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RESEARCH ARTICLE
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PM_{10} Emissions in Kitchens using Charcoal for Cooking in Rural Homes in Thailand and a Health Risk Assessment

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ABSTRACT

Households in rural areas of Thailand use charcoal as their cooking fuel. This study aimed at assessing the risk of PM_{10}, determining the exposure among rural cooks, and at measuring the PM_{10} levels in households that use charcoal as a cooking fuel in Ubon Ratchathani Province. The study included 400 people, who were living in homes with both open and closed kitchens. The data was collected by measuring the PM_{10} levels in the designated locations and administering the questionnaire to the participants. The standard NIOSH (0600) was used to collect the PM_{10} levels. The Environmental Protection Agency's criteria were used to examine PM_{10}'s non-carcinogenic qualities. The gathered data was subjected to a descriptive statistical analysis. The findings showed that the PM_{10} levels had been higher than the standard at every examined location, including homes with open and closed kitchens. In closed kitchens, the values peaked at 1,020µg/m^3. Hazard quotient (HQ) studies have shown that residents in both types of kitchens had non-cancer health risks that are within acceptable ranges, despite the high PM_{10} levels. In conclusion, the elevated PM_{10} levels in closed kitchens highlighted the pressing need for improved ventilation, even though cooking with charcoal in rural houses does not pose a significant risk to non-cancer health. Interventions that are able to encourage different cooking methods and improve ventilation could significantly reduce exposure hazards and improve the air quality in such settings.

Keywords: Health risk assessment, PM_{10}, Charcoal fuel, Cooking, Kitchen, Rural homes.

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INTRODUCTION

Particulate matter (PM) refers to microscopic particles, which are small enough to be inhaled and could potentially cause significant health issues. Particles smaller than 10 micrometers in diameter can penetrate deep into the lungs, and some may even enter the bloodstream, impacting the cardiovascular, brain, and respiratory systems (Huang, 2023; Guo et al., 2023). Cooking with charcoal releases particulate matter indoors, making it a significant source of air pollution (Eriksson et al., 2022; Mencarelli et al., 2023). According to several studies, PM contains compounds, such as inorganic ions, heavy metals, acidic aerosol species and polyaromatic hydrocarbons (PAHs) (Pirhadi et al., 2020; Vega et al., 2021; Xue et al., 2022; Yabueng et al., 2024). Global ambient air pollution contributes to environmental issues, such as climate change and additionally, endangers public health. Organic carbon (OC) and elemental carbon (EC) make up carbonaceous aerosols, which contribute significantly to particle mass and pose health risks due to the presence of toxic substances.

The primary sources of emissions in Thailand include industries, transportation, and the burning of biomass (Outapa & Ivanovitch, 2019; Sirithian & Thanatrakolsri, 2022; Chansuebsri et al., 2022; Suriyawong et al., 2023). Particulate matter less than 2.5µm ($PM_{2.5}$), particulate matter less than 10µm (PM_{10}), tropospheric ozone (O_3) and volatile organic compounds (VOCs) are among the air pollutants that have exceeded the National Ambient Air Quality Standards (NAAQSs) threshold levels (Nakharutai et al., 2022; Nuchdang et al., 2023).

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The Northeastern region of Thailand comprises agricultural settlements. The farmers' incomes are primarily contingent upon the variability of annual agricultural produce. Consequently, the majority of people in the Northeastern region continue to use charcoal as a cooking fuel in their homes because it can be self-produced or acquired at a lower cost than alternative fuel sources. In the Pho Yai Subdistrict of the Warin Chamrap District of Ubon Ratchathani Province in Thailand, charcoal remains a significant cooking fuel since it is used by over 95percent of homes. Previous research has indicated that the risk of exposure to fine particulate matter from domestic cooking depends on the characteristics of the kitchen (Sidhu et al., 2017), and on the levels of NO_2, SO_2, and CO that are elevated in those kitchens using charcoal and firewood (Raheem et al., 2022). A study by Srithawirat et al. (2024) found that the average concentration of PM_{10} in the kiln zone had exceeded both Thailand's National Ambient Air Quality Standards (NAAQS) and the recommendations of the World Health Organization (WHO) (Srithawirat et al., 2024). Households in the Pho Yai Subdistrict feature both closed kitchen and open kitchen designs. The use of charcoal may generate fine particulate matter (PM_{10}), potentially exposing household members to the dust. However, PM_{10} levels have not been monitored in homes in those regions that use charcoal as a cooking fuel .Therefore, the researchers aimed at measuring the PM_{10}levels in Ubon Ratchathani Province households that use charcoal as a cooking fuel and at assessing the risk of PM_{10}exposure among the resident cooks.

