Original Article

Association of early menopause with indoor air pollution: A multilevel modelling analysis of the nationally representative cross-sectional study in India

Pritam Halder[1], Anamika Soni[2], Ashwani Seth[3], Dheenadahayalan Vijayakumar[1], Anamika Das[4], Sujata Sankhyan[5], Anshul Mamgai[1], Saumyarup Pal[6], Jaya Tiwari[1], Aparna Baranwal[7], Chaitra CM[2]

[1]Department of Community Medicine and School of Public Health, Postgraduate Institute of Medical Education and Research, Chandigarh, India, [2]Department of Community Medicine, Gandhi Medical College, Bhopal, Madhya Pradesh, India, [3]Department of Community Medicine, All India Institute of Medical Sciences, Raebareli, Uttar Pradesh, India, [4]Department of Obstetrics and Gynaecology, Employees State Insurance Corporation Hospital and Postgraduate Institute of Medical Sciences and Research Basaidarpur, New Delhi, India, [5]Department of Paediatrics, Indira Gandhi Medical College and Hospital, Shimla, Himachal Pradesh, India, [6]Department of Geriatrics, All India Institute of Medical Sciences, New Delhi, India, [7]Department of Obstetrics and Gynaecology, All India Institute of Medical Sciences, Raebareli, Uttar Pradesh, India

Abstract

Background: Early onset of menopause poses a risk for various health issues in women. This study aimed to primarily examine the link between early menopause and indoor air pollution (IAP) and demonstrate this association within the Indian population, considering their place of residence. **Methods:** This longitudinal study included 24,862 eligible participants out of 73,000 surveyed. Logistic regression analyses, both crude and adjusted odds ratios (aOR), were used to examine the association between early menopause and various sociodemographic factors, IAP, and place of residence (rural/urban). **Results:** The study identified a significant correlation between early menopause and body mass index (BMI), educational status, marital status, occupation, physical activity, self-rated health, and smoking status. Women using unclean fuels did not show increased odds of early menopause (aOR: 1.00, 95% confidence interval [CI]: 0.93-1.08). Poor ventilation was linked to a slightly higher incidence (28.1% vs. 26.9%, aOR: 1.07, 95% CI: 0.99-1.15). Exposure to pollution-generating sources was significantly associated with early menopause (28.8%, aOR: 1.10, 95% CI: 1.02-1.18), especially in urban areas (aOR: 1.17, 95% CI: 1.01-1.36) but not rural (aOR: 1.08, 95% CI: 0.99-1.17). Indoor smoking was linked to higher odds (aOR: 1.09, 95% CI: 1.02-1.17), particularly in rural areas (aOR: 1.09, 95% CI: 1.01-1.18). Overall, IAP was significantly associated with early menopause (aOR: 1.07, 95% CI: 1.01-1.15). **Conclusion:** The findings reveal that IAP, from sources such as smoke and pollutants, significantly increases the risk of early menopause among Indian women. Urban women are more affected by pollution, whereas indoor smoking impacts both urban and rural women. Enhancing indoor air quality could reduce early menopause and improve women's health in India.

Keywords: Early menopause, indoor air pollution, LASI, menopause, modelling

Address for correspondence: Dr. Pritam Halder, Department of Community Medicine and School of Public Health, Postgraduate Institute of Medical Education and Research, Chandigarh, Sector 12, pin - 160 012, India.
E-mail: rynedann@gmail.com

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Introduction

Menopause is a significant transition in a woman's life, marking her menstrual cycles and reproductive capacity cessation. When

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menopause occurs before the age of 40 years, it is considered premature, whereas menopause between the ages of 40 and 44 years is termed early. This is noteworthy because the average age range for menopause typically falls between 45 and 50 years old.[1] Premature menopause is not just a reproductive health issue but also carries substantial implications for overall well-being.

Menopause signifies the natural cessation of fertility in women, marked by the cessation of ovulation and a decrease in the production of vital hormones, notably estrogen. This hormonal decline triggers a variety of physical and psychological changes, one of which includes irregular menstrual cycles. Women experiencing premature menopause face increased risks of health problems such as osteoporosis and cardiovascular disease.[2,3] Additionally, menopause brings with it a slew of symptoms such as hot flashes, mood swings, and cognitive changes, all of which can significantly impact a woman's quality of life and daily functioning.[1]

Various factors, including lifestyle choices and environmental exposures, can influence the onset of menopause at an earlier age. For instance, habits such as smoking and excessive alcohol consumption have been associated with earlier menopause onset.[4] Furthermore, environmental factors such as exposure to air pollutants can play a role. Household air pollution, often stemming from the burning of biomass sources such as wood, animal dung, and crop waste, has been linked to disruptions in hormonal balance, potentially contributing to premature menopause.[5] Additionally, certain chemicals present in indoor air pollution (IAP), such as perfluorochemicals, have been implicated in triggering premature menopause.[6–10] as well as certain consumer products such as air fresheners containing phthalates can contribute to early menopause. Even passive smoking has been found to impact the timing of menopause.[11,12]

It is important to highlight that the burden of IAP disproportionately affects women and children, particularly those living in low-income countries. The lack of access to clean cooking technologies in these regions exacerbates their vulnerability to the harmful effects of indoor air pollutants.

