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Household air pollution as a determinant of health status: A study on older adults in Siliguri Municipal Corporation, India

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Household air pollution (HAP), stemming from solid fuels, traditional cooking practices, and indoor pollutants like incense and mosquito oils, poses severe health risks, particularly for older adults. This study assesses the impact of HAP on self-reported health (SRH) among older adults in Siliguri municipal corporation, India. A cross-sectional survey of 400 older adults used multiple binary logistic regression to analyze HAP's impact on poor SRH. Solid fuel use, traditional cooking, lack of ventilation, and exposure to mosquito oil and family smoking were significantly linked to poorer health. Findings underscore the need for policy measures to reduce HAP through cleaner energy and ventilation improvements, aligning with SDG 7 goals to enhance the health of vulnerable populations.

Keywords Household air pollution, Older adults, Health status, Siliguri Municipal Corporation, Sustainable development goal 7

Air pollution within homes, known as household air pollution (HAP), poses an increasing health risk to older adults in India, primarily due to traditional cooking practices and the widespread use of solid biomass fuels[1]. The extensive use of conventional biomass fuels like wood, shrubs, animal dung, crop residue, and coal combustion is a major contributor to this problem, particularly in developing nations where these solid biomass fuels are prevalent for domestic cooking[2]. The reliance on solid biomass fuels and traditional cooking practices in households across India exacerbates the health implications of HAP for older adults[3].

Household air pollution primarily stems from the use of solid fuels for cooking, heating, and lighting, as well as the burning of incense sticks, mosquito repellents, and smoking within homes[4]. The combustion of these fuels and materials releases a plethora of harmful pollutants, including particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs), which pose severe health risks[5]. The elderly are particularly vulnerable to these pollutants due to their weakened immune systems and pre-existing health conditions, such as respiratory and cardiovascular diseases[6].

The extensive use of unclean solid biomass fuels in household cooking releases harmful substances, leading to various health problems, including lung diseases, respiratory issues, diabetes, and more[7]. Sustainable Development Goal (SDG)-7 aims to ensure universal access to clean fuels and technologies, highlighting the imperative to reduce dependence on harmful energy sources for cooking, heating, and lighting[8]. HAP constitutes 4% of the total global disease burden, with its major source being solid biomass cooking fuels. This issue disproportionately affects the health of women and older adults, who spend significant time in cooking areas. According to the World Health Organization (WHO), HAP was responsible for an estimated 3.2 million deaths globally in 2020. The combined effects of ambient (outdoor) and HAP are associated with approximately 6.7 million premature deaths annually[9].

The reliance on solid fuels varies significantly between urban and rural areas. In rural India, the majority of households continue to depend on solid biomass fuels such as wood, cow dung, and agricultural residue for cooking due to limited access to clean fuel alternatives and affordability constraints[10]. Despite efforts to promote cleaner cooking fuels like liquefied petroleum gas (LPG) through government initiatives, many rural households still prefer traditional biomass fuels due to cost-effectiveness and cultural familiarity.

In contrast, urban areas have witnessed a transition toward cleaner fuels, with a higher proportion of households using LPG and electricity for cooking[11]. However, socio-economic disparities within cities mean that low-income urban households, particularly in slums and informal settlements, still rely on solid fuels for cooking and heating[12]. Additionally, urban settings present unique air pollution challenges due to high

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population density, poor ventilation in small homes, and exposure to multiple sources of indoor pollution such as incense burning, mosquito repellents, and smoking.

In India, the older adult population constitutes 8.6% and is projected to reach 19.1% by 2050[10]. Consequently, Indian policymakers express concerns about the rapid growth of the older population and the increased use of traditional biomass burning, adversely affecting the health of older adults[11]. Health, as per the WHO definition, is holistic, encompassing physical, mental, and social well-being. This study builds on prior research about the impact of HAP on health, including components like fuel sources and methods of cooking practices[12–14].

Previous studies have explored the impact of household air pollution on health across different countries, providing a conceptual framework for understanding the selected variables in this study. For instance, in a cross-country analysis, Oluwatosin et al. examined the health effects of household air pollution in sub-Saharan Africa and found a significant association between solid fuel use and respiratory diseases[15]. Similarly, Luo et al. conducted a global analysis and reported that household air pollution is a major risk factor for chronic obstructive pulmonary disease (COPD) and lung cancer, particularly in women and older adults who spend considerable time near cooking areas[16]. These findings underscore the importance of evaluating various sources of household air pollution and their health impacts.

In addition, studies by Balmes highlighted that the type of fuel used for cooking significantly affects indoor air quality and health outcomes[6]. His research demonstrated that transitioning from traditional biomass fuels to cleaner alternatives can lead to substantial improvements in respiratory health. Similarly, research by Wang and Yang emphasized the role of household air pollution in contributing to cardiovascular diseases, indicating that exposure to pollutants from cooking with solid fuels increases the risk of hypertension and heart disease among older adults[17].

In the context of India, studies by Krishnamoorthy et al. and Ashwani & Kalosona have highlighted the detrimental health effects of household air pollution, with significant implications for respiratory and cardiovascular health[18,19]. These studies provide a basis for examining the specific variables selected in this research, such as fuel type, cooking place, and the use of incense sticks, mosquito oil, and fast cards. By focusing on these variables, this study examines the association between health status and various independent factors, including fuel type (clean vs. polluting), cooking place (indoor vs. outdoor), way of cooking (modern vs. traditional), use of incense sticks, fast cards, mosquito oil, and smoking by family members. By analyzing these factors, the study aims to elucidate the extent to which household air pollution affects the health of the elderly in Siliguri Municipal Corporation (SMC).

Despite these insights, research specifically addressing the impact of HAP on the SRH of older adults in India remains limited. Most existing studies focus on macro regions or specific demographic groups like women health, and child health, leaving a gap in understanding the effects of HAP on the elderly in urban contexts[20–24]. SMC, a rapidly urbanizing city in West Bengal, India, presents a unique context for examining the impact of household air pollution on elderly health in (Fig. 1). The city's diverse population and varying socio-economic conditions contribute to different levels and types of indoor air pollution, providing an opportunity to study its effects comprehensively. By employing a context-specific approach, this study builds on existing evidence and extends the understanding of HAP in urban areas, where indoor air pollution sources and their impacts may differ from rural or national averages. This study aims to fill this gap by providing a detailed analysis of how various sources of indoor air pollution affect the health of older adults in SMC.

