Estimation of Nitrogen Dioxide (NO$_2$) Due to Burning of Household Biomass Fuel and Assessment of Health Risk among Women In Rural West Bengal

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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 showed that there 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.

Introduction

The predominant cause of indoor air emissions globally and 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,
and ultrafine particulate matter, carbon monoxide, nitrogen and sulfur oxide, transitional metals, polycyclic, aromatic, and bio-aerosol compounds. Recent studies in rural home revealed that the main sources of indoor air pollution were burning of biomass fuels in poorly designed stoves. However, wood stove emissions in different developed countries are the major cause of indoor air pollution in several poor homes. 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. Many gaseous contaminants such as NO\textsubscript{2}, CO, CO\textsubscript{2} and O\textsubscript{3}, including relative humidity and temperature, are generated during biomass burning. Due to inefficient burning in traditional stove, pollutants like oxides of nitrogen, PM\textsubscript{2.5}, organic hydrocarbons are usually emitted. However, Begum et al. figured out that the estimated concentration varies on spatio-temporal monitoring and the difference may present room to room. To the best of our knowledge there are scars study on nitrogen dioxide concentration estimation in rural indoor environment. However, researchers studied that, in rural household, high concentrations of NO\textsubscript{2} are due to the use of poor combustion stoves. In fact, peak occurrences of NO\textsubscript{2} are closely correlated with the use of gas and solid fuel stoves, during cook practices. 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\textsubscript{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\textsubscript{2}. Short-term NO\textsubscript{2} toxicity that had negligible human harmful effects was smaller than 0.2 mg/m\textsuperscript{3} and 0.9 mg/m\textsuperscript{3}. Exposure to reported high NO\textsubscript{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\textsubscript{2} levels may be responsible for asthma production and the potential rise in respiratory sensitivity. To the best of our knowledge there are no study on specifically NO\textsubscript{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 the concentrations of indoor NO\textsubscript{2} in rural households and to predict human health risks associated with NO\textsubscript{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\textsubscript{2}) was measured according to Mondal and Chakraborty\textsuperscript{5} by APM 821 (Envirotechmade). During cooking times in both the kitchen and living room, the concentration of NO\textsubscript{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.

Human Health Risk Assessment
Exposure Assessment
The non-carcinogenic exposure assessment from NO\textsubscript{2} were done by the following equation.\textsuperscript{18}

\[
AHD = C \times IR/BW \quad \text{(1)}
\]

here, AHD = average hourly dose for inhalation (µg/kg/hour).
IR = inhalation rate (m$^3$/hour)

C = concentration of NO$_2$ (µg/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:

$$\text{ADD} = \frac{(C \times IR \times ED)}{(BW \times AT)} \quad \text{...(2)}$$

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

C = concentration in air (µg/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:

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

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

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 µg/m$^3$ and 15.413 ± 0.626 µg/m$^3$, respectively.
In monsoon season the NO\textsubscript{2} concentration in kitchen and living room were 45.062 ± 2.761 µg/m\textsuperscript{3} and 14.777 ± 0.591 µg/m\textsuperscript{3}, respectively and in case of winter season the NO\textsubscript{2} concentration in kitchen and living room were 75.502 ± 1.423 µg/m\textsuperscript{3} and 20.353 ± 0.852 µg/m\textsuperscript{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.\textsuperscript{21,22} The mean 24-hour nitrogen dioxide concentration was found 97 µg/m\textsuperscript{3} in a sample in Ethiopia, where biomass, crop residue and animal dung were the major household fuels.\textsuperscript{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.\textsuperscript{24}

**Table 2: ANOVA results for Nitrogen dioxide (NO\textsubscript{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\textsubscript{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\textsubscript{2} Concentration in different Season**

Table 2 and 3 presented the ANOVA result of NO\textsubscript{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\textsubscript{2} concentration present in three seasons in both kitchen room and living room. Similar variation of results has been found by few previous studies.\textsuperscript{25,26} Zota et al.,\textsuperscript{10} conducted study in the kitchen, living room, and outdoors during one year period, and found 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\textsubscript{2}. Sometime outdoor to indoor transmission of NO\textsubscript{2} also may cause of higher concentration in indoor.

**Health Risk Assessment from Indoor NO\textsubscript{2}**

Kitchen and living room NO\textsubscript{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\textsubscript{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. Some studies also found an association between NO$_2$ concentration and acute ischaemic stroke. However, there were some studies that did not find any significant associations between exposure to NO$_2$ and human health.

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 NO₂

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 NO₂ showed the chronic health effects because of that Monte-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 NO₂ 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 NO₂ 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 NO₂ 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 NO₂ 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 NO₂) kitchen NO₂ 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 NO₂ emitted from burning during cooking process.

Conclusion

This study found women health risk from gaseous NO₂ arises from burning of biomass fuel while cooking. There was significantly higher concentration of NO₂ found irrespective of all seasons. This study found probable health hazards from NO₂ 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 modification of 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 NO₂ 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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