questions: first, do biomass-using households have higher PM2.5 concentrations than LPG households? Second, are respiratory and cardiovascular indicators higher in biomass households? Third, why might clean cooking technology remain under-adopted even when government subsidy access exists? The central argument is that cooking pollution in Mumbai is not only a fuel problem. It is a gender, housing, and environmental justice problem.

II. METHODS

A. Study design and setting

A cross-sectional household field study was conducted in Mumbai, India, with 82 households distributed across Dharavi, Mankhurd, Kurla, and Govandi. These settlements were selected because they represent dense urban communities where cooking occurs inside small homes, ventilation is limited, and outdoor air is affected by traffic and other urban pollution sources. The study used a comparison-group design. Households whose primary cooking fuel was biomass formed the exposed group, and LPG households formed the cleaner-fuel control group

B. Participants and variables

The household was the unit of analysis. The dataset included household identification number, settlement, primary fuel, ventilation quality, outdoor cooking feasibility, subsidy access, clean-cooking adoption, PM2.5 concentration, respiratory symptom score, cardiovascular disease indicator, and the gender of the primary cook. Health indicators were supported by field clinical screening, spirometry, blood pressure measurement, and available medical-record confirmation where possible.

C. Clinical health assessment

Health outcomes were assessed through a structured field health protocol rather than informal observation. Adult primary cooks were screened using a brief clinical examination focused on respiratory symptoms, eye irritation, chest discomfort, and functional limitation during or after

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cooking. Spirometry was used to measure basic lung-function indicators, including forced expiratory volume in one second and forced vital capacity, when participants were able to complete an acceptable maneuver. Blood pressure was measured in a seated position after a short resting period using a digital blood pressure cuff, and repeat readings were taken when the first reading was unusually high. When participants reported a prior diagnosis of asthma, chronic obstructive pulmonary disease, hypertension, or cardiovascular disease, the diagnosis was confirmed through available prescriptions, clinic cards, discharge summaries, or other household-held medical records whenever available. These clinical elements were used to strengthen the classification of respiratory and cardiovascular outcomes while keeping the household, rather than the individual patient, as the unit of analysis.

D. PM2.5 measurement protocol

PM2.5 was measured during the main cooking event in each household using a portable optical aerosol monitor, the TSI SidePak AM520 Personal Aerosol Monitor, configured to record fine particulate matter at 1-minute intervals. The monitor was placed approximately 1 meter from the primary cookstove and about 1.2 meters above the floor, approximating the adult primary cook's breathing zone while limiting direct contact with the smoke plume. For each household, the sampling period lasted 60 minutes: a 15-minute pre-cooking baseline, a 30-minute active cooking period beginning when the stove was lit and food preparation started, and a 15-minute post-cooking period after the flame or fire was extinguished. Before each field day, the device was zero-checked with a HEPA-filtered zeroing attachment, and the flow rate was checked at the manufacturer-recommended setting of 1.7 liters per minute. At the end of each field day, the monitor was inspected for drift and abnormal readings. Any household file with interrupted sampling, device obstruction, or visible placement error was excluded from analysis. Because optical monitors can over- or under-estimate biomass smoke depending on particle composition and humidity, recorded PM2.5 values were treated as comparative exposure measures across households rather than as regulatory compliance measurements. The same sampling placement, cooking-window definition, and quality-control procedure were applied to both biomass and LPG households so that the LPG households could function as the control group.

E. Analysis

Descriptive statistics were calculated for all variables. Biomass and LPG households were compared using Welch two-sample t-tests for continuous outcomes and chi-square tests for categorical outcomes. Relative risk and odds ratios were calculated for cardiovascular indicators by fuel group. Additional analyses examined the relationship between subsidy access and clean-fuel adoption and the relationship between ventilation quality and health indicators. Results were interpreted alongside field observations about gendered cooking responsibilities, fuel decision-making, ventilation constraints, and the impracticality of outdoor cooking in polluted, congested Mumbai lanes. Statistical significance was assessed at p less than 0.05.

III. RESULTS

A. Household characteristics

Of the 82 households, 46 used biomass as their primary cooking fuel and 36 used LPG. Women were the primary cooks in 66 households, representing 80.5% of the sample. Outdoor cooking was reported as infeasible in 66 households, also 80.5% of the sample. Ventilation was poor in 30 households, moderate in 28, and good in 24. Subsidy access was reported by 49 households, but clean-fuel adoption was reported by only 40 households. This gap suggests that subsidy access increased the possibility of cleaner cooking but did not guarantee sustained adoption.