Methods

Study area

Siliguri is situated at the foothills of the Himalayas along the Mahananda River in the Darjeeling district plains, at approximately 26.72°N latitude and 88.41°E longitude.

Siliguri municipality was established in 1949 and gained Corporation status in 1994, expanding its jurisdiction to include parts of both Darjeeling and Jalpaiguri districts. Of its 47 wards, 14 are in Jalpaiguri, covering a total area of 41.90 km^2 (16.18 sq mi).

Figure 1 illustrates the location of the study area. This map was generated using ArcGIS Desktop version 10.8, a comprehensive geographic information system software developed by Esri[25]. The map was created by the corresponding author, utilizing spatial data to accurately represent the geographical context of SMC within the specified coordinates.

Data source and sampling design

This study is grounded in primary data collection conducted within the SMC of West Bengal. Data collection occurred from April, 2023 to September, 2023. Employing a cross-sectional design, A multistage stratified random sampling method was employed to select sample respondents. In the first stage, all wards within the SMC were included.

In the second stage, we stratified the population based on their residential status, distinguishing between slum and non-slum residents. We selected 200 individuals from each stratum, ensuring equal representation of both residential categories. The third stage involved stratification based on sex, with an equal number of male and female respondents selected from both residential categories. This resulted in a balanced sample of 200 males and 200 females. The sample selection procedure has been presented (Fig. 2).

Determination of sample size

In this study, it is important to note that the total number of older adults (aged 60 years and above) living in both slum and non-slum areas of SMC is not fully estimated or accounted for. The reason for this uncertainty stems from the diverse and dynamic nature of slum populations, which are often categorized into three types: notified, non-notified, and recognized slums. Additionally, the floating nature of slum populations—where residents

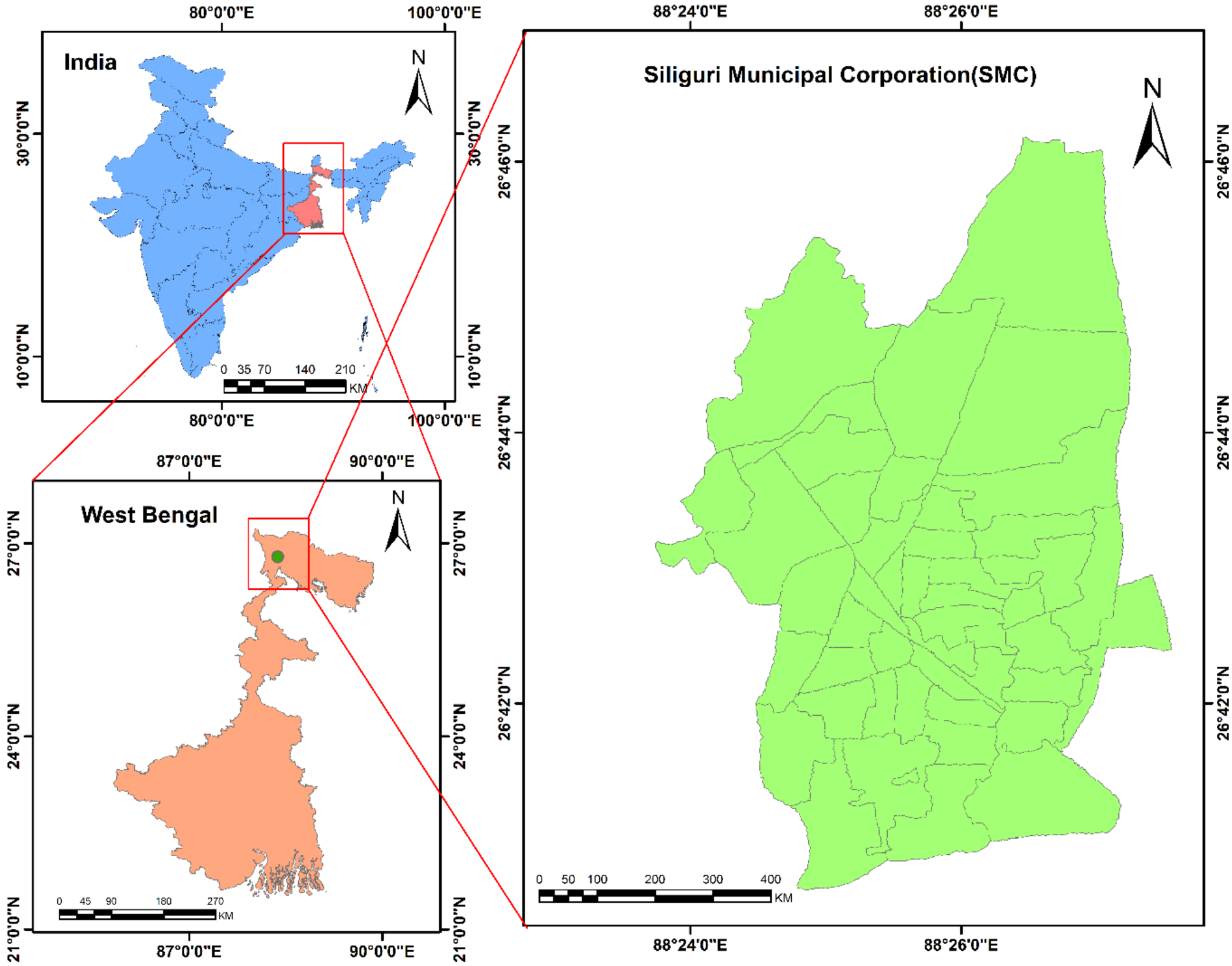

Fig. 1. Location map of the study area.

frequently move in and out—further complicates the ability to estimate the exact number of older adults living in these areas. To address this issue, the study utilized Cochran's formula to determine the ideal sample size[26]. This formula is particularly useful in cases where the total population size is unknown, as it helps researchers select a sample size that ensures the study remains rigorous and reliable.

Cochran's equation is represented as follows:

$$n = \frac{Z^2.p(1-p)}{E^2}$$

where:

n = sample size.

