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Research Article

Indoor Air Quality among the Rural Community of Bhutan

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A B S T R A C T

Introduction: Poor indoor air quality (IAQ) in Bhutan remains a concern, as firewood and biomass combustion are the fuels generally used for cooking and heating. The adverse impact of indoor air pollution (AIP) on health is inevitable and requires further evidence to be acquainted with strategic modifications. This study aimed to determine IAQ in the rural communities of Bhutan.

Method: Air sampling equipment DUSTTRA DRX Aerosol Monitor was used to collect samples from 161 rural households with randomised sampling from February to June 2021. An hourly survey included data extraction regarding particulate matter (PM_1, $PM_{2.5}$, and PM_{10}) and common health problems among household members.

Results: IAQ worsened during the cooking hours, where PM_{10}, $PM_{2.5}$, and PM_1 increased by 118%, 112.2%, and 111.6%, respectively. Overall, 77% of households used firewood for cooking, 96.3% used it for room heating, and 100% used fodder for cooking. The main source of higher indoor air pollution was associated with the combustion of sawdust, firewood, and biogas. Similarly, traditional mud stoves generated more IAP than gas and modified mud stoves. It is found that there is a significant association of longer hours of window-opening ($p < 0.05$) and more numbers of rooms ($p < 0.001$), with IAP. Common health-related complaints comprised eye irritation (22%), headache (22%), coughing (19%), and skin irritation (11%).

Conclusion: This study recorded high concentrations of PM during biomass combustion in rural houses in Bhutan. The Study demonstrated the importance of modified stoves with efficient venting systems as alternatives to counter the long-term burden of IAP.

Keywords: Indoor Air Pollution, Indoor Air Quality, Particulate Matters

Introduction

Indoor air quality (IAQ) for occupants in rural parts of Bhutan remains a concern because firewood and biomass combustion remains the primary cooking and space heating fuels, which in turn contribute to indoor air pollution (IAP). The resulting IAP poses a significant health risk. However, approximately 99% of the world's population is exposed to air quality that exceeds WHO-recommended limits, posing a significant threat to global health. WHO has estimated that the burden of disease due to air pollution is more than 3.8 million in 2016 and the Pacific and Southeast Asia regions bear the highest burden with 1.2 million and 1.5 million deaths respectively.[1] Approximately 4.1% of global deaths in 2019 were attributed to indoor air pollution, and death rates were exponentially high in low- and middle-income countries.[2]

Despite the prevalence of indoor air pollution, a significant proportion of the population was found to spend 90% of their time indoors, either at home or at work.[3-5] Indoor air quality (IAQ) at home is greatly influenced by migrated outdoor air and indoor activities, such as cooking, smoking, use of electronic machines, consumer products, or emissions from building materials. A study in Nepal found that poorly ventilated kitchens were polluted 100 folds comparatively.[6]

The Population and Housing Census showed that the proportion of households using firewood for cooking in rural areas decreased from 56.6% in 2005 to 36.7% in 2017.[7] Although 99% of households in Bhutan have access to electricity, 33.3% of rural households currently use firewood as an energy source. Solid fuels, such as different types of firewood and other related biofuels, are mostly combusted in inefficient traditional mud stoves without smoke venting systems. Indoor air pollution poses a significant health risk. Incidences were prevalent among people in the Gasa district (91.5%), followed by Haa (89%) and Bumthang (87%), who are also highlanders, as recorded,[7] and 40% of the households in Thimphu still use firewood[8]. To further evaluate indoor pollution, the combustion by-products of widely used kerosene stoves, heaters, and lamps, aside from firewood alone, were found to be inevitable in the rural community of Bhutan.

The emissions and exposure to volatile organic compounds (VOC) due to firewood combustion include benzene, toluene, and xylene, which have adverse effects on human health, and no negligible amount is recommended as safe. Their implications are further complicated, as most communities do not follow the exposure regulations set by the Occupational Health and Safety Administration (OSHA).[9,10] The Annual Health Bulletin states that acute respiratory disease (ARI) has been one of the top ten diseases in Bhutan over the last five years.[11] However, there is no or limited study assessing the correlation between air pollution and the occurrence of respiratory diseases. Some indoor air pollutants include particulate matter (PM), aerosols, carbon monoxide, volatile organic compounds, and biological pollutants,[12,13] causing a greater threat to health owing to their penetration into the alveoli. Irrespective of duration, exposure to indoor air pollution is susceptible to non-communicable diseases, including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD), lung cancer, severe eye diseases, middle ear complications,[14] and sick building syndrome due to decreased indoor air quality.[1,4,15]