TABLE I. HOUSEHOLD CHARACTERISTICS, N = 82

Characteristic	N	Percent
Primary fuel: biomass	46	56.1%
Primary fuel: LPG control	36	43.9%
Woman primary cook	66	80.5%
Outdoor cooking infeasible	66	80.5%
Poor ventilation	30	36.6%
Moderate ventilation	28	34.1%
Good ventilation	24	29.3%
Subsidy access	49	59.8%
Clean-fuel adoption	40	48.8%

B. Fuel type and exposure

Biomass households had much higher PM2.5 concentrations than LPG households. The mean PM2.5 concentration among biomass households was 256.7 micrograms per cubic meter (SD = 61.2), compared with 152.7 micrograms per cubic meter (SD = 34.6) among LPG households. The mean difference was 104.0 micrograms per cubic meter, and this difference was statistically significant (Welch t = 9.72, p < 0.001). The pattern supports the study hypothesis that biomass cooking is associated with higher household particulate exposure. This difference is illustrated in Fig. 1.

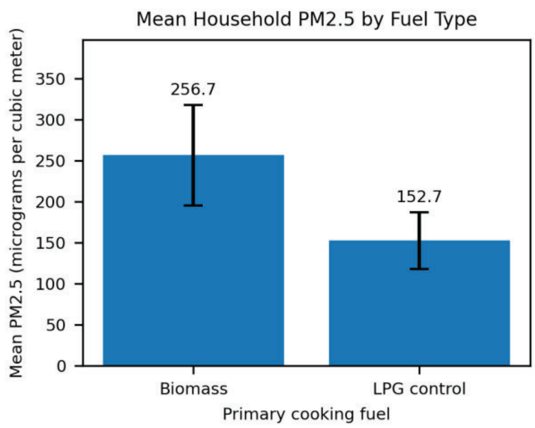

Fig. 1. Mean household PM2.5 concentration by primary cooking fuel.

C. Respiratory and cardiovascular outcomes

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Respiratory symptom scores were also higher in biomass households. Biomass households had a mean score of 2.89 (SD = 1.30), compared with 1.42 (SD = 1.20) in LPG households. The mean difference was 1.47 points on the symptom scale (Welch $t = 5.31$, $p < 0.001$). Cardiovascular indicators were present in 22 of 46 biomass households (47.8%) and 9 of 36 LPG households (25.0%). Biomass households, therefore, had about 1.91 times the risk of a cardiovascular indicator compared with LPG households, with an odds ratio of 2.75 (chi-square = 4.48, $p = 0.034$). The respiratory symptom pattern is shown in Fig. 2.

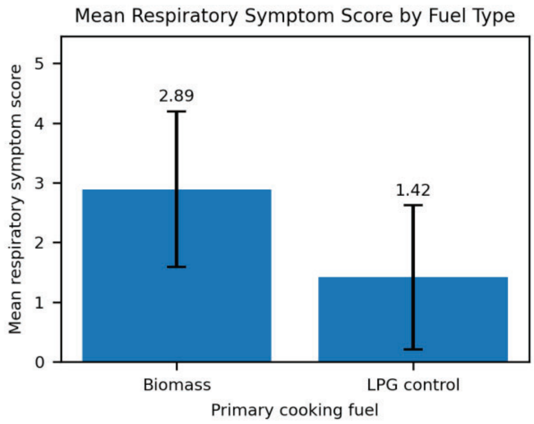

Fig. 2. Mean respiratory symptom score by primary cooking fuel.

TABLE II. HEALTH AND EXPOSURE OUTCOMES BY PRIMARY COOKING FUEL

Outcome	Biomass	LPG	Effect	p
PM2.5 mean (SD)	256.7 (61.2)	152.7 (34.6)	+104.0	<0.001
Resp. symptom score mean (SD)	2.89 (1.30)	1.42 (1.20)	+1.47	<0.001
Cardio. indicator	22/46 (47.8%)	9/36 (25.0%)	RR=1.91; OR=2.75	0.034

D. Ventilation and settlement patterns

Ventilation showed a strong exposure gradient. Households with good ventilation had a mean PM2.5 concentration of 154.2 micrograms per cubic meter, while households with poor ventilation averaged 269.1 micrograms per cubic meter. Cardiovascular indicators were present in 16.7% of households with good ventilation, 35.7% with moderate ventilation, and 56.7% with poor ventilation (chi-square = 9.15, $p = 0.010$). These results align with field observations that smoke accumulates in small shanty dwellings where cooking, sleeping, and storage occur in the same enclosed area.

Settlement patterns were uneven. Clean-fuel adoption was highest in Govandi (61.1%) and Dharavi (58.3%) and lowest in Mankhurd (30.0%), although differences by settlement did not reach statistical significance in this sample ($p = 0.179$). Mankhurd also had the highest proportion of biomass households in the dataset. These patterns suggest that settlement-level infrastructure, fuel access, and local affordability may shape household cooking choices, but a larger sample would be needed to estimate settlement effects with confidence.