Z = Z-score for a 95% confidence level, approximately 1.96.

p = estimated proportion (for this study, we assume p =0.5 $p = 0.5$ or 50%).

E = margin of error, set at 0.05 (5%).

Taking these parameters into account, the calculated ideal sample size is determined to be 385. To account for potential issues such as missing data, non-responses, or incomplete answers, an additional 15 samples (about 4%) were added. Therefore, the total sample size for this study is 400.

Outcome variable

In this study, the dependent variable is health status, measured as a binary outcome based on participants' self-evaluation of their well-being. Health status reflects a range of socioeconomic, biological, and psychological factors. Participants were asked: "Overall, how is your health in general? Would you say it is very good, good, fair, poor, or very poor?"

Responses were dichotomized into "good" (including ratings of fair, good, and very good) and "poor" (including ratings of poor and very poor). This dichotomization aligns with established research practices[27],

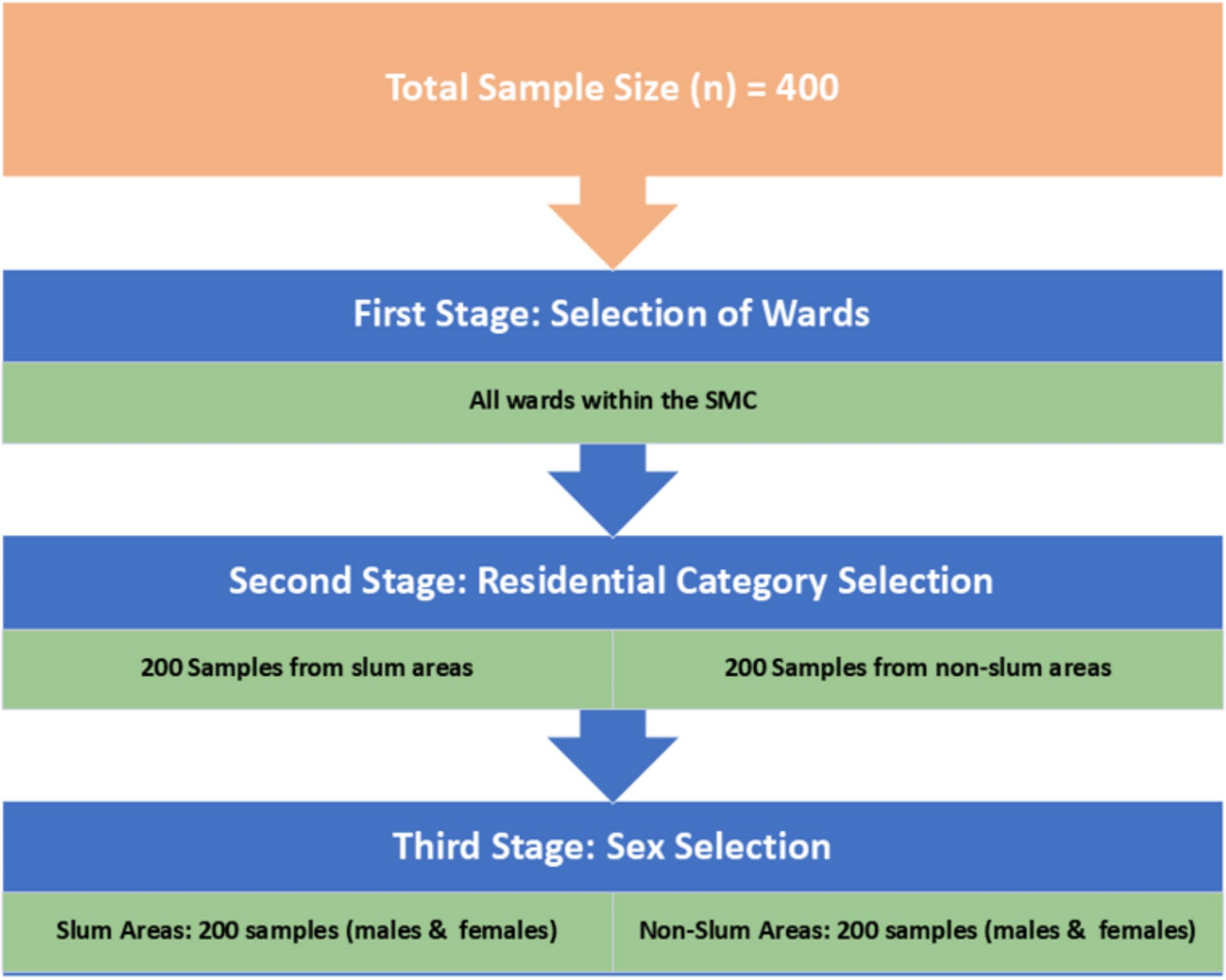

Fig. 2. Sample selection procedure.

enabling a focused analysis of household air pollution factors influencing health outcomes among older adults in Siliguri Municipal Corporation.

Predictor variables

Based on previous research, the present study considers various independent variables related to household air pollution that impact the health status among the elderly[28–31]. These variables include age, sex, residence, cooking fuel usage, cooking environment, cooking methods, use of incense sticks, use of fast cards, use of mosquito oil, and exposure to secondhand smoke from family members. The study categorizes participants into three age groups: young age (60–70 years), middle age (71–80 years), and old age (81 years and above). Participants are classified by sex into male and female categories. The study distinguishes between participants residing in slum areas and those in non-slum areas. A brief description of independent variables has been presented in (Table 1).

Statistical analysis

Statistical analyses were conducted to explore factors of household air pollution associated with poor health status among older adults in SMC. Initially, descriptive statistics were calculated to determine the prevalence of poor health. Pearson's Chi-square test was performed to evaluate the statistical significance of associations between categorical variables. The chi-square value in Table 2 represents the strength of association, with a p-value < 0.05 indicating statistical significance. To further assess the influence of HAP components on poor SRH, multiple logistic regression analysis was performed. Unadjusted odds ratios were first estimated to provide an initial measure of association between each independent variable and poor SRH. This was followed by the computation of adjusted odds ratios, which control for potential confounding variables, providing a more accurate estimate of the independent effects of each predictor. Statistical significance was determined using a p-value threshold of 0.05. All analyses were performed using STATA software (Mehmetoglu & Jakobsen, 2022).