With studies showing the average time spent indoors and various health issues resulting from polluted air, this study aims to draw the facts regarding IAQ for scientific evidence and a way forward. Methodologically, this study aimed to determine the IAQ in a rural community by measuring PM_1, $PM_{2.5}$, and PM_{10} concentrations produced by the types of stoves and fuels used. The study also aimed to explore other sources of contributing factors such as building materials. Furthermore, this study examined the correlation between IAQ, ventilation systems, and related health issues.

Materials and Method

Sample Design and Consent

A cross-sectional study was conducted among rural households in Bhutan using the convenience sampling method for selecting sample size and the grab sampling method for sampling air samples. A total of 161 households from 20 villages were selected for the study, covering two Dzongkhags.

Informed consent to conduct an interview was obtained using an informed consent form and the reason and benefit of the study were explained to the interviewee before an interview.

Data Collection

The data were collected using direct-reading air sampling equipment DUSTTRA DRX Aerosol Monitor which simultaneously measures size-segregated mass fraction concentrations corresponding to PM_1, $PM_{2.5}$, PM_{10}, respirable, and total PM size fractions measuring both mass and size fraction. Information on the household characteristics was recorded using a structured questionnaire.

The samples were collected from 161 rural households in 20 villages in Haa and Chhukha Dzongkhags. Five villages (69 households) from Haa Dzongkhag and 15 villages (92 households) under Chhukha Dzongkhags were included in the study.

The indoor air sampling instrument was positioned at a height of one meter or breathing zone level while in a sitting position. It was also a common area where black carbon (BC) concentrations were observed in most households. The instrument was placed at a location where a person stayed or spent most of their time during cooking or non-cooking hours in the house.

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Time Series

Indoor PM_1, $PM_{2.5}$, and PM_{10} data were collected from each household for over an hour. This study recorded the Particulate Matter (PM) in different locations of the household based on (i) the kitchen combined with the living room and bedroom and (ii) where the kitchen is separated from the living room and bedroom. Sampling was performed during two different hours: (i) cooking hours and (ii) non-cooking hours.

The study was conducted from the month of February to June 2021.

Statistical Analysis

Descriptive analyses were performed using frequencies and percentages to determine the prevalence and correlations between the various variables. All statistical analyses were conducted using SPSS software, version 26.

Ethical Approval

Ethical approval was obtained from the Research Ethics Board of Health (REBH). The study was approved by the REBH, visa letter number No. REBH/Approval/2019/015 dated 21 February 2019.

Results and Discussion

This study examined IAQ during cooking and non-cooking hours. It was found that IAQ deteriorated during cooking hours compared with non-cooking hours. PM_{10} increased by 118% during cooking hours, $PM_{2.5}$ by 112.2%, and PM_1 by 111.6%, as illustrated in Table 1 which is consistent with the study conducted by Dahal et al.[6]

Table 1.PM Values between Cooking and Non-cooking Hours

PM Values	Cooking Hours	Non-cooking Hours	% Increase in PM during Cooking Hours
PM_{10} (Avg)	13.6	6.2	118.0
PM_{10} Max	76.8	13.2	481.0
PM_{10} Min	8.1	5.4	51.9
$PM_{2.5}$ (Avg)	13.5	6.4	112.2
$PM_{2.5}$ Max	75.8	12.9	486.2
$PM_{2.5}$ Min	7.5	5.3	40.0
PM_1 (Avg)	13.5	6.4	111.6
PM_1 Max	74.1	12.9	473.9
PM_1 Min	8.8	7.2	22.0

Source of IAP

Many heat sources are used for cooking, which can cause indoor air pollution (IAP). Using firewood for cooking or heating can result in a higher concentration of IAP in wood smoke.[6] It was found that approximately 77% of households used firewood for cooking, 96.3% used it for room heating, and 100% used fodder for cooking in comparison to other sources of fuel. The widespread use of firewood as a primary fuel in these rural households was due to it being more economical and easily available.