MATERIALS & METHODS

Study Design and Population

This cross-sectional descriptive study evaluated exposure to fine particulate matter (PM_{10}) using quantitative methods that have been developed by the U.S. EPA. The study examined the potential non-cancer risks in the Pho Yai Subdistrict of the Warin Chamrap District of Ubon Ratchathani Province, where residents use charcoal for cooking. The study was conducted between June 2024 to December 2024.

Population and Sample: The Pho Yai Subdistrict comprises 13 villages with 1,756 households using charcoal as a cooking fuel. The sample group consisted of individuals aged 18 years or older, who represented those households that use charcoal as a cooking fuel. The sample group was selected using the population proportion estimation formula, which is outlined in Equation (1).

$$n = \frac{[NZ_{\alpha/2}^2 P(1-P)]}{[e^2(N-1)+Z_\alpha^2 P(1-P)]} \quad (1)$$

in which

n =the sample size

N =the population (1,756 households)

$Z\alpha/2$ = the coefficient under the standard normal curve at 95% confidence level, Z (0.025)=1.96

p =the proportion of health risks from exposure to fine dust particles obtained from a review of relevant literature (Tantipanjaporn et al., 2019)

e =the precision of the estimate (0.044)

$$n = \frac{1756(1.96^2)(0.90)(1-90)}{(0.044^2)(1756-1)+(1.96^2)(0.90)(1-0.90)}$$

$$n = 373.58$$

To prevent errors in field data collection and to minimize dropouts among the research participants, the researchers gathered an additional 400 data samples.

Air samples: Air samples were collected from homes that used charcoal for cooking. They were collected from two similar exposure groups: open kitchens and closed kitchens. A total of fourteen samples were collected, with seven from open kitchens and seven from closed kitchens.

Research Tools

1) The questionnaire collected information that aided in calculating the health risks associated with PM_{10}exposure, consisting of gender, height, age, weight, congenital conditions, smoking history, sources of PM_{10}exposure from other activities, kitchen characteristics, and the duration of PM_{10}exposure in the home.

2) In addition to the record of sample collection, the tools and equipment that were used to gather dust samples in the homes smaller than 10microns consisted of a desiccator, aluminum cyclone, PVC filter, filter cassette, a flow rate calibrator (electronic bubble meter) brand Bios, Model: Defender 510M, Serial No.: 112114, a personal sampling pump, and other laboratory equipment.

The Quality Assessment of the Research Tool

1) The content validity of the questionnaire was examined by three experts, and the Item-Objective Congruence (IOC) Index ranged from 0.67 to 1.00.

Data Collection

1) 400 residents, who were the household representatives of 13 villages of the Pho Yai Subdistrict of Ubon Ratchathani Province, were interviewed to gather general information.

2) Fourteen samples of PM_{10} were collected from households with both open and closed kitchens, adhering to the standard NIOSH collection method number 0600, which is customarily utilized to define the sampling methodology for respiratory PM_{10} (Centers of Disease Control and Prevention 1998). The aluminum cyclone sampler was calibrated with a tarred 5μm PVC membrane utilizing a bubble meter. The sampler was then employed to gather samples in accordance with the previously outlined technique. An eight-hour sample collection was conducted to encompass and represent the measurement. A filter cartridge was attached to the cassette holder and was firmly secured to a tripod, ensuring it was positioned at a minimum height of 0.50meters from the ground (the breathing zone for people, who are cooking while seated). For every ten samples, two blank filter papers were created. Samples were collected at a rate of 2 liters per minute. Upon completion of the sample, the filter cartridge was removed by sealing both ends, thereby facilitating air exchange. The recorded information consisted of the duration of the sample collecting process, the temperature, the relative humidity, the atmospheric pressure, and the type of storage pump utilized and the location of the sample collection. Samples were securely stored in appropriate containers to prevent any potential loss and were subsequently delivered to the laboratory for analysis. The final stage was examined in a laboratory

