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Estimation of Nitrogen Dioxide (NO_2) Due to Burning of Household Biomass Fuel and Assessment of Health Risk among Women In Rural West Bengal

DEEP CHAKRABORTY* and NABA KUMAR MONDAL

Environmental Chemistry Laboratory, Department of Environmental Science, The University of Burdwan, West Bengal.

Abstract

More than 75% population living in rural sectors in India and mostly rely on biomass fuels due to their easy availability. Here in this study we examined the health risk from the smoke emitted due burning of biomass fuels while cooking in rural houses in West Bengal. Out of numerous gaseous pollutant this study selected NO_2 component to find out the health risk of women. NO_2 has been monitored in kitchen and adjacent living room in N= 30 households in three season namely summer, monsoon and winter, respectively. Study results found that highest NO_2 concentration found in kitchen room than in living room in all seasons and the difference between the concentrations showed significant results (< 0.001). However, ANOVA analysis has been done to check the seasonal variation within the kitchen and living room NO_2 concentrations and results have revealed that there was significant (< 0.001) difference present within kitchen and living room concentration seasonally. Moreover, women health risk were assessed with established empirical model. Results showedthathere were no immediate acute health risk present among women whereas women possessed chronic health risk (HQ > 1) from kitchen room NO_2 concentration. This study concluded that NO_2 has chronic health effects on women who habituated to continue cooking with unprocessed biomass fuels. Study also suggested to use more clean fuel like LPG, electric and solar energy for daily use and in this respect PMUY is doing a significant work.

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Keywords
Household Air Pollution; Health Risk Assessment; Monte-Carlo Simulation; NO_2.

Introduction

The predominant cause of indoor air emissions globallyand in most developed countries is incomplete burning of biomass; it is burnt open and creates a lot of smoke.[1,2] The biomass smoke contains a wide range of high-risk pollutants, such as coarse, small,

CONTACT Deep Chakraborty deepckbty@gmail.com Environmental Chemistry Laboratory, Department of Environmental Science, The University of Burdwan, West Bengal.

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and ultrafine particulate matter, carbon monoxide, nitrogen and sulfur oxide, transitional metals, polycyclic, aromatic, and bio-aerosol compounds.[3] Recent studiesin rural home revealed that the main sources of indoor air pollution were burning of biomass fuels in poorly designed stoves.[4,5] However, wood stove emissions in different developed countries are the major cause of indoor air pollution in several poor homes.[6] Biomass is really the only origin that creates a great deal of contaminants that are detrimental to human health and impact climate change as well.[7] Many gaseous contaminants such as NO_2, CO, CO_2 and O_3, including relative humidity and temperature, are generated during biomass burning.[8] Due to inefficient burning in traditional stove, pollutants likeoxides of nitrogen, $PM_{2.5}$, organic hydrocarbons are usually emitted.[6] However, Begum *et al*. figured out that the estimated concentration varies on spatio-temporal monitoring and the difference may present room to room.[9] To the best of our knowledge there are scarsstudy on nitrogen dioxide concentration estimation in rural indoor environment. However, researchersstudied that, in rural household, high concentrations of NO_2 are due to the use of poor combustion stoves.[10-13] In fact, peak occurrences of NO^2 are closely correlated with the use of gas and solid fuel stoves, during cook practices.[14] Due to greater heating usage, reduced ventilation rates and higher outside concentrations, indoor concentration are usually higher in winter than in any other seasons.

NO_2 has the ability to reduce antioxidant tissue defences and thus, as revealed in a number of vitro test systems, induce damage and inflammation. Findings also have demonstrated that the progression of chronic diseases, such as infections and obstructive pulmonary disease, can affect individuals by prolonged exposure to NO_2. Short-term NO_2 toxicity that had negligible human harmful effects was smaller than 0.2 mg/m^3 and 0.9 mg/m.[315,16] Exposure to reported high NO_2 concentrations caused respiratory damage. Furthermore, it can cause irritation when you touch the skin or eye. Analysis has also demonstrated that extended exposures to elevated NO_2 levels may be responsible for asthma production and the potential rise in respiratory sensitivity.[17] To the best of our knowledge there are no study on specifically NO_2 and health risk among the rural women in West Bengal. Many study has been done on the cumulative effects on health of the women. Keeping in view of diverse nature and effects of nitrogen dioxide this study aims to determine theconcentrations of indoor NO_2 in rural households and to predict human health risks associated with NO_2 exposure in rural West Bengal, India.