Although existing research sheds some light on the potential link between IAP and early menopause,[13] there is a need for more extensive and detailed studies. These studies should aim to elucidate precisely how indoor air pollutants influence the timing of menopause, taking into account various factors such as exposure levels, biological mechanisms, and socioeconomic factors. Such research is essential for developing effective interventions to mitigate the adverse health effects of IAP on women's reproductive health and overall well-being.

Objective

I. To show the association of early menopause with IAP among the Indian population aged >45 years.
II. To show the association of early menopause with IAP among the Indian population as per residence.

Methods-(weighted value)

LASI-1st wave is a longitudinal survey with a national representation that intends to collect detailed information on the psychological, social, economic, and health aspects of ageing in India from all the states and union territories. It was developed to fill the information vacuum regarding thorough and internationally comparable survey data on India's ageing population. The funding agencies were the National Institute on Ageing, the Government of India's Ministry of Health and Family Welfare, and the United Nations Population Fund. The University of Southern California, the International Institute for Population Sciences, and the Harvard T.H. Chan School of Public Health were the contributors. Over 73,000 adult Indians were surveyed. Out of them, 248,62 participants were included in the present study [Figure 1].

The study, which is the biggest of its kind in the world and the first of its kind in India, evaluated the scientific evidence in the context of variables such as demographics, household economic status, chronic health conditions, symptom-based health conditions, functional health, mental health (cognition and depression), biomarkers, healthcare utilisation, family and social networks, social welfare programmes, employment, retirement, satisfaction, and life expectations. The survey intends to follow a representative sample of the older adult population every 2 years for the following 25 years, with a revised sample size to account for attrition due to death, migration, non-reachable, and non-responses.[14]

Ethics

The Indian Council of Medical Research's (ICMR) Central Ethics Committee on Human Research (CECHR) gave its ethical

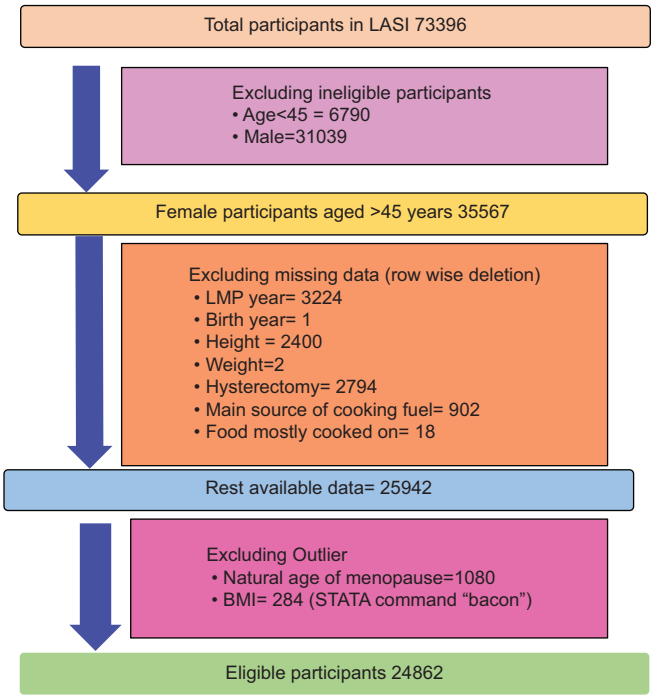

Figure 1: Flowchart showing participants' selection process in this study

clearance for the LASI survey' execution as per the Helsinki Declaration.[14]

Outcome variable

The outcome variable of choice was early menopause (natural age of menopause <45 years).

Explanatory variables

Indoor air pollution

Participants exposed to IAP was the explanatory variable of choice. IAP includes contamination of the air from physical, chemical, and biological sources. A distinct component of IAP was surveyed as part of the LASI study. Six questions from the LASI survey were used to calculate IAP. There were two questions concerning the fuel utilised for cooking and other purposes: (i) "What is your main source of cooking fuel?" and (ii) "What are those other sources of fuel used for other purposes (such as boiling water for bathing, lighting, etc.)?" (Responses: liquefied petroleum gas [LPG], biogas, kerosene, electric, charcoal/lignite/coal, crop residue, wood/shrub, dung cake, do not cook at home, other, please specify). "Fuel type" was generated considering LPG, biogas, and electric methods as clean fuels and the rest as unclean or solid fuels. "Pollution-generating source" was generated from the type of oven used: (iii) "In this household, is food mostly cooked on a mechanical stove, on a traditional Chullah or over an open fire?" (Responses: mechanical stove/improved cook stove, traditional chullah, open fire, other, please specify). Traditional Chullah and the opened fire were taken as the higher pollution-generating source. Next two questions were about the place of cooking and ventilation: (iv) "Is the cooking usually done in the house, in a separate building, or outdoors?" (Responses: in the house, in a separate building, outdoors, other, please specify), (v) "Is the cooking mainly done under a traditional chimney, exhaust fan, electric chimney or near window/door?" (Responses: traditional chimney, electric chimney, exhaust fan, near window/door, none). No ventilation with in-house cooking was considered vulnerable ventilation. The next question was on "household indoor smoking," (vi) "Does any usual member of your household smoke inside the home?"(Responses: yes, no). Thus, all six factors were used to generate "IAP": exposed (participants using unclean/solid fuel for cooking and others by utilizing traditional chullah or open fire and inhouse cooking without any ventilation system along with the presence of indoor smoking) and non-exposed participants. Thus "fuel type," "pollution-generating source," "vulnerable ventilation," "household indoor smoking" and "IAP" were considered as explanatory variables.