A higher concentration of IAP was found among the households using sawdust (PM_{10} 18.7 mg/m^3, $PM_{2.5}$ 18.6 mg/m^3, and PM_1 18.5 mg/m^3) and firewood (PM_{10} 13.7 mg/m^3, $PM_{2.5}$ and PM_1 with 13.6 mg/m^3) in comparison to biogas ($PM_{10,2.5,1}$ 8.4 mg/m^3) as fuel for cooking. The study also found that the use of firewood and IAP had a significantly negative relationship with PM_{10} and PM_1 ($r(159) = -0.261$, $p = 0.001$) and $PM_{2.5}$ $r(159) = -0.260$, $p = 0.001$.

Furthermore, the study found that the use of a traditional mud stove for cooking resulted in higher IAP compared to the use of gas and mud-improved stoves. These findings were expected because the majority of the traditional cooking stoves were open combustion chambers without chimney ventilators, enabling all primary particles emitted during combustion to freely diffuse inside the kitchen and exaggerate the IAP.

The particulate matters measured in the households using traditional mud stoves were $PM_{10,2.5}$ 16.2 mg/m^3, and PM_1 16.1 mg/m^3, for gas stoves were $PM_{10,2.5,1}$ 8.4 mg/m^3, and mud improved stoves were $PM_{10,2.5,1}$ 5.8 mg/m^3. Thus, a mud improved stove was found to be significantly ($p < 0.001$) associated with IAQ or negatively correlated with IAP as shown in Table 2. The household that used a mud improved stove showed a lower level of IAP.

The majority of rural households in the study used traditional mud stoves (35.1%), mud improved (23.4%), zip 3 stone (21.1%) compared to gas (2.3%) and electrical stoves (18.1%) for cooking. However, most households used mud improved, mud traditional, and zip 3 stone stoves for room heating and fodder cooking.

Ventilation

This study examined IAQ among households that kept their windows open for longer hours. It is assumed that keeping the windows open will emit indoor pollution into the ambient environment and improve the IAQ. A positive correlation was found between IAQ and long window-opening hours.

The IAP decreased with longer window-opening hours, as shown in Table 3. The likeliness of the IAP concentrations was highly correlated with the type and method of ventilation used. These findings are further complimented by the result of Wangchuck T et al.,[16] who reported that the mean $PM_{2.5}$

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concentrations with metal chimney smoke were 3 and 4 times higher than the mean concentrations measured before heating, whereas mean $PM_{2.5}$ concentrations with the traditional mud stove were 64 and 69 times, respectively. The above-mentioned background might be the probable reason why this study observed that the majority (23% to 50%) of households kept their windows open for long hours.

These results are consistent with those reported in another study[17] where high concentrations of $PM_{2.5}$ were significantly associated with poorer ventilator conditions for stove/ chimneys.

Table 2.Correlation between PM and Mud Improved Stove

		Mud Improved stove	PM_{10}	$PM_{2.5}$	PM_1
Mud Improved stove	Pearson Correlation	1	-0.301**	-0.298**	-0.297**
	Sig. (2-tailed)		0.00	0.00	0.00
	N	161	161	161	161
PM_{10}	Pearson Correlation	-0.301**	1	0.999**	0.999**
	Sig. (2-tailed)	0.00		0.00	0.00
	N	161	161	161	161
$PM_{2.5}$	Pearson Correlation	-0.298**	0.999**	1	1.000**
	Sig. (2-tailed)	0.00	0.00		0.00
	N	161	161	161	161
PM_1	Pearson Correlation	-0.297**	0.999**	1.000**	1
	Sig. (2-tailed)	0.00	0.00	0.00	
	N	161	161	161	161
**Correlation is significant at 0.01 level (2-tailed).					