The final multiple logistic regression model included only those independent variables that were statistically significant (p-value < 0.05) in the unadjusted model. A variance inflation factor (VIF) analysis was conducted to

HAP component	Question	Operational definition & coding
Fuel type	What is your main source of cooking fuel?	Liquid fuels (code 1): Households that primarily use clean sources of fuel for cooking, including liquefied petroleum gas (LPG), Biogas, Kerosene, or Electric. These fuels are less polluting and are considered safer for indoor air quality.
		Solid fuels (code 2): Households that rely on traditional sources of fuel such as wood, dung cake, crop residue, or coal. These fuels produce higher emissions and contribute significantly to indoor air pollution.
Cooking place	Where is cooking usually done?	Separate kitchen (code 1): Households that have a separate kitchen area, which may be a room specifically for cooking that is separate from the living space. This arrangement helps reduce exposure to indoor air pollution.
		In the room (code 2): Households where cooking occurs in the same area where the family lives, such as the main room or common area. This situation can lead to higher exposure to harmful pollutants due to inadequate ventilation.
Cooking method	How is cooking primarily done?	Traditional methods (code 1): Households that use conventional cooking methods without modern ventilation. This may involve open flames or simple stoves, resulting in higher levels of indoor smoke and pollutants.
		Modern ventilation (code 2): Households that use modern cooking methods with effective ventilation systems, including electric chimneys or exhaust fans that help eliminate smoke and improve air quality.
		Other methods (code 3): Households using alternative methods that do not fit traditional or modern categories, such as cooking near windows or doors or using portable fans for ventilation. These methods may provide some airflow but may not significantly reduce pollution levels.
Incense stick usage	Does your household regularly burn incense sticks?	No (code 1): Households that do not engage in burning incense sticks, thus minimizing exposure to particulate matter and other pollutants released from burning incense.
		Yes (code 2): Households that frequently burn incense sticks, typically for religious or cultural reasons. This practice can contribute to increased levels of indoor air pollution due to the smoke produced.
Fastcards	Does your household use fast-burning mosquito repellent cards?	Yes (code 1): Households that utilize fast-burning mosquito repellent cards, which emit smoke to deter mosquitoes. This practice introduces additional indoor air pollutants.
		No (code 2): Households that do not use these products, thereby reducing the risk of increasing indoor air pollution levels.
Mosquito oil usage	Does your household use mosquito repellent oils?	No (code 1): Households that do not use mosquito repellent oils, reducing overall indoor air pollutants and improving air quality.
		Yes (code 2): Households that apply mosquito repellent oils, often using them on burners or vaporizers. These products can release harmful fumes or smoke when heated, contributing to indoor air pollution.
Smokking in home by family member	Does anyone in your household smoke inside the home?	No (code 1): Households where no members smoke tobacco products inside the home, thereby reducing exposure to harmful indoor smoke and improving overall air quality.
		Yes (code 2): Households where one or more family members smoke inside, significantly contributing to indoor air pollution and increasing health risks for all residents.

Table 1. Description of independent variables included in the study.

Components of HAP	*N*%	f	Prevalence	X^2 value	*P*-value
Fuel type					
Liquid	79.75	116	36.4	26.25	< 0.001
Solid	20.25	55	67.9		
Cooking place					
Separate kitchen	68	92	33.8	27.67	< 0.001
In the room	32	79	61.7		
Way of cooking					
Traditional	25.75	61	59.2	16.84	< 0.001
Chimney & exh	70.75	107	37.8		
Others	3.5	3	21.4		
Incense stick					
Yes	32.5	72	55.4	12.56	< 0.001
No	67.5	99	36.7		
Fast card					
Yes	52	96	46.2	2.05	0.152
No	48	75	39.1		
Mosquito oil					
Yes	46.25	93	50.3	7.95	0.005
No	53.75	78	36.3		
Smoking at home					
Yes	47	97	51.6	11.34	0.001
No	53	74	34.9		

Table 2. Prevalence of poor SRH by HAP components among older adults in SMC, India. X^2 value means chi-square value, p-values are derived from Pearson's chi-square test.

assess multicollinearity among predictor variables. Following Alkan et al. (2023), a VIF of 5 or higher indicates moderate multicollinearity, while a VIF of 10 or higher indicates high multicollinearity. In this study, no variables exhibited multicollinearity issues, with a mean VIF value of 1.34.

Ethical approval
Ethical approval was secured from the Research Advisory Committee of Raiganj University before data collection. A formal letter detailing the research objectives was submitted to the Siliguri Municipal Corporation to request their cooperation. Ethical considerations were given paramount importance throughout the study. Informed consent was obtained from all respondents at the beginning of data collection. The research follows the ethical principles set forth in the World Medical Association (WMA) Declaration of Helsinki.

Results
Background characteristics of the respondents by HAP components in the study
Our study includes a sample of 400 older adults, distributed across three age categories: Young-old (56.0%), Middle-old (31.3%), and Old-old (12.8%). The analysis of HAP components among these older adults in SMC also presented a significant differences between slum and non-slum areas. In SMC overall, 79.75% of households use liquid fuels, with a high concentration in non-slum areas (96%) compared to 63.5% in slum areas, where 36.5% still rely on solid fuels in (Fig. 3). Kitchen location also varies substantially; 94.5% of non-slum households have a separate kitchen, while only 41.5% of slum households do, with 58.5% of slum households cooking in the living area.

Cooking methods differ notably as well, with 97% of non-slum households using electric chimneys or exhaust fans, compared to 44.5% in slum areas. In slum areas, 51.5% use traditional cooking methods, compared to none in non-slum households, reflecting lower access to ventilation-enhancing appliances. Incense stick burning is reported by 67.5% in SMC overall, but it is notably higher in slum areas (58.5%) than in non-slum areas (6.5%).

The use of fast-burning mosquito repellents is higher in non-slum households (60.5%) than in slum households (43.5%). In contrast, mosquito oil usage is more common in slum areas, with 67% of non-slum households opting not to use it, while 59.5% of non-slum households do. Smoking indoors by family members is slightly more common in slum households (54.5%) than in non-slum households (39.5%).