Covariates

Minimum education (illiterate, less than primary. primary completed, middle completed, secondary school, higher secondary, and diploma/graduate), residence (rural, urban), marital status (unmarried, married/in live-in, widow/separated/divorced), mpce (monthly per capita expenditure-poorest, poorer, middle, richer, richest) quintile, health insurance (no, yes), occupation (unemployed, professional and semi-professional-"legislators and senior officials, professionals, technicians and associate professionals," clerical and skilled-"clerks, service workers and shopkeepers, skilled agriculture and fishery workers, craft and related trade worker, plant and machine operator," unskilled), physical activity (every day, once per week, 1-3 times per week, once per month, never), self-rated health (excellent, very good, good, fair, poor,), tobacco abuse (no, yes), alcohol consumption (no, yes) and body mass index (BMI) categories, multimorbidity were taken as other explanatory variables. BMI was calculated from documented weight and height (BMI = weight [kg]/height [meter]^2). Participants were categorised as BMI <18.5 (underweight), 18.5-22.9 (normal), 23.0-24.9 (overweight), 25.0-29.9 (pre-obese) and obese (>30.0). Chronic morbidities included hypertension, diabetes, cancer, chronic lung diseases (e.g. chronic obstructive pulmonary disease, asthma, chronic bronchitis, other chronic lung problems), chronic heart disease (e.g. congestive heart failure, myocardial infarction, heart attack, other chronic heart diseases), stroke, musculoskeletal disorder (MSD e.g. rheumatism, arthritis, osteoporosis, other chronic joint or bone disorders), dyslipidaemia (high cholesterol), thyroid disorders, chronic renal failure, visual impairment and hearing impairment. The interviewer asked related questions about chronic health conditions/morbidities with dichotomous answers (no/yes)-"Has any health professional ever diagnosed you with the following chronic conditions or diseases?" Participants having at least two chronic health conditions were described as multimorbidity.

Statistical analysis

Data were analysed in Stata version 17 (StataCorp. 2017. Stata Statistical Software: Release 17. College Station, TX: StataCorp LP.). Characteristics of participants were described as mean (standard deviation) for continuous variables frequencies and percentages for categorical variables. The age of menopause was calculated by subtracting the year of last menstruation (ht236_year) from the birth year (dm004_year). Outliers were removed by the Stata command "bacon." Individual sample weights were considered during the analysis Univariate logistic regression was conducted between the outcome variable and each explanatory variable. To avoid multicollinearity among explanatory variables VIF (variance inflation factor) was applied. VIF >5 indicates a high correlation between a given explanatory variable and other explanatory variables in the model, which might create problems with the regression analysis. Self-related health and marital status had VIF >5 [Supplementary Table 1]. Hence, all explanatory variables except these two were included in the final association. *P* values < 0.05 were considered as statistically significant. *P* value < 0.2 was taken for further multivariable logistic regression.

Results and Discussion

This study explored the relationship between IAP and the age of menopause in Indian women, specifically focusing on those who experience early menopause (before the age of 45 years).

The findings reveal significant associations between various socio-demographic, health, and environmental factors and the incidence of early menopause. The study included 24,862 participants, and among them, 6,872 (27.6%) showed early menopause (<45 years). In contrast, previous research found early menopause in 3.4% of US women and 7.2% of Korean women.[15] The average age of participants was around 58.5 years, with those experiencing early menopause averaging 58.3 years. The mean age at natural menopause for the entire cohort was 46.8 years, whereas it was significantly lower at 40.4 years for those with early menopause.

The average BMI for the cohort was 23.2 kg/m², with women experiencing early menopause having a slightly lower average BMI of 22.9 kg/m². Women classified as underweight had a higher incidence of early menopause (29.3%) compared to other BMI categories, indicating a potential link between lower BMI and earlier menopause. Supporting studies include Kundu *et al.* (2024),[16] showing higher early menopause rates among underweight women (20.4%), Yeo *et al.*[17] (2023), linking low (<18.5 kg/m²) and high (≥25 kg/m²) BMIs to early and late menopause, respectively; Szegda *et al.* (2017)[18] reporting a 30% higher odds of early menopause for women with BMI <18.5 kg/m² and 21-30% lower odds for BMI 25.0-29.9 kg/m²; Ahuja *et al.*[19] (2016) associating lower BMI with earlier menopause); and Dorjgochoo *et al.* (2008)[20] reported a slightly later menopause onset for women with a BMI ≥21.4. Conversely, Zhao *et al.* (2018)[21] found no correlation between BMI and menopause occurrence.