setting. The filter paper was placed in a desiccator for 16 to 24 hours in order to remove any moisture. Next, one sheet of filter paper was removed using forceps and then placed on a scale. The mass of the filter paper was determined, and the measurement was recorded. The concentration of PM_{10} was then determined by following the formula shown in Equation (2) (Thongchom et al., 2021):

$$C = \frac{[(W2-W1)-(B2-B1)]\times 100}{V} \quad (2)$$

in which.
C = particle concentration (mg/m³)
W1 = initial filter weight (mg)
W2 = final filter weight (mg)
B1 = initial blank filter weight (mg)
B2 = final blank filter weight (mg)
V = air volume (m³)

To assess the risk of PM_{10} exposure among the residents, based on the available reference values, the average daily dose (ADD) values were calculated using Equation (3) (U.S. EPA, 2009) in order to determine the daily intake of PM_{10} via the inhalation exposure route:

$$ADD = \frac{(C \times IR \times ET \times EF \times ED)}{BW \times AT} \quad (3)$$

In which
ADD = average daily dose (mg/kg/day)
C = contaminant PM_{10} concentration in the air (measured values were converted to mg/m³)
IR = inhalation rate (m³/h) (U.S. EPA, 2009)
ET = exposure time (hours/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
BW = body weight (kg)
AT = time on average (days) (U.S. EPA, 1997)

Even though the PM_{10} values that were examined were classified as hazardous, only the non-carcinogenic risk was assessed using the hazard quotient (HQ) values, which is described in Equation (4) (U.S. EPA, 2009).

$$HQ = \frac{ADD}{Rf D} \quad (4)$$

in which
HQ = the hazard quotient (unitless)
ADD = the average daily dosage (mg/ kg/ day)
RfD = the reference dose (mg/ kg/ day). The computations were done using the RfD value for PM_{10}, which is 1.1×10^{-2}mg/kg/day (Gruszecka-Kosowska et al., 2021).

Data Analysis

1) The quantitative data was analyzed using means and standard deviations, whereas the qualitative analysis was conducted using descriptive statistics, such as frequencies and percentage distributions.
2) The Hazard Quotient (HQ) is interpreted as follows: if the HQ is higher than 1, it indicates a health risk that must be controlled. Conversely, if the HQ is equal to or less than 1, it indicates an acceptable degree of health risk (Saju et al., 2023; Ihsan et al., 2023). The analysis was conducted using descriptive statistics, such as frequencies and percentage distributions.

RESULTS & DISCUSSION

General Characteristics

The characteristics of the participants were as follows: 78.8% were female; the average age was 55.34±11.13; and the average weight was 58.53±10.37. Moreover, 59.8% did not have congenital diseases; 90.5% were non-smokers; and 38.0% had been exposed to PM_{10} from other sources, such as burning garbage. In addition, 62.5 %of the participants were preparing their food in open kitchens, while 37.5% were preparing their food in closed kitchens. The average duration of charcoal use was 1.5±0.86 hours/day; the average frequency of using charcoal was 318.53±88.93 days/year; and the average duration of residing in the home was 1.59±17.56 years, as shown in Table 1.

Table 1: The demographic information of the participants (n=400)

Characteristics	n	Percentages
Gender		
Female	315	78.8
Male	85	21.2
Age (years) Mean = 55.34±11.13, Min = 22, Max = 88		
20-40	30	7.5
41-60	259	64.8
80- 61	104	26.0
81≤	7	1.7
Weight (kg) Mean = 58.53±10.37, Min = 35, Max = 90		
30-50	104	26.0
5 1-70	249	62.3
≤71	47	11.7
Congenital diseases		
No	239	59.8
Yes	161	40.2
Diabetes	91	56.5
Blood pressure disease	65	40.4
Asthma	3	1.9
Allergy	2	1.2
History of Smoking		
Smokers	30	7.5
Non-smokers	362	90.5
Former smokers (smoked but quit)	8	2.0
PM_{10} exposure received from other activities		
Burning garbage	175	38.0
Agricultural burning	86	18.7
Lighting incense and candles	48	10.5
Exhaust from automobile smoke or traffic	151	32.8
Kitchen characteristics		
Open	250	62.5
Closed	150	37.5
Duration of charcoal use as a cooking fuel (hours/day):		
Min = 1 Max = 6 Mean = 1.59±0.86		
Frequency of using charcoal (days/year):		
Min = 15 Max = 36 Mean = 318.53±88.93		
Duration of residence in the home (years):		
Min = 1 Max = 85 Mean = 1.59±17.56		