Materials and Methods

Study Area and Research Design

The adjoining rural area of the Purulia town, West Bengal, a state in Eastern India was selected for the study. Informed consent of the each participants was acquired prior to the study.

Ethical Approval

Ethical approval (No. IEC/BU (2016/1)) was taken from the Ethical Committee Board of the University of Burdwan, West Bengal, India.

Indoor Air Quality Measurements

Nitrogen dioxide (NO_2) was measuredaccording to Mondal and Chakraborty[5] by APM 821 (Envirotechmade). During cooking times in both the kitchen and living room, the concentration of NO_2 was monitored. Sampling was performed mostly in the evening when most of the villagers cooked their meals for night. All the instruments were charged and calibrated prior to sampling. The instruments were positioned 1.5 m away from the stove and kept at breathing height of the women in sitting condition.

Quality Assurance and Control

APM 821 can maintain flow rate from 0.5 to 1 LPM up to 7 ± 1 h. Standardization of the instrument was done by the following method approved by CPCB, GoI. A constant flow rate of 1 LPM were maintained during sampling. Repeated data taken in laboratory and field condition showed >95% efficiency in both place.

Human Health Risk Assessment

Exposure Assessment

The non-carcinogenic exposure assessment from NO_2 were done by the following equation.[18]

$$AHD = C \times IR/BW \qquad ...(1)$$

here, AHD = average hourly dose for inhalation (µg/kg/hour),

IR = inhalation rate (m^3/hour)
C = concentration of NO_2 ($\mu g/m^3$), and
BW = body weight (kg).

For exposure to non-carcinogenic pollutants (NO_2), the chronic exposure equation[19] was used for the inhalation exposure route:

$$ADD = (C \times IR \times ED)/ (BW \times AT) \quad ...(2)$$

Where, ADD = average daily dose of the pollutant of interest (µg/kg/day),

C= concentration in air ($\mu g/m^3$),
ED = exposure duration (days),
IR = inhalation rate (m^3/ day),
AT = averaging time (days),
BW =body weight of the women (kg)

Risk characterization by Hazard Quotient (HQ)

Here, the hazard quotient (HQ) is used to quantify potential non-carcinogenic consequences from exposure to a known pollutant. It represents the risk of a possible adverse result for people who are stable and/or receptive. Both acute and chronic exposure cases, non-cancer likelihoods were estimated as:

$$\text{Chronic HQ} = ADD/REL \quad ...(3)$$

$$\text{Acute HQ} = AHD/REL \quad ...(4)$$

Where, REL (reference exposure level), as adopted from WHO.

An HQ of 1.0 is known as the protection benchmark. An HQ < 1.0 suggests a marginal risk, i.e. the carcinogen under investigation, even for a susceptible human, is not likely to cause adverse health consequences. An HQ >1.0 suggests that as a result of exposure, there could be certain risks to susceptible people.

Uncertainty and Sensitivity Analyses

In the process of analyses of risk there may present large quantity of uncertainty due to the fixed input values rather than the range of measured data in the NO_2 risk calculations. Monte-Carlo simulation was run to estimate the uncertainty and sensitivity of the NO_2 risk factors to find out their role in the measured risk certainty.

Statistical Analysis

The study results were statistically analyzed using SPSS, Minitab 16, and Crystal Ball software ver. 11.1.2.4 (Oracle) was used to run the Monte-Carlo simulation. Pair t-test, ANOVA were applied to analyse the differences between pollutant concentrations at 5% level of significance.