The study shows a significant portion of the participants were illiterate (65.4%), with similar rates of early menopause (27.6%). However, women with higher secondary education or diplomas/graduate degrees showed different trends, with those holding diplomas/graduates experiencing the lowest rate of early menopause (20.3%). Previous studies support these findings: Kundu *et al.* (2024)[16] demonstrated that women with higher education levels have lower chances of premature menopause. Ahuja *et al.* (2016)[19] found that more educated women have a significantly higher menopausal age. Gold *et al.* (2013)[22] showed that college graduates tend to have a later age of menopause; and Mikkelsen *et al.* (2007)[23] reported that a high educational level is negatively associated with early menopause.

Rural and urban residents showed nearly similar rates of early menopause (26.4% and 30.7%, respectively), suggesting that urbanization alone may not be a strong determinant of early menopause without considering other factors. However, Kundu *et al.* (2024)[16] found that rural women experienced menopause earlier (2.6%) compared to urban women, and Ohn Mar and Mona (2020)[24] observed that in Asian regions, rural women reached menopause earlier than urban women, unlike trends observed in non-Asian regions, indicating regional variations in the rural-urban menopause age difference.

Unmarried women exhibited the highest incidence of early menopause (63.7%), followed by widowed, separated, or divorced women (30.7%). Married or live-in women had the lowest incidence (25.4%). Similar trends were observed in previous studies: Saraç *et al.* (2011)[25] found divorced women had a higher risk of early menopause (OR: 1.79), and Mikkelsen *et al.* (2007)[23] showed widowed women had nearly double the odds of early menopause compared to married women (OR: 1.89). However, Kundu *et al.* (2024)[16] found that widowed, divorced, or separated women had a much higher risk of premature menopause compared to never-married women (HR: 2.671, $P < 0.01$) [Table 1].

The present study found no strong independent association between economic status and early menopause, with rates being consistent across all quintiles. However, previous studies showed different results: Kundu *et al.* (2024)[16] found that the richest women had a 36.8% lower chance of premature menopause than the poorest women (HR: 0.632, $P < 0.001$), and Ahuja *et al.*[19] (2016) reported that women from upper socioeconomic statuses had a higher menopausal age (46.1 ± 5.2 years) compared to those from poorer backgrounds (48.1 ± 4.2 years).

Access to health insurance did not significantly impact the incidence of early menopause, as similar rates were observed regardless of insurance status. Previous studies have consistently shown no significant correlation between early menopause and the availability of health insurance.

According to our study, women in professional or semi-professional roles had a lower incidence of early menopause (17.6%), whereas unemployed women and those in clerical or skilled roles had higher rates. Similar trends were noted in previous research. Gold *et al.* (2013)[22] found that participants who were employed during follow-up had a later age of menopause (HR = 0.87, 95% CI: 0.77–0.98). However, contrasting results were observed in other studies. Kundu *et al.* (2024)[16] reported a 13.6% higher probability of premature menopause among employed women compared to unemployed women (HR: 1.136; $P < 0.001$), Saraç *et al.* (2011)[25] identified employment status (OR: 1.94) as a significant risk factor for early menopause.

Studies have revealed that regular physical activity is linked to varying rates of early menopause. Women exercising daily experienced a higher incidence (30.6%), whereas those engaging in less frequent activity had lower rates. Gold *et al.* (2013)[22] found that increased physical activity during follow-up was associated with an earlier age of menopause (HR =1.07, 95% CI: 1.02–1.12). Conversely, Dorjgochoo *et al.* (2008)[20] discovered that women engaging in moderate to high levels of exercise during both adolescence and adulthood were more likely to experience later menopause and an extended reproductive span ($P < 0.01$). In contrast, Zhao *et al.* (2018)[21] found no significant association between adulthood physical activity and early menopause (95% CI: 0.76–1.04; $P = 0.26$).

Women rating their health as excellent had a higher incidence of early menopause (32.6%), suggesting a complex interplay between self-perception and actual health outcomes. A literature

Table 1: Various characteristics of the Indian female population aged >45 years as per early menopause