Max: Maximum; Min: Minimum; S.D.: Standard Deviation.

According to the analysis of weight status changes among the residents, the older residents had exhibited a heightened risk of becoming obese and extra obese, as shown in Fig. 1. The distribution of chronic diseases among the 400participating residents was analyzed by gender and age group. Both men and women exhibited an increased risk for chronic diseases, which was shown to intensify with age. The prevalence of multiple morbidities was higher in males than in females across all age cohorts. The age range of 41 to 60years represented a significant transition during which the prevalence of chronic diseases had markedly escalated. The prevalence of three or more diseases was shown to be increasingly common from the age of 61, with diabetes frequently being the first diagnosis. Diabetes frequently coexists with hypertension. Generally speaking, those individuals with three or more disorders have respiratory issues, as shown in Fig. 2. An investigation into air pollution exposure among residents with various chronic diseases versus those without the diseases revealed that agricultural burning is a significant source of pollution, which impacts all disease categories, particularly those residents with asthma and allergies. The incineration of waste and vehicular emissions are significant secondary contributors, as shown in Fig. 3. An analysis of the aforementioned demographic data indicated that residents, particularly older adults, who live in households that use charcoal as a cooking fuel face an elevated risk of exposure to PM_{10} due to age-related physiological changes. This aligns with findings from other studies, which have indicated that hazardous particulate matter, notably PM_{10}, from the combustion of charcoal and other biomass fuels poses increased risks for adults (Peng et al., 2022; Jaiswal et al., 2024).

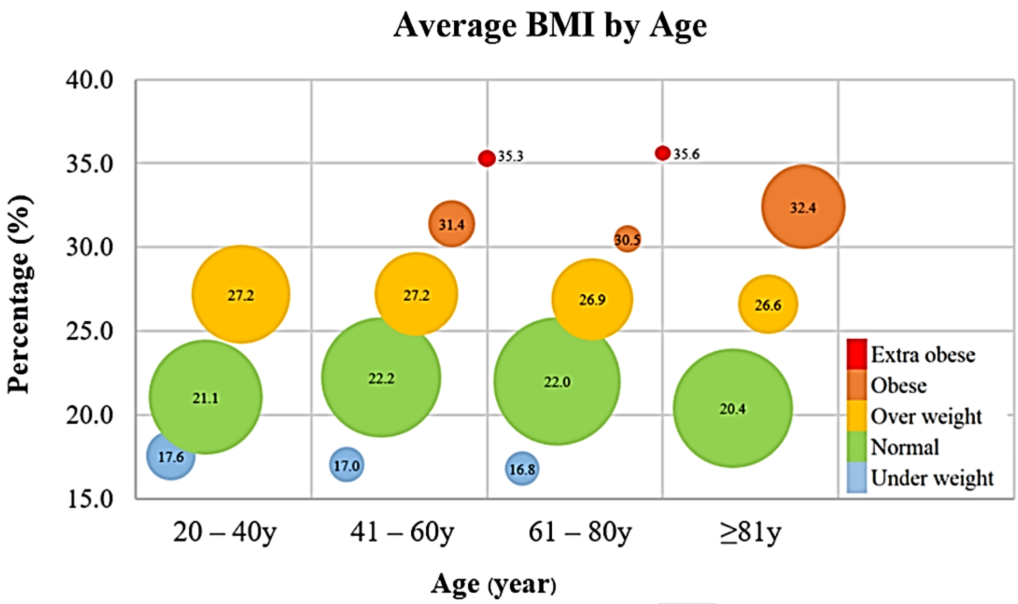

Fig. 1: The average BMI by Age.