Prevalence of poor SRH by HAP components among older adults in the study
The Table 2 indicates significant differences in poor SRH among older adults based on various HAP components in the SMC. Among households using different fuel types, those relying on solid fuels have a much higher prevalence of poor SRH at 67.9%, compared to only 36.4% in households using cleaner, liquid fuels. Cooking location also shows a notable difference, with poor SRH being reported by 61.7% of those cooking within the living room area, compared to 33.8% among those with a separate kitchen space.

Cooking method similarly impacts SRH, as older adults in households using traditional cooking methods report poor SRH at a rate of 59.2%, whereas those using chimneys or exhaust fans report a lower prevalence of 37.8%. For households that burn incense sticks, the prevalence of poor SRH is higher (55.4%) than in those that do not (36.7%). The use of mosquito repellent oil is also associated with higher rates of poor SRH, with a prevalence of 50.3% in users compared to 36.3% in non-users. Lastly, the presence of indoor smoking shows a higher prevalence of poor SRH at 51.6%, compared to 34.9% in households where no smoking occurs.

Influence of HAP components on poor SRH among older adults in SMC
The logistic regression model in this study shows significant associations between certain components of HAP and poor self-rated SRH among older adults in the SMC, presented in (Table 3).

Older adults living in households that use solid fuels, such as wood or coal, for cooking are over twice as likely to report poor SRH compared to those using cleaner fuels (AOR: 2.13; CI 1.18–3.82). Similarly, cooking within the living area is associated with more than double the odds of poor SRH (AOR: 2.09; CI 1.16–3.78), highlighting the risks posed by exposure to indoor air pollutants in spaces without designated kitchens.

Traditional cooking methods without modern ventilation, such as open flames, also increase the likelihood of poor SRH (AOR 1.73; CI 0.95–3.12).Furthermore, households that use mosquito repellent oils, which often release smoke or fumes when heated, have a higher risk of poor SRH among older adults (AOR 1.79; CI 1.15–2.78). The presence of a family member who smokes indoors is also significantly associated with a 73% higher likelihood of poor SRH in older adults (AOR 1.73; CI 1.13–2.66). These findings suggest that indoor air pollution factors, including the use of solid fuels, cooking within living spaces, mosquito repellent oils, and indoor smoking, play a crucial role in influencing the health outcomes of older adults in this community, as shown in (Fig. 4).

Comparison of UOR and AOR in Table 3 reveals key modifications after adjustment. For instance, the UOR for solid fuel use was 3.70 (95% CI 2.20–6.22), but after adjusting for other variables, the AOR reduced to 2.13 (95% CI 1.18–3.82). This reduction suggests that other confounders partially explain the association between solid fuel use and poor SRH, but it remains statistically significant. Similarly, for cooking in the living area, the AOR was 2.09 (95% CI 1.16–3.78), confirming a significant health risk.

Interestingly, the use of incense sticks, which had a significant UOR of 2.14 (95% CI 1.40–3.28), showed an AOR of 0.97 (95% CI 0.54–1.73) after adjustment. This shift suggests that the initial association was likely confounded by other household factors, such as socioeconomic status or ventilation. To determine the relative impact of HAP components, we ranked them based on their AOR values from (Table 3):

i. Solid fuel use (AOR = 2.13).
ii. Cooking in the living area (AOR = 2.09).