Table 1: Concentration of Nitrogen dioxide (NO_2) in kitchen and living room and statistical analysis

Monitoring site and season	Mean ± SD	t- value	P value
NO_2-KS	43.21 ± 5.72	26.29	P < 0.001
NO_2-LS	15.413 ± 0.626		
NO_2-KM	45.062 ± 2.761	56.44	P < 0.001
NO_2-LM	14.777 ± 0.591		
NO_2-KW	75.502 ± 1.423	178.57	P < 0.001
NO_2-LW	20.353 ± 0.852		

KS-kitchen/summer, KM- kitchen/monsoon, KW-kitchen/winter; LS-living/summer, LM-living/monsoon, LW-living/winter

Results and Discussion

Indoor NO_2 concentration monitoring in kitchen and living Room

Monitoring of household air pollution took place in both kitchen and living room in three different season namely, summer, monsoon and winter while the cooking activity takes place. The result has been presented in table 1. During summer season the NO_2 concentration in kitchen and living room were 43.21 ± 5.72 $\mu g/m^3$ and 15.413 ± 0.626 $\mu g/m^3$, respectively.

In monsoon season the NO_2 concentration in kitchen and living room were 45.062 ± 2.761μg/m^3 and 14.777 ± 0.591 μg/m^3, respectively and in case of winter season the NO_2 concentration in kitchen and living room were 75.502 ± 1.423 μg/m^3 and 20.353 ± 0.852 μg/m^3, respectively. Study showed that in each season there wasa significant difference ($P < 0.001$) present between kitchen room and living room pollutant concentration which can been defined with t-values also. Pair- t-test were conducted between kitchen and living room pollutant concentration and found t-values 26.29, 56.44 and 178.57 in summer, monsoon and winter season, respectively. Most of the studied rural households having the kitchen room adjacent to living room which may play a vital role for the higher concentration in living room. During survey smoky smell has been noticed all over the living room. Most of the kitchen room display improper ventilation which means lack of cross ventilation. Previous research also found the same kind of pattern in their study which support our recent research output.[21-22] The mean 24-hour nitrogen dioxide concentration was found 97 μg/m^3 in a sample in Ethiopia, where biomass, crop residue and animal dung were the major household fuels.[23] The dominance of outside sources (mainly diesel generators and traffic) responsible for elevated level of indoor nitrogen dioxide concentrations was found in a study in Agra, India.[24]

Table 2: ANOVA results for Nitrogen dioxide (NO_2) concentrations among the three seasons in kitchen room

Source	DF	SS	MS	F	P
Season	2	19727.8	9863.9	698.49	P < 0.001
Error	87	1228.6	14.1		
Total	89	20956.4			

Table 3: ANOVA results for Nitrogen dioxide (NO_2) concentrations among the three seasons in living room

Source	DF	SS	MS	F	P
Season	2	558.9	279.45	571.34	P < 0.001
Error	87	42.552	0.489		
Total	89	601.452			

One-way ANOVA Analysis of Indoor NO_2 Concentration in different Season

Table 2 and 3 presented the ANOVA result of NO_2 in three season in kitchen and living room respectively. From table 2 the F value found 698.49 and table 3 the F value was 571.34 which both were found significant ($P < 0.001$). Moreover, the result revealed that there were significant variation in NO_2 concentration present in three seasons in both kitchen room and living room. Similar variation of results has been found by few previous studies.[25,26] Zota *et al.*,[10] conducted study in the kitchen, living room, and outdoors during one year period, andfound the highest concentration in the kitchen was during the summer season. It is general that windows are generally kept open during other season than winter season which allow the exit of NO_2. Sometime outdoor to indoor transmission of NO_2 also may cause of higher concentration in indoor.

Health Risk Assessment from Indoor NO_2

Kitchen and living room NO_2 concentrations of three season were used to calculate HQ. The HQ calculated for acute exposures showed no immediate adverse health effects for women($HQ<1.0$). Moreover, chronic exposure to NO_2 was found to be higher ($HQ>1.0$) for women who cook with biomass fuel (shown in table 4) which suggested an adverse health condition may appear in near future.