Variable	Total Participants *n*=24862 *n* (%)	Early (<45 years) Menopause *n*=6872 (27.6%) *n* (%)	*P*
Age (years)[a]	58.5 (10.2)	58.3 (9.7)	-
Age at natural menopause (years)[a]	46.8 (5.2)	40.4 (3.5)	-
BMI[a]	23.2 (4.9)	22.9 (4.9)	-
BMI category[b]			
Underweight (<18.5)	5250 (21.1)	1,536 (29.3)	<0.001
Normal (18.5-22.9)	8698 (35.0)	2,365 (27.2)	
Overweight (23-24.9)	3494 (14.1)	920 (26.3)	
Preobese (25-29.9)	5221 (21.0)	1,328 (25.4)	
Obese (>30)	2199 (8.8)	723 (32.9)	
Education[b] (minimum)			
Illiterate	16,264 (65.4)	4,481 (27.6)	<0.001
Less than primary	2,312 (9.3)	660 (28.5)	
Primary completed	2,437 (9.8)	686 (28.2)	
Middle completed	1,367 (5.5)	318 (23.3)	
Secondary school	1,201 (4.8)	374 (31.2)	
Higher secondary	659 (2.7)	226 (34.4)	
Diploma/Graduate	623 (2.5)	126 (20.3)	
Residence[b]			
Rural	17534 (70.5)	4622 (26.4)	0.172
Urban	7328 (29.5)	22250 (30.7)	
Marital status[b]			
Unmarried	274 (1.1)	175 (63.7)	<0.001
Married/in live-in	15873 (63.8)	4023 (25.4)	
Widow/separated/divorced	8715 (35.1)	2674 (30.7)	
MPCE quintile[b]			
Poorest	5,463 (22.0)	4,005 (26.7)	0.162
Poorer	5,375 (21.6)	3,971 (26.2)	
Middle	5,083 (20.5)	3,709 (27.0)	
Richer	4,839 (19.5)	3,405 (29.6)	
Richest	4,101 (16.5)	2,899 (29.3)	
Health insurance[b]			
No	24644 (99.1)	6822 (27.7)	0.625
Yes	218 (0.9)	50 (23.0)	
Occupation[b]			
Unemployed	16552 (66.6)	4696 (28.4)	0.003
Professional and semi-professional	177 (0.7)	31 (17.6)	
Clerical and skilled	4852 (19.5)	1308 (27.0)	
Unskilled	3281 (13.2)	837 (25.5)	
Physical activity[b]			
Everyday	4,491 (18.1)	1,373 (30.6)	0.050
More than once/week	1,364 (5.5)	333 (24.4)	
Once/week	757 (3.1)	154 (20.3)	
1-3 times/month	1,405 (5.7)	311 (22.1)	
Never	16,845 (67.8)	4,702 (27.9)	
Self-rated health[b]			
Excellent	835 (3.4)	272 (32.6)	<0.001
Very good	4162 (16.7)	1166 (28.0)	
Good	9550 (38.4)	2544 (26.6)	
Fair	7653 (30.8)	2165 (28.3)	
Poor	2662 (10.7)	725 (27.2)	
Tobacco usage[b]			
No	19906 (80.1)	5461 (27.4)	0.047
Yes	4956 (19.9)	1411 (28.5)	
Alcohol consumption[b]			
No	24130 (97.5)	6726 (27.8)	0.070
Yes	632 (2.5)	146 (23.2)	

[a]Mean (SD), [b]*n* (%)

review revealed that no previous studies have shown a significant correlation between early menopause and women's self-rated health.

The present study showed that tobacco users had a slightly higher incidence of early menopause (28.5%). This aligns with several previous studies. Kundu *et al.* (2024)[16] identified smoking as a significant predictor of premature menopause, with smokers having a 20.8% higher risk (HR: 1.208, $P < 0.01$) compared to non-smokers. Yeo *et al.* (2023)[17] also found that current smokers had an increased risk of premature menopause (odds ratio =3.99, 95% CI: 1.35–11.81). Whitcomb *et al.* (2018)[26] reported an elevated risk for women with 11–15 pack-years (HR = 1.29, 95% CI: 1.07, 1.55), 16–20 pack-years (HR = 1.42, 95% CI: 1.13–1.79), or more than 20 pack-years (HR = 1.54, 95% CI: 1.23–1.93) of smoking. Yang *et al.* (2015)[27] found that smokers experienced menopause 0.75 years earlier than non-smokers ($P < 0.001$). Sun *et al.* (2012)[28] showed smoking was significantly associated with earlier menopause in both dichotomous (OR = 0.67, 95% CI: 0.61–0.73, $P < 0.01$) and continuous studies (WMD = −0.90, 95% CI: −1.58 to −0.21, $P = 0.01$). Similar findings were reported by Haytabakhsh *et al.* (2012),[29] Saraç *et al.* (2011),[25] Dorjgochoo *et al.* (2008),[20] Chang *et al.* (2007),[30] Mikkelsen *et al.*. (2007),[23] Prospero *et al.* (2004),[31] and Everson RB *et al.* (1986).[32] However, Zhao *et al.* (2018)[21] found no association between smoking and early menopause.

The present study found no significant correlation between alcohol consumption and earlier age of menopause ($P = 0.070$). Similar findings were reported by Yeo *et al.* (2023).[17] However, other studies have shown contrasting results. Freeman *et al.* (2021)[33] found that women with moderate alcohol intake had a lower risk of early menopause, with those consuming 10.0–14.9 g/day having a hazard ratio of 0.81 (95% CI: 0.68–0.97). Taneri *et al.*[34] (2016) observed that low and moderate alcohol consumption (more than one drink per week: RR = 0.60, 95% CI: 0.49–0.75; three or fewer drinks per week: RR = 0.75, 95% CI: 0.60–0.94) was associated with later menopause onset compared to non-drinkers. Gold *et al.* (2013)[22] also found a significant association between higher alcohol consumption and a reduced risk of early menopause (HR =0.90, 95% CI: 0.83–0.98).