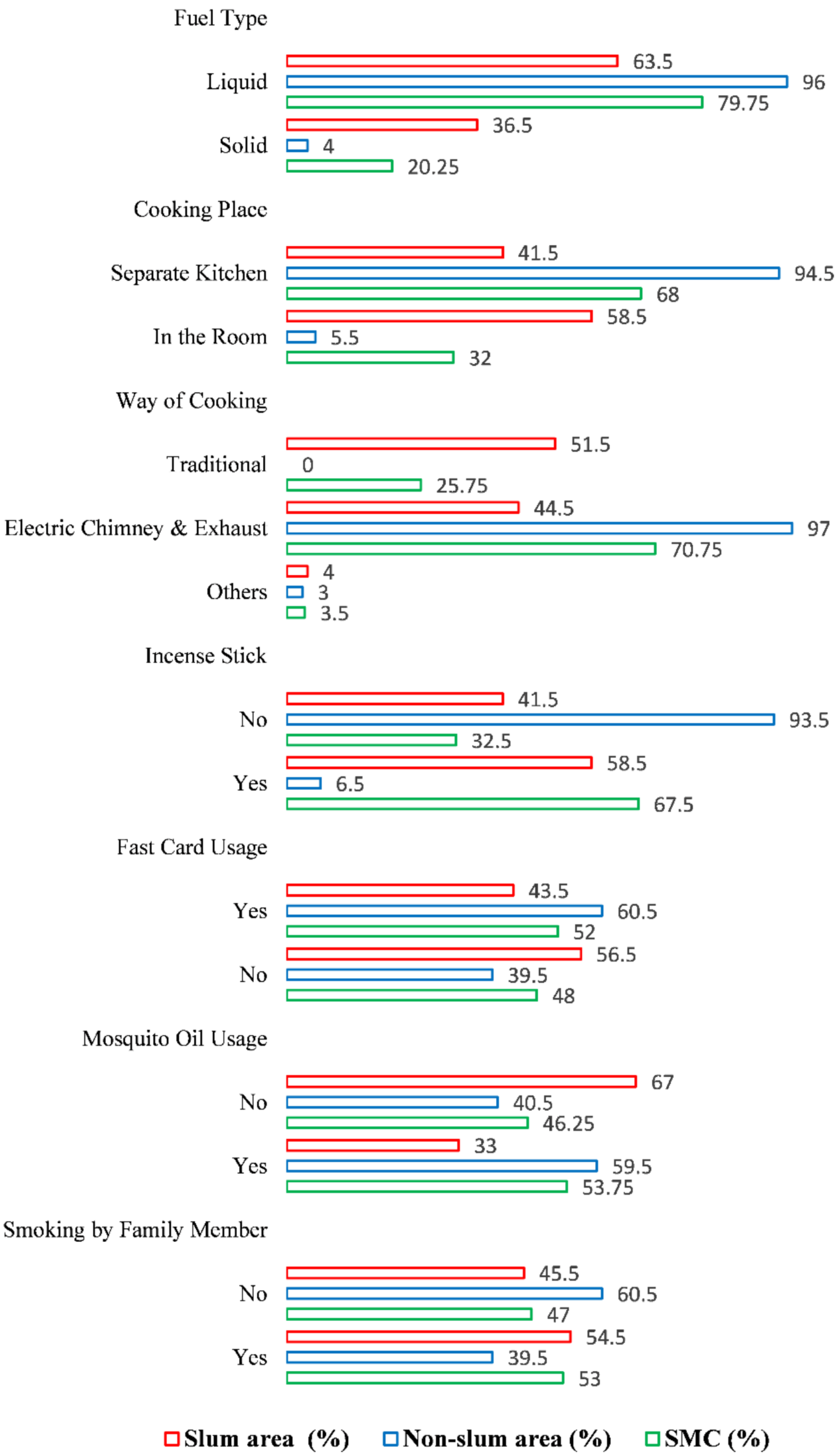

Fig. 3. Residence-wise distribution of HAP components in SMC, India.

iii. Mosquito oil use (AOR = 1.79).
iv. Smoking at home (AOR = 1.73).
v. Traditional cooking methods (AOR = 1.73).
vi. Incense stick use (AOR = 0.97).

This ranking highlights the need for interventions focused on reducing solid fuel use, improving ventilation in cooking spaces, and limiting exposure to mosquito oil fumes and household smoking. By prioritizing these

Components of HAP	UOR	95% CI		AOR	95% CI	
		Lower	Upper		Lower	Upper
Fuel type						
Liquid (ref.)	1			1		
Solid	3.70***	2.20	6.22	2.13*	1.18	3.82
Cooking place						
Separe kitchen (ref.)	1			1		
In the room	3.15***	2.04	4.88	2.09*	1.16	3.78
Cooking method						
Modern ventilation (ref.)	1			1		
Traditional	2.39***	1.51	3.79	1.73*	0.95	3.12
Others	0.45	0.12	1.64	0.33	0.08	1.37
Incense stick						
No (ref.)	1			1		
Yes	2.14***	1.40	3.28	0.97	0.54	1.73
Mosquito oil						
No (ref.)	1			1		
Yes	1.78**	1.19	2.65	1.79**	1.15	2.78
Smoking by family member in home						
No (ref.)	1			1		
Yes	1.99**	1.33	2.97	1.73*	1.13	2.66

Table 3. Association of components of HAP with poor SRH among older adults in SMC. Significance levels: *** ≤ 0.001, ** ≤ 0.01, *≤ 0.05. *UOR* unadjusted odds ratio, *AOR* adjusted odds ratio, *CI* confidence interval, *Ref.* reference category.

factors, public health initiatives can better address the risks associated with household air pollution in the aging population of SMC.

Discussion

This study meticulously investigates the relationship between various components of HAP and their implications on the health status of older adults residing in SMC. Specifically, it examines the effects of indoor air pollution resulting from the use of solid cooking fuels, the practice of cooking within the same room as living areas, traditional cooking methods (particularly those that do not utilize modern ventilation systems such as electric chimneys or exhaust fans), and the use of additional pollutants including incense sticks, mosquito oil, and Indoor Smoking.

The study indicates that the use of solid fuels for cooking is associated with more than twice the odds of adverse health outcomes compared to the use of liquid fuels. This finding is consistent with extensive research highlighting the significant health risks linked to solid fuel use. Solid fuels, including wood, coal, and biomass, emit pollutants such as particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs) during combustion. These pollutants are well-documented contributors to respiratory and cardiovascular diseases, particularly among older adults who are more susceptible due to age-related health vulnerabilities[32]. Previous research by Hystad et al. has demonstrated that solid fuel use is linked to increased risks of respiratory and cardiovascular diseases[33]. Additionally, studies by Lee et al. and Vardoulakis et al. confirm the detrimental health impacts of solid fuel use, including worsened respiratory and cardiovascular conditions[31,34]. Based on these findings, it is recommended that policy initiatives like the Ujjwala Yojana be expanded to ensure wider access to cleaner cooking fuels. This could significantly reduce the reliance on harmful solid biomass fuels and improve health outcomes among older adults. Addressing these issues is crucial for aligning with Sustainable Development Goal 7, which advocates for universal access to clean and renewable energy sources. Transitioning to cleaner fuels is essential for improving health outcomes and advancing global sustainability objectives. However, while solid fuels are often identified as the primary contributors to household air pollution, it is critical to acknowledge that liquid fuels are not entirely free from health risks. Liquid fuels such as kerosene and liquefied petroleum gas (LPG) are often considered cleaner alternatives, but under certain combustion conditions, they can also produce hazardous emissions. Incomplete combustion of liquid fuels, such as kerosene, can lead to the release of CO, VOCs, and fine particulate matter (PM2.5), all of which are known to pose significant health risks. The extent and nature of these emissions depend on multiple factors, including the chemical composition of the fuel, the design of the stove, and the efficiency of combustion.

The toxicity of emissions from cooking fuels is not solely determined by whether the fuel is solid or liquid but is heavily influenced by the chemical composition of the fuel and the combustion process. Solid biomass fuels, including wood, crop residues, and animal dung, contain high levels of lignin, cellulose, and hemicellulose. When burned, these components generate harmful byproducts such as polycyclic aromatic hydrocarbons (PAHs), CO, fine particulate matter (PM2.5 and PM10), and carcinogenic VOCs. PAHs, in particular, have