From table 4 it was found that in all the seasons both in kitchen and living room the acute exposure were found to be safe e.g. for kitchen; 2.36E-02, 2.46E-02, 4.12E-02 in summer, monsoon and winter, respectively and for living room these were; 8.41E-03, 8.06E-03, 1.11E-02 in summer, monsoon and winter, respectively. It is important to note that chronic health risk only found from kitchen room NO_2 i.e. 1.04E+00, 1.09E+00, and 1.83E+00 in summer, monsoon and winter, respectively. However, no significant chronic health risks were found from living room NO_2 concentration. Evidence from the recent risk assessment showed a low risk from acute exposure to indoor NO_2. However, some recent studies have found that low levels of NO_2 exposure can lead to acute and obstructive lung diseases.[28,29] Some studies also found an association between NO_2 concentration and acute ischaemic stroke.[27, 30] However, there were some studies that did not find any significant associations between exposure to NO_2 and human health.[31-32]

Table 4: Hazard quotients for acute and chronic exposure from nitrogen dioxide (NO_2) at different season

Monitoring site and season	Acute HQ	Chronic HQ
NO_2-KS	2.36E-02	1.04E+00
NO_2-KM	2.46E-02	1.09E+00
NO_2-KW	4.12E-02	1.83E+00
NO_2-LS	8.41E-03	3.73E-01
NO_2-LM	8.06E-03	3.57E-01
NO_2-LW	1.11E-02	4.92E-01

KS-kitchen/summer, KM- kitchen/monsoon, KW-kitchen/winter; LS-living/summer, LM-living/monsoon, LW-living/winter

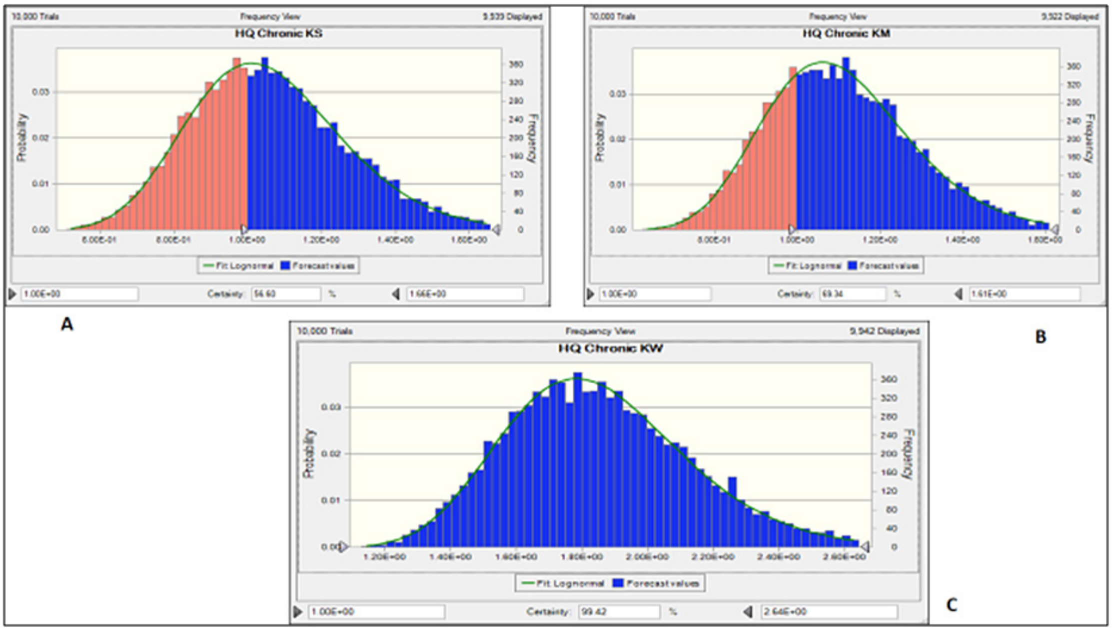

Fig.1: Monte-Carlo probabilistic distribution of the Hazard quotient (HQ) for NO_2 in kitchen room during summer (A), monsoon (B) and winter (C) season