The present study showed that women exposed to unclean or solid fuels had a higher incidence of early menopause (28.1%) compared to those using clean fuels (26.2%). Multivariable logistic regression models did not find a significant association between unclean/solid fuel use and early menopause after adjusting for other factors. However, poorer ventilation was linked to higher odds of early menopause in Model 3. Across all models, a consistently significant association was observed between exposure to pollution-generating sources and higher odds of early menopause. Additionally, a significant association was found between household smoking and early menopause after full adjustment in Model 3.

Women using unclean/solid fuels did not show a significant increase in odds of early menopause (adjusted OR [aOR] in Model 3: 1.00, 95% CI: 0.93–1.08). No significant association was found in either rural (aOR in Model 3: 0.99, 95% CI: 0.92–1.07) or urban settings (aOR in Model 3: 1.02, 95% CI: 0.86–1.21). A literature review revealed that no previous studies have shown a significant correlation between IAP and the type of fuel used by women [Tables 2 and 3].

The present study found that poor ventilation was associated with a marginally higher incidence of early menopause (28.1%) compared to better-ventilated homes (26.9%). However, poor ventilation was linked to slightly higher, but not significant, odds of early menopause (aOR in Model 3: 1.07, 95% CI: 0.99–1.15). Similar non-significant trends were observed in both rural (aOR in Model 3: 1.05, 95% CI: 0.96–1.15) and urban settings (aOR in Model 3: 1.14, 95% CI: 0.97–1.34). A literature review revealed that no previous studies have examined the relationship between ventilation quality and age at menopause.

The present study found that exposure to pollution-generating sources was significantly associated with early menopause (28.8%). Women exposed to these sources had significantly higher odds of early menopause (aOR in Model 3: 1.10, 95% CI: 1.02–1.18). This association was significant in urban areas (aOR in Model 3: 1.17, 95% CI: 1.01–1.36) but not in rural areas (aOR in Model 3: 1.08, 95% CI: 0.99–1.17). Similar findings were observed in previous studies. Cucinella *et al.* (2023)[35] reported that European menopausal women

Table 2: Distribution of Indian population as per indoor air pollution and early menopause according to residence

Characteristics		Overall *n*=24862		Rural *n*=17534		Urban *n*=7328	
		Total %	Early Menopause %	Total %	Early Menopause %	Total %	Early Menopause %
Fuel type	Clean	59.5	26.2	46.3	26.1	90.9	30.0
	Unclean/soiled	40.5	28.1	53.7	25.9	9.1	30.8
Vulnerable ventilation	Lower	81.0	26.9	77.5	26.6	89.4	26.7
	Higher	19.0	28.1	22.5	26.7	10.6	31.3
Pollution generating source	No	49.1	25.7	33.0	25.6	87.7	26.0
	Yes	50.9	28.8	67.0	26.5	12.3	30.9
Household Indoor Smoking	No	76.7	26.5	74.1	26.3	82.7	29.4
	Yes	23.3	28.4	25.9	26.8	17.3	32.0
Indoor air pollution	No	46.6	25.0	34.5	25.2	75.7	24.6
	Yes	53.4	29.3	65.5	26.9	24.3	32.0

*P<0.05=significant

living in greener neighbourhoods experienced menopause at a median age of 1.4 years later. Neff *et al.* (2022)[36] showed that exposure to environmental contaminants, such as PFAS, cigarette smoke, PCBs, phthalates, bisphenols, and pesticides, can cause premature menopause. Additionally, Kim *et al.* (2024)[37] found an association between particulate matter (PM) exposure and early menopause, with PM2.5 (aOR: 1.27, 95% CI: 1.23–1.32) and PM10 (aOR: 1.17, 95% CI: 1.15–1.20) being significant factors.

The present study found that women in households with indoor smoking had a higher incidence of early menopause (28.4%). Indoor smoking was significantly associated with higher odds of early menopause (aOR in Model 3: 1.09, 95% CI: 1.02–1.17).

Table 3: Univariate and multivariable logistic regression of early menopause and indoor air pollution among the Indian population

Characteristics		Early menopause			
		Univariate		Multivariable	
		Crude odds ratio (95% confidence interval)	Adjusted odds ratio (95% confidence interval) Model-1	Adjusted odds ratio (95% confidence interval) Model-2	Adjusted odds ratio (95% confidence interval) Model-3
		Overall (>45 years)[a]			
Fuel type	Clean	Reference	Reference	Reference	Reference
	Unclean/soiled	0.97 (0.91-1.03)	1.00 (0.93-1.07)	1.00 (0.94-1.08)	1.00 (0.93-1.08)
Vulnerable ventilation	Lower	Reference	Reference	Reference	Reference
	Higher	1.04 (0.96-1.13)	1.07 (0.99-1.15)	1.07 (0.99-1.16)	1.07 (0.99-1.15)
Pollution generating source	No	Reference	Reference	Reference	Reference
	Yes	1.05 (0.99-1.11)	1.09 (1.02-1.17)*	1.09 (1.02-1.18)*	1.10 (1.02-1.18)*
Household Indoor smoking	No	Reference	Reference	Reference	Reference
	Yes	1.05 (0.98-1.13)	1.08 (1.1-1.16)*	1.08 (1.01-1.16)*	1.09 (1.02-1.17)*
Indoor air pollution	Unexposed	Reference	Reference	Reference	Reference
	Exposed	1.02 (0.96-1.08)	1.07 (1.01-1.14)*	1.07 (1.01-1.14)*	1.07 (1.01-1.15)*
Pseudo R^2		0.035	0.0073	0.0095	0.0096