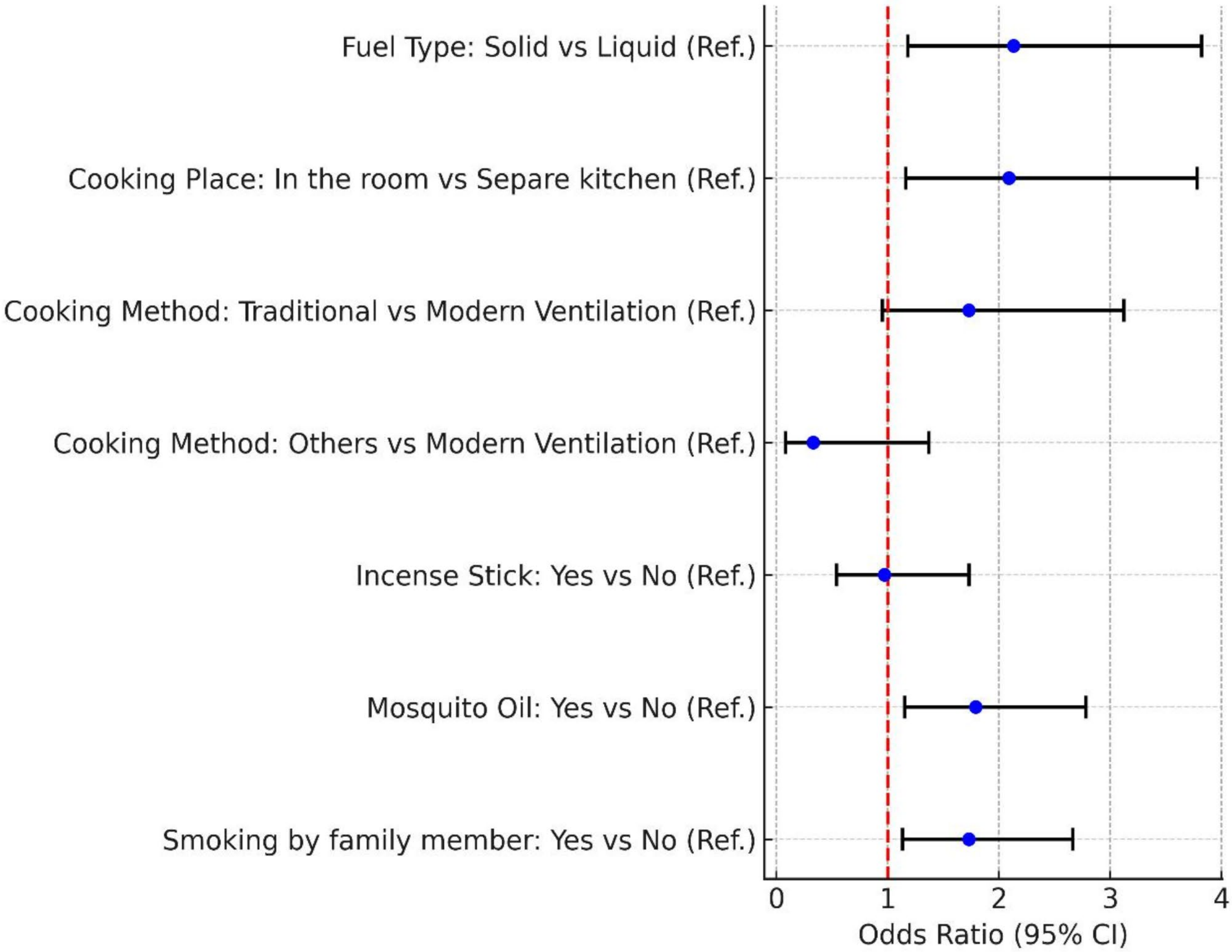

Fig. 4. Forest plot of the adjusted odds ratio of poor SRH by HAP components among older adults in SMC.

been associated with severe respiratory conditions and an increased risk of lung cancer due to their mutagenic properties (Kim et al., 2013).

On the other hand, liquid fuels, while generally producing fewer particulates, may release other hazardous pollutants. For instance, kerosene, which is commonly used in low-income households, has been found to emit significant levels of sulfur oxides (SOx) and nitrogen oxides (NOx), both of which contribute to indoor air pollution and adverse health effects. NOx exposure has been linked to an increased risk of respiratory infections, lung inflammation, and cardiovascular diseases, particularly among older adults with preexisting conditions (Dherani et al., 2008). Furthermore, exposure to incomplete combustion byproducts from kerosene, such as formaldehyde and benzene, can cause chronic respiratory problems and may contribute to the development of chronic obstructive pulmonary disease (COPD) over time.

Another critical factor influencing indoor air pollution is combustion efficiency, which depends on variables such as air supply, temperature, and stove design. Higher combustion temperatures generally improve fuel efficiency and reduce incomplete combustion byproducts. However, in some cases, higher temperatures can lead to the formation of more toxic pollutants, such as NOx, which can further degrade indoor air quality. Studies have demonstrated that inefficient combustion at lower temperatures can increase the emission of reactive oxygen species and free radicals, which are strongly associated with oxidative stress and respiratory diseases (Atwi et al., 2021).

Cooking in the same room where people live is linked to an increased risk of health problems compared to cooking in a separate room. This finding highlights the crucial role of cooking location in influencing health outcomes. When cooking occurs in the living space, pollutants such as PM, CO, and VOCs accumulate in the air that residents breathe[35].These pollutants are associated with a range of health issues, including respiratory and cardiovascular diseases, particularly among vulnerable groups such as older adults[36,37]. Previous research from various countries underscores the health risks associated with cooking in living areas. In China, studies have shown that cooking in the same room significantly increases indoor pollutant levels, contributing to higher rates of respiratory illnesses among residents[38]. Similarly, research in sub-Saharan Africa indicates that cooking in shared living spaces exacerbates exposure to indoor air pollutants, leading to adverse health effects[39]. In

India, Saha et al. found that poor ventilation and proximity of cooking activities to living areas result in higher exposure to harmful emissions, further illustrating the health risks associated with this practice[27]. To address this, public health initiatives should promote the use of separate, well-ventilated cooking areas to minimize indoor air pollution exposure. This could significantly reduce the risk of respiratory and cardiovascular diseases among older adults. Therefore, cooking in a separate, well-ventilated room is essential for reducing exposure to indoor air pollutants and improving health outcomes.