Monte Carlo Probabilistic Simulation of Toxicological Risk of NO_2

It is generally evident that uncertainty will exist in the monitoring of the pollutants, different exposure variables, toxicity potential of different pollutants, duration of exposure, etc. As from table 3 it was observed that concentration of kitchen room NO_2 showed the chronic health effects because of thatMonte-Carlo simulation model has been run only for chronic HQ values of the kitchen room. In the simulation model, the lognormal curve was fitted to the frequency distribution of the forecast values. HQ of NO_2 during summer exposure showed the median value of 1.04E+00 and there was 56.60% of certainty that the women having the chronic health risk from NO_2 with the HQ values > 1 (Fig. 1A). In case of monsoon season exposure showed the median value of 1.09E+00 and there was 69.34% of certainty that the women having the chronic health risk from NO_2 with the HQ values > 1 (Fig. 1B). Moreover, In case of winter season exposure showed the median value of 1.82E+00 and there was 99.42% of certainty that the women having the chronic health risk from NO_2 with the HQ values > 1 (Fig. 1C). Sensitivity analysis indicates the most robust influential input parameters of risk assessment. In the case of summer season (HQ of NO_2) kitchen NO_2 concentration emerges as the highest contributing factors (43.7%) whereas, duration of exposure (18.2%) is the second most risk contributor (Fig 2A). However, in monsoon season duration of exposure (27.8%) emerges as the highest contributing factor followed by second highest exposure time (27.6%) (Fig 2B). Moreover, in winter season exposure time (31.3%) emerges as the highest contributing factor followed by second highest duration of exposure (31.1%) (Fig 2C).From the study results it was clear that in winter season the rural women who habituated to cooking with biomass fuel are more prone to higher health risk due to NO_2 emitted from burning during cooking process.

Conclusion

This study found women health risk from gaseous NO_2 arises from burning of biomass fuel while cooking. There was significantly higher concentration of NO_2 found irrespective of all seasons. This study found probable health hazards from NO_2 as assessed through the human health risk modelling. This study will keep significant contributions to exposure assessment researchers, government and investors while taking more concrete steps to improve and protect human lives for long-term basis. Additionally, the findings will help legislators in modificationof existing system. Implementation of Pradhan Mantri Ujjala Yojona (PMUY) should be more rigidly in deep sector of rural West Bengal and also in India. For more clean and sustainable healthy indoor environment more awareness needed among rural population in India. In this respect local body like NGO, society can play an important role along with government bodies.

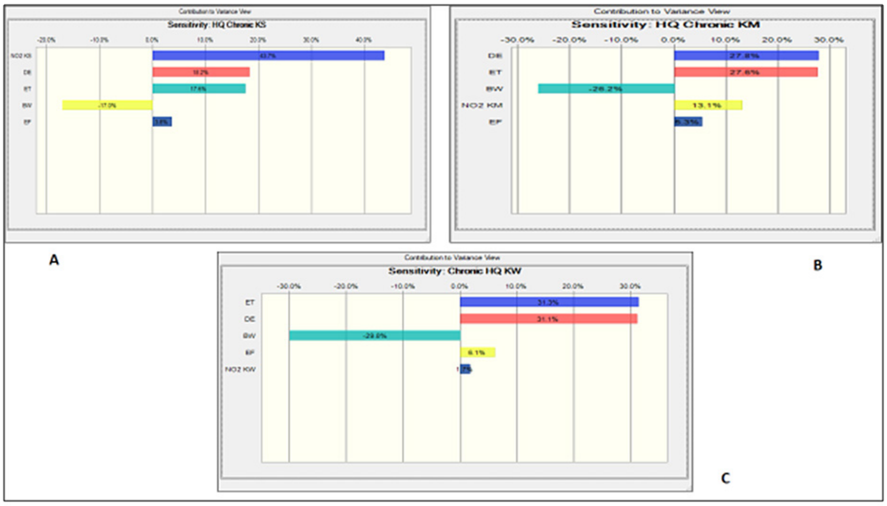

Fig. 2: Sensitivity factors in risk estimation for NO_2 in kitchen room during summer (A), monsoon (B) and winter (C) season

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Conflict of Interest

The authors do not have any conflict of interest.

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