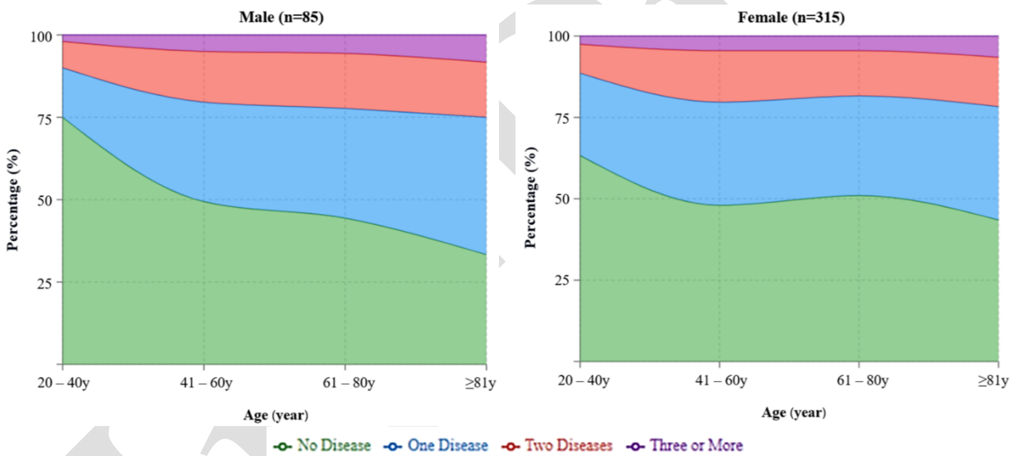

Fig. 2: The distribution of chronic diseases among residents categorized by gender and age group.

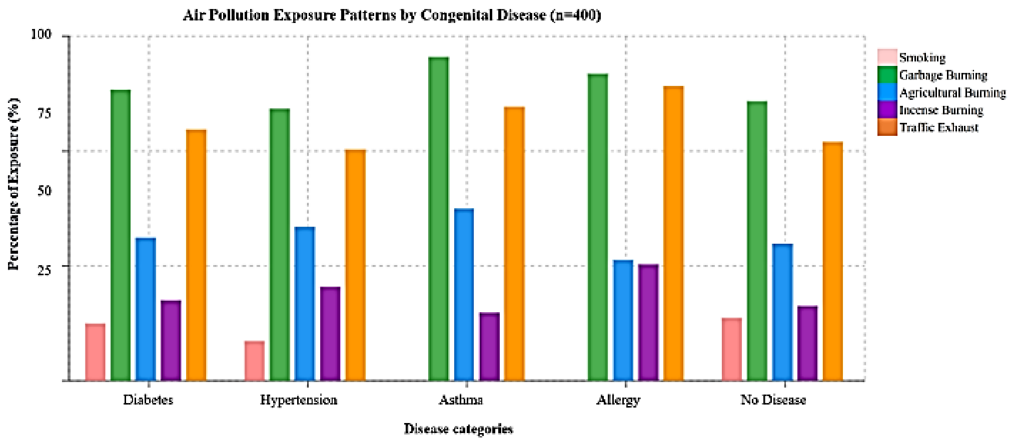

Fig. 3: Air pollution exposure patterns by congenital diseases.