The study reveals that traditional cooking methods are associated with a significantly higher risk of adverse health outcomes compared to modern cooking methods, such as those utilizing electric chimneys and exhaust fans. Specifically, the use of traditional cooking methods results in a 73% higher risk of poor SRH among older adults who lack such ventilation mechanisms. This finding underscores the critical impact that cooking practices have on health outcomes for the elderly. In US, Zhang et al. identified a consistent link between HAP components, such as cooking practices and the use of solid fuels, and deteriorating SRH among older adults[40]. Similarly, research by Su et al. highlighted that traditional cooking methods, which often lack adequate ventilation, are associated with increased respiratory and cardiovascular health issues[41]. Hooper et al. also observed that inadequate ventilation and the use of traditional cooking fuels contribute significantly to health problems in older populations in various settings[42]. Given these findings, strengthening initiatives like the Ujjwala Yojana to ensure access to cleaner fuels and encouraging the use of modern ventilation systems (e.g., chimneys or exhaust fans) in households could improve health outcomes and reduce the burden of household air pollution. The global evidence reinforces the urgent need for the Ujjwala Yojana scheme in India, which aims to reduce solid fuel exposure by facilitating access to cleaner cooking alternatives. Strengthening such initiatives is crucial for improving health outcomes among older adults and addressing the broader issue of indoor air pollution.

The finding of the study show that use of mosquito oil adversely effect health among elderly. The use of mosquito oil, a common household product intended to repel insects, has been linked to various health issues. In Bangladesh, a study conducted by Islam et al. revealed that mosquito repellents, particularly those with oil-based formulations, are associated with respiratory problems and skin irritations[43]. The research found that these products contain chemicals such as DEET and other VOCs, which, when released into indoor air, contribute to poor air quality. This degradation in air quality poses a heightened risk for respiratory conditions, especially among vulnerable populations such as the elderly. The study highlights that exposure to these chemical agents can lead to chronic respiratory issues and exacerbate pre-existing conditions. Similarly, Sharma et al. examined the health impacts of chemical-based mosquito repellents[44]. The study found a significant association between the use of these products and an increase in respiratory ailments and skin problems. The research noted that the combustion or volatilization of these repellents introduces harmful substances into indoor environments, which can have detrimental effects on respiratory health, particularly in confined spaces where ventilation is limited. To mitigate these risks, we recommend promoting the use of alternative mosquito repellent options, such as non-chemical repellents like citronella and eucalyptus essential oils, or physical barriers like mosquito nets and window screens. These alternatives pose less of a risk to indoor air quality and could significantly reduce the adverse health effects associated with chemical-based mosquito repellents. The study reported that the emissions from fast cards contribute to indoor air pollution, which has been associated with an increased risk of respiratory and cardiovascular diseases. The prolonged exposure to these pollutants is particularly harmful to older adults, who are more susceptible to the adverse effects of poor air quality. The evidence emphasizes the need for greater awareness and intervention strategies to mitigate the impact of these products on health, particularly in populations that are more vulnerable to indoor air pollution. Addressing these issues through improved ventilation, the use of alternative products, and public health education could significantly enhance health outcomes and reduce the adverse effects associated with these commonly used items.

The study's findings showed that smoking by family members increased the likelihood of health issues among the elderly aligns with substantial international research on the adverse effects of secondhand smoke. For instance, research in the United States highlights that secondhand smoke exposure significantly raises the risk of respiratory diseases, cardiovascular conditions, and cancers, with even brief exposure proving harmful to non-smokers, including older adults[45]. Similarly, the British Lung Foundation reports that elderly individuals exposed to secondhand smoke face higher rates of respiratory infections and chronic obstructive pulmonary disease[46]. A research by Eisner et al. further corroborates these findings, demonstrating a significant correlation between secondhand smoke and increased prevalence of respiratory and cardiovascular conditions among older adults[47]. In response to these risks, it is important to strengthen tobacco control measures, such as the National tobacco control programme (NTCP), and promote smoke-free environments, particularly in households with older adults. Expanding the reach of these programs and supporting stricter enforcement of tobacco control policies could significantly reduce the adverse health effects of secondhand smoke among the elderly. The findings of our study underscore the necessity to intensify these efforts. Strengthening the implementation of NTCP and expanding its reach could mitigate the adverse health impacts associated with tobacco use, fostering a healthier environment for the elderly and enhancing public health outcomes.

Conclusion

This study underscores the significant health risks posed by HAP among older adults in SMC. The findings demonstrate that the use of solid fuels for cooking, cooking within living spaces, traditional cooking methods lacking modern ventilation, the use of mosquito oil, and indoor smoking by family members all contribute to poorer health outcomes in this population. Strengthening initiatives such as NTCP and the Pradhan Mantri Ujjwala Yojana, which promote clean cooking fuels and aim to reduce tobacco use, is essential. These targeted interventions are vital for decreasing HAP, supporting cleaner cooking practices, and limiting exposure to harmful pollutants. Such efforts align directly with sustainable development goal 7 (Affordable and Clean Energy), which advocates for clean, sustainable energy access and improved air quality. Addressing HAP through these initiatives will not only support environmental sustainability but also improve public health, ultimately enhancing the quality of life for older adults in SMC.

Limitations of the study and future research

This study has several limitations. First, because it is cross-sectional, it cannot establish causal relationships between household air pollution and health status. Although strict protocols were followed during data collection, the use of self-reported data may introduce bias, as participants' responses can vary based on their personal interpretations. Another limitation is the classification of mixed fuel users (those using both liquid and solid fuels) as solid fuel users, which may oversimplify the analysis of fuel use patterns and their health impacts. To address this limitation, future studies should integrate objective pollutant exposure measures, such as indoor PM2.5 and carbon monoxide monitoring, to provide a more accurate assessment of household air pollution levels. This would enhance the reliability of the findings and offer stronger evidence for targeted interventions. Additionally, while the sample size was carefully determined, the findings are only applicable to the specific area studied and may not be generalizable to the larger district or state. Furthermore, the cross-sectional nature of this study restricts the ability to establish causation between household air pollution and health outcomes. To overcome this, we recommend the use of longitudinal study designs that track individuals over time, allowing researchers to better understand the long-term health impacts of household air pollution and establish clearer causal relationships.

For future research, it would be beneficial to expand the scope to include the entire city or region of India. This broader approach would provide a more comprehensive understanding of the challenges faced by older adults. Conducting studies at both regional and national levels, while incorporating additional variables that may affect the health and well-being of older adults, would enhance the quality and depth of the findings. Such efforts could lead to more effective interventions and policies to support this vulnerable population.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Author contributions
MH analyzed the data, wrote and edited the paper. NK conceived and designed the study and edited the paper. MH and NK read the manuscript and edited the paper.

Declarations

Competing interests
The authors declare no competing interests.

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