Model 1-Adjusted for education, residence, mpce quintile, health insurance, and occupation. Model 2- Model 1 + physical activity, BMI, and multimorbidity. Model 3- Model 2 + tobacco and alcohol abuse.
*P<0.05=significant

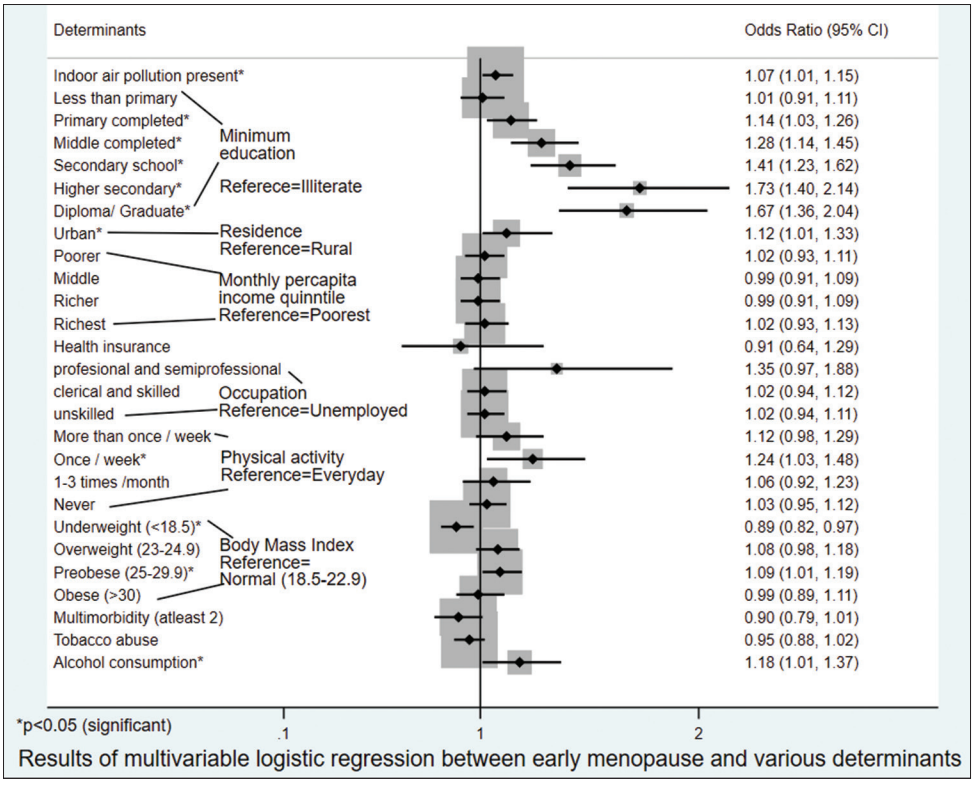

Figure 2: Multivariable logistic regression of early menopause with indoor air pollution and various determinants among the Indian population (Model 3)

This association was significant in rural areas (aOR in Model 3: 1.09, 95% CI: 1.01–1.18) but not in urban areas (aOR in Model 3: 1.10, 95% CI: 0.97–1.26). Similar results were observed in a study by Ertunc *et al.* (2015),[12] which found that second-hand smoking was associated with a significantly lower age of menopause compared to the non-exposed group (47.0 ± 4.7 vs. 48.1 ± 5.2 years, $P = 0.002$) [Figure 2].

Exposure to IAP was significantly associated with early menopause (aOR in Model 3: 1.07, 95% CI: 1.01–1.15). This association was not significant in rural areas (aOR in Model 3: 1.06, 95% CI: 0.97–1.14) or urban areas (aOR in Model 3: 1.10, 95% CI: 0.97–1.23). According to a study by Everson *et al.* (1986),[32] the mean ages of menopause for non-smokers whose spouses also did not smoke and for non-smokers with smoking spouses were 51.9 and 49.8 years, respectively (OR: 1.9; CI 1.0–3.9). The study found an increased risk of early menopause associated with both active (OR 2.3; CI 1.1–4.9) and passive smoking (OR: 2.1; CI 1.0–4.5) [Table 4].