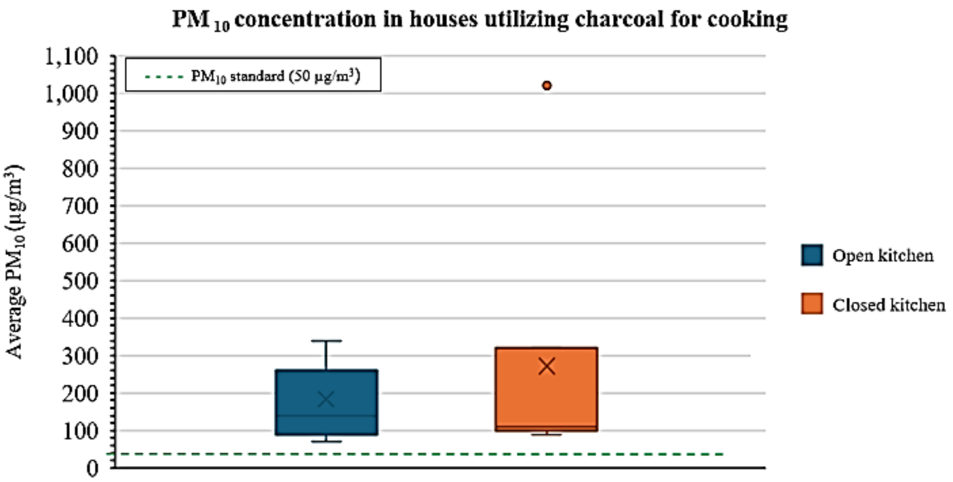

Fig. 4: The PM_{10} levels in residential settings compared to the standard of air quality monitoring in public buildings in Thailand.

The Measurement Results of PM_{10} Concentrations in Homes Using Charcoal for Cooking in the Pho Yai Subdistrict of Ubon Ratchathani Province

This study examined PM_{10} concentrations in rural households in the Pho Yai Subdistrict of Ubon Ratchathani Province, where charcoal is used as a cooking fuel. The measurement outcomes for PM $_{10}$concentrations indicated that open kitchens had exhibited an average dust concentration of 184.285±271.428µg/m^3 (Minimum=70, Maximum=340), while closed kitchens had demonstrated an average dust concentration of 271.428±339.824µg/m^3 (Minimum=90, Maximum=1,020). Compared to the indoor air quality standards established by the Department of Health, these concentrations were deemed to be non-compliant across all categories in Fig. 4. This study found that the levels of PM_{10} at all sampled locations, including both open and closed kitchens, had exceeded the 2022 standards set by the Department of Health for air quality monitoring in public buildings. The highest level was observed in closed kitchens, with a concentration of 1,020µg/m^3. It is probable that the researchers had collected data on PM_{10} concentrations from cooking during the winter season, a period characterized by elevated dust emissions relative to other seasons (Jamloki et al., 2022). This was due to the differences in the characteristics between the open and closed kitchens, which can influence the amount of PM $_{10}$that is released during cooking. In line with other studies, it was demonstrated that cooking in closed kitchens had significantly correlated with elevated PM_{10} concentrations (Muteti-Fana et al., 2023; Enyew et al., 2023). This study's results aligned with those of Mbanya et al. (2017), who discovered that charcoal use had produced elevated PM_{10} levels of 1159µg/m^3 in Ibadan households (Mbanya & Sridhar, 2017). Additional investigations found that the average concentration of PM had exceeded air quality standards (Abulude et al., 2022; Srithawirat et al., 2024).

Risks Associated with PM_{10} Exposure in Case of Non-Carcinogenic Settings

Using the U.S. EPA risk assessment technique, the study of PM_{10} exposure in residences within the Pho Yai Subdistrict of the Warin Chamrap District in Ubon Ratchathani Province, revealed that those households with open kitchens had exhibited values ranging from 0.0001to 0.0169mg/kg/day. Meanwhile, those with closed kitchens had displayed values ranging from 0.0001 to 0.0194 mg/kg/day as shown in Table 2.

Table 2: The results of the assessment of the sample group's exposure to PM $_{10}$through breathing (n=400)

Kitchen characteristics	Daily exposure to PM_{10} (mg/kg/day)
Open kitchens (n=250)	0.0001 – 0.0169
Closed kitchens (n=150)	0.0001 – 0.0194

The processes of health risk assessment, which were involved with data utilization, are organized and shown in Table 3. When the risks associated with exposure to PM_{10} in non-carcinogenic settings were assessed for those residents living in households with open kitchens, the Hazard Quotient (HQ) score had ranged from 0.008 to 1.516, which is considered to be acceptable and which accounted for 97.2% of the cases. The HQ in residents living in households with closed kitchens had ranged from 0.006to 1.706, indicating an acceptable threshold that constituted 96.0% of the cases, as shown in Table 4. The results indicated that the residents living in households with either open or closed kitchens are unlikely to have non-cancer health problems. It is likely that other factors can influence health risks, not just the PM concentration. The following variables can play a part: 1) weight, 2) the duration of charcoal use as a cooking fuel, and 3) the length of residency in the home. Thus, the evaluation of PM_{10} exposure risk revealed that most levels