Table 3.IAP with Conventional Venting System (Windows Opening)

Hours of keeping the Windows Open during a Day	Number of HHs	PM_{10}		$PM_{2.5}$		PM_1	
		Cooking hrs	Non-cooking hrs	Cooking hrs	Non-cooking hrs	Cooking hrs	Non-cooking hrs
1-3	38	16.37	10.8	16.11	11.4	16.02	11.4
4-6	14	24.35	11.3	24.32	11.3	24.18	11.3
7-9	22	7.08	2.1	7.07	2.0	7.05	2.0
10-13	80	12.60	4.6	12.64	4.6	12.60	4.6
≥ 14	7	8.91	3.0	8.80	2.9	8.64	2.9

Table 4.Correlation between PM and Hours of Window Opening

		Hours of Window Opening	PM_{10}	$PM_{2.5}$	PM_1
Hours of window opening	Pearson Correlation	1	-0.164*	-0.157*	-0.156*
	Sig. (2-tailed)		0.037	0.047	0.048
	N	161	161	161	161
PM_{10}	Pearson Correlation	-0.164*	1	0.999**	0.999**
	Sig. (2-tailed)	0.037		0	0
	N	161	161	161	161
$PM_{2.5}$	Pearson Correlation	-0.157*	0.999**	1	1.000**
	Sig. (2-tailed)	0.047	0		0
	N	161	161	161	161

PM_1	Pearson Correlation	-0.156*	0.999**	1.000**	1
	Sig. (2-tailed)	0.048	0	0	
	N	161	161	161	161
*Correlation is significant at the 0.05 level (2-tailed).					
**Correlation is significant at the 0.01 level (2-tailed).					

Further investigation revealed that indoor air pollution (IAP) and the number of hours of window opening had a negative relationship, as shown in Table 4. The longer hours of the window opening were significantly ($p < 0.05$) associated with a decrease in IAP or better IAQ.

Furthermore, a significant correlation ($p < 0.01$) is found between the IAQ and the number of rooms and rooms with separate kitchens. Table 5 highlights the PM quantifications in each room measured in the breathing zone area for an hour each. IAQ was advantageous in households with more rooms, particularly in rooms away from the combustion activity. Households having 5 rooms represent the room furthest from the kitchen or the area of combustion of solid fuel. However, it was found that about 72% of the households do not have separate kitchens and out of these households that do not have separate kitchens, 77% have a kitchen combined with a sitting room, and 23% kitchen combined with a bedroom.

Table 5.PM as per the Number of Rooms

No. of Rooms	PM_{10}	$PM_{2.5}$	PM_1
1	21.0	20.8	20.8
2	14.7	14.7	14.7
3	10.3	10.2	10.2
4	5.8	5.8	5.7
5	4.8	4.8	4.7

Health Impact

Although this study could not establish an association between IAQ and health impact directly due to heterogeneity in responses acquired, it reports the results of the most prevalent health conditions experienced by household members surveyed. Approximately 22% of household members experienced eye irritation, 22% headache, 19% coughing, and approximately 11% skin irritation while they were exposed to IAP during cooking hours. Continuous and painful cough during IAP exposure could be because studies have found that respiratory infections are associated with exposure to household air pollution.[18] Inhaled toxic substances that either directly or indirectly affect lens tissues and drying lubricants can be exaggerating factors for eye irritation, with a prevalence of 22%. Although this study did not record any mortality due to IAP, air pollution is the largest environmental cause of death worldwide, accounting for approximately 3·5-4 million deaths every year. Women and children living in severe poverty have the greatest exposure to household air pollution.[18]

At present, there are no regulations or limits set for volatile organic compounds (VOCs) such as benzene, toluene, and xylene, resulting from firewood combustion in Bhutan. Benzene is a genotoxic carcinogen, and no safe level is recommended according to the Agency for Toxic Substances and Disease Registry.[9] The legal limits of emissions and exposure to VOCs differ from nation to nation and usually rely on levels set by the Occupational Safety and Health Administration (OSHA).[10]

IAP is relevant to health because people spend most of their time indoors. Eye irritation (22%), prolonged headache (22%), painful coughing (19%), and skin irritation (11%) were the most prevalent health complications among household members who were frequently exposed to significant IAP. Although the desirable change to clean fuels is unlikely in the near future, the current study's findings provide scientific evidence to move forward with the necessary advocacy, plans, and implementations to counter the long-term burden of IAP. This study demonstrates the importance of using modified stoves with efficient venting systems as alternatives.

Conclusion

This study recorded high concentrations of particulate matter (PM) during the combustion of biomass in rural houses in Bhutan, with IAP rising by 111.6% during cooking hours compared to non-cooking hours. Opening the windows used in conventional venting systems resulted in a drastic reduction in IAP, which highlights the importance of proper venting systems. The structures used for combustion resulted in differences in the IAP, indicating the importance of stove structure modifications.

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Conflict of Interest: None

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