Conclusion

The findings suggest that IAP, particularly from pollution-generating sources and indoor smoking significantly increases the likelihood of early menopause among Indian women. Urban populations seem to be more affected by pollution-generating sources, whereas indoor smoking has a consistent impact across rural settings. These results underscore the importance of public health interventions aimed at improving indoor air quality, particularly in urban environments and households with indoor smoking practices. In conclusion, improving indoor air quality could be a crucial step in mitigating early menopause and enhancing the overall health and well-being of women in India.[38,39]

Ethical clearance

This is a analysis of secondary dataset of LASI-1st wave survey. Original LASI survey obtained it's ethical clearance from ICMR. So, our study does not require separate ethical clearance.

Consent for publication

Proper consent was taken for publication from the authority.

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Table 4: Univariate and multivariable logistic regression of early menopause and indoor air pollution among the Indian population as per residence

Characteristics		Early menopause			
		Univariate		Multivariable	
		Crude odds ratio (95% confidence interval)	Adjusted odds ratio (95% confidence interval) Model-1	Adjusted odds ratio (95% confidence interval) Model-2	Adjusted odds ratio (95% confidence interval) Model-3
Rural					
Fuel type	Clean	Reference	Reference	Reference	Reference
	Unclean/soiled	0.96 (0.89-1.03)	0.97 (0.91-1.06)	0.99 (0.92-1.07)	0.99 (0.92-1.07)
Vulnerable ventilation	Lower	Reference	Reference	Reference	Reference
	Higher	1.03 (0.94-1.13)	1.04 (0.95-1.14)	1.05 (0.96-1.15)	1.05 (0.96-1.15)
Pollution-generating source	No	Reference	Reference	Reference	Reference
	Yes	1.03 (0.95-1.11)	1.07 (0.99-1.15)	1.07 (0.99-1.16)	1.08 (0.99-1.17)
Household Indoor smoking	No	Reference	Reference	Reference	Reference
	Yes	1.06 (0.98-1.15)	1.08 (0.99-1.17)	1.07 (0.99-1.16)	1.09 (1.01-1.18)*
Indoor air pollution	Unexposed	Reference	Reference	Reference	Reference
	Exposed	1.01 (0.94-1.09)	1.04 (0.97-1.13)	1.05 (0.97-1.13)	1.06 (0.97-1.14)
Pseudo R^2		0.0033	0.0060	0.0085	0.0089
Urban					
Fuel type	Clean	Reference	Reference	Reference	Reference
	Unclean/soiled	0.89 (0.76-1.04)	1.03 (0.87-1.22)	1.03 (0.87-1.22)	1.02 (0.86-1.21)
Vulnerable ventilation	Lower	Reference	Reference	Reference	Reference
	Higher	1.06 (0.91-1.24)	1.15 (0.98-1.35)	1.14 (0.97-1.34)	1.14 (0.97-1.34)
Pollution-generating source	No	Reference	Reference	Reference	Reference
	Yes	1.05 (0.91-1.20)*	1.17 (1.01-1.35)*	1.18 (1.02-1.36)*	1.17 (1.01-1.36)*
Household Indoor smoking	No	Reference	Reference	Reference	Reference
	Yes	1.03 (0.90-1.16)	1.11 (0.97-1.26)	1.11 (0.98-1.26)	1.10 (0.97-1.26)
Indoor air pollution	Unexposed	Reference	Reference	Reference	Reference
	Exposed	0.99 (0.89-1.10)	1.11 (0.8-1.24)	1.11 (0.99-1.27)	1.10 (0.97-1.23)
Pseudo R^2		0.0038	0.0136	0.0160	0.0161

Model 1-Adjusted for education, mpce quintile, health insurance and occupation. Model 2- Model 1 + physical activity, BMI and multimorbidity. Model 3- Model 2 + tobacco and alcohol abuse. *P<0.05=significant

Conflicts of interest

There are no conflicts of interest.

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Supplementary

Supplementary Table 1: Distribution of participants as per variance inflation factor

Variable	VIF	1/VIF
Indoor air pollution	1.31	0.76
Education		
Less than primary	1.08	0.93
Primary completed	1.15	0.87
Middle completed	1.13	0.88
Secondary school	1.17	0.85
Higher secondary	1.11	0.90
Diploma/Graduate	1.25	0.80
Residence	1.38	0.72
MPCE quintile		
Poorer	1.63	0.62
Middle	1.65	0.61
Richer	1.67	0.60
Richest	1.77	0.57
Marital status		
Married/in live-in	24.03	0.04
Widow/separated/divorced	24.18	0.04
BMI_CAT		
Normal (18.5-22.9)	1.29	0.77
Overweight (23-24.9)	1.25	0.80
Preobese (25-29.9)	1.41	0.71
Obese (>30)	1.30	0.77
Health insurance	1.04	0.96
Occupation		
Professional and semi-professional	1.12	0.89
Clerical and skilled	1.25	0.80
Unskilled	1.14	0.88
Physical activity		
More than once/week	1.25	0.80
Once/week	1.16	0.87
1-3 times/month	1.23	0.81
Never	1.80	0.55
Multimorbidity	1.21	0.83
Tobacco abuse	1.10	0.91
Alcohol consumption	1.05	0.95
Self-rated health		
Very good	5.33	0.19
Good	8.17	0.12
Fair	7.33	0.14
Poor	3.82	0.26
Mean VIF	3.26	