Table 3: The variables used to evaluate health risks

Variables	Open kitchens	Closed kitchens	Units
	Range of values (Minimum - Maximum)		
PM_{10} Concentration	70-340	90-1020	µg/m^3
Body weight (BW)	39-90	35-83	kilograms
Exposure duration (ED)	22-85	25-80	years
Exposure frequency (EF)	15-366	15-366	days/year
Exposure times (ET)	1-6	1-5	hours/day
IR: Inhalation rates per person for adult	0.83	0.83	m^3/hr
AT: Averaging time	ED x 365 (days)	EDx365 (days)	days
RfD: Inhalation Reference Dose	0.011	0.011	mg/kg/day

Table 4: The outcomes from the risk assessment for non-carcinogenic PM $_{10}$ exposure from residences using charcoal as a cooking fuel

Kitchen characteristics	Hazard Quotients (HQ)	Interpretations	
		Acceptable n(%)	Unacceptable n(%)
Open kitchens (n=250)	0.008 - 1.516	243(97.2)	7(2.8)
Closed kitchens (n=150)	0.006 - 1.706	144(96)	11(4%)

had been within an acceptable range. This study, along with several others, also found that the use of charcoal fuel for cooking results in a hazard quotient of less than 1.0 (Embiale et al., 2020; Ocampos et al., 2023).

Due to variations in airflow, closed kitchens typically present a greater risk of PM_{10} exposure than open kitchens. Residents, who live in homes with closed kitchens, are more prone to heightened exposure to PM_{10} during cooking or other activities. The restricted airflow in closed kitchens limits the dispersion of particulate matter, resulting in its accumulation in elevated quantities over time. Conversely, the benefits of open kitchens include enhanced ventilation, which can more efficiently release airborne contaminants. The open design allows unrestricted air circulation, which in turn dilutes and disperses PM_{10} into the ambient environment. This natural ventilation reduces the concentration of risky particulates in the cooking area, and hence, lessens the associated health hazards for residents. According to several studies, ventilation is the most significant element controlling indoor PM concentrations (Huang et al., 2022; Lachowicz et al., 2023; Enyew et al., 2023).

Conclusion

This study highlighted how using charcoal as a cooking fuel in rural homes in the Pho Yai Subdistrict of Ubon Ratchathani Province poses serious air quality issues. With levels peaking at 1,020µg/m³ in closed kitchens, PM_{10} concentrations in both open and closed kitchen environments had been higher than the Department of Health's guidelines. Despite these high PM_{10} levels, hazard quotient (HQ) studies indicated that residents in both types of kitchens had been experiencing non-cancer health risks within acceptable bounds, with HQ values primarily less than 1.0. In conclusion, even though cooking with charcoal in rural homes does not present a serious risk to non-cancer health, the increased PM_{10} levels in closed kitchens highlight the urgent need for better ventilation. In such environments, interventions that promote alternative cooking techniques and improve airflow could significantly lower exposure risks and enhance air quality.

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Conflicts of Interest: The authors reaffirm that there were no conflicts of interest during the study's conduct.

Ethics Approval and Consent to Participate: This research, which was conducted between June 2024 and December 2024, received approval from the Human Research Ethics Committee of Ubon Ratchathani University (Code: UBU-REC-175/2567).

Authors' Contribution: Conceptualization: LB, PP, CT, PR, and SK; Methodology: LB, PP, CT,SK, and ST; Software: SC and LB; Validation: LB, PP, CT,PR, and SK; Formal analysis: LB, PP, and CT; Investigation: LB, PP, CT, PR , SK, ST, SC and AS; Resources: LB, and ST; Data curation: LB, PP, CT, PR, and SK; Writing—original draft preparation: LB and PR; Writing—review and editing: LB, PP, CT, PR , SK, ST, SC, and AS; Visualization: LB, PP, CT, PR , SK, ST, SC, and AS; Supervision: PR; Project Administration: LB; and Funding acquisition: LB. All authors have read and agreed to the manuscript's published version.

Data Availability: The data is available from the corresponding author based upon a reasonable request.

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