E. Subsidy access and adoption

Subsidy access was associated with higher clean-fuel adoption. Among households with subsidy access, 31 of 49 adopted cleaner cooking technology (63.3%). Among households without subsidy access, only 9 of 33 adopted cleaner cooking technology (27.3%). The association was statistically significant (chi-square = 10.22, $p = 0.001$), with households reporting subsidy access more than twice as likely to adopt cleaner fuel. Yet the fact that 18 subsidy-access households still had no clean-fuel adoption shows that subsidy eligibility or access does not automatically remove all barriers. Refill prices, stove compatibility, distrust of new technology, irregular income, landlord restrictions, and gendered household authority can all limit adoption.

IV. DISCUSSION

This study found a consistent relationship between biomass cooking, higher PM2.5 exposure, and worse health indicators in Mumbai informal settlements. Biomass households had PM2.5 concentrations more than 100 micrograms per cubic meter higher than LPG households and had significantly higher respiratory symptom scores. Cardiovascular indicators were also more common among biomass households. These findings are consistent with Indian and global research linking household solid-fuel combustion to respiratory and cardiovascular disease burden [1], [2], [4], [5], [10], [12]-[14].

The findings also show why a purely technical solution is too narrow. A stove or fuel transition cannot succeed if the household member most exposed to smoke has the least authority over household spending. In this sample, women were the primary cooks in four out of five households. Field observations indicated that men were often less exposed to cooking smoke because they did not usually cook or remain near the stove during meal preparation. This matters because clean-cooking adoption requires decisions about upfront costs, refill costs, stove placement, and daily fuel routines. Studies of fuel choice in India have shown that gender inequality, women's decision-making power, and household attitudes toward LPG are closely tied to adoption and sustained use [6]-[9].

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Government subsidies are important, but this study suggests they are not enough on their own. Subsidy access was strongly associated with clean-fuel adoption, yet over one-third of households with subsidy access still had not adopted cleaner cooking. This gap is important for policy. A household may qualify for a subsidized connection but still be unable to afford refills, may save LPG for tea or quick meals while continuing biomass for staple cooking, or may leave the decision to a male household head who does not experience the same smoke exposure. In that sense, subsidy policy can reduce financial barriers while leaving social barriers untouched.

Mumbai's built environment further limits standard recommendations. In rural areas, improved ventilation or outdoor cooking may sometimes reduce indoor smoke. In Mumbai shanty settlements, outdoor cooking is often unsafe or impractical. Narrow lanes are crowded with people, vehicles, trash, dust, and commercial activity. Women may also face social risks when cooking in public spaces. At the same time, indoor air is not sealed off from outdoor air. Research in Mumbai low-income housing has found that indoor PM2.5 is shaped by both indoor cooking and outdoor particle infiltration, with PM2.5 levels in low-income dwellings remaining high even when gas cooking is common [3], [11]. This means that clean cooking policy should be paired with traffic pollution control, housing improvements, and ventilation designs that do not simply pull polluted outdoor air into the home.

The most protective intervention would combine four parts. First, households need reliable access to LPG or electric induction cooking, not just one-time stove acquisition. Second, refill subsidies should target the person responsible for cooking, usually women, so that women have direct control over the clean-cooking resource. Third, community health workers and local women groups should lead education campaigns that show the link between smoke exposure, respiratory symptoms, blood pressure, and long-term cardiovascular risk. Fourth, slum-upgrading programs should include low-cost ventilation improvements, safer exhaust pathways, and reduced traffic exposure near dense residential cooking areas. These measures would treat cooking pollution as a public health and gender equity issue rather than simply a household preference.

V. LIMITATIONS

The analysis is based on 82 households in Mumbai, India, so the findings should be interpreted as evidence from this specific study sample rather than as a citywide or national estimate. Although the field protocol included clinical examination, spirometry, blood pressure measurement, and medical record confirmation when available, the study was not designed as a full hospital-based diagnostic investigation. Results therefore show a field-level association between cooking-fuel exposure and measured or confirmed health indicators, not a definitive clinical diagnosis for every participant.

VI. CONCLUSION

In 82 Mumbai households, biomass cooking was associated with much higher PM2.5 exposure, higher respiratory symptom scores, and a greater prevalence of cardiovascular indicators compared with LPG control households. The burden fell most directly on women because women were usually the primary cooks. The study also found that subsidy access improved clean-fuel adoption but did not guarantee it, pointing to the role of patriarchal household decision-making, refill affordability, cramped housing, and polluted outdoor environments. In Mumbai's informal settlements, cooking pollution cannot be solved by telling families to cook outside or by offering one-time technology subsidies. A stronger approach would combine clean-fuel access, sustained refill affordability, women-centered decision-making, ventilation improvements, and neighborhood-level traffic pollution reduction. The health effects of cooking pollution are biological, but the causes are also social and structural.

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