

Original Research Article

Sources of variation for indoor nitrogen dioxide in rural residences of Ethiopia

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Abstract

Background: Unprocessed biomass fuel is the primary source of indoor air pollution in developing countries. This study assesses factors affecting the level of indoor air pollution through the characterization of the use of biomass fuel and measurements of indoor NO₂.

Materials and Methods: This study assesses household factors affecting the level of indoor pollution by measuring nitrogen dioxide. Repeated measurements of indoor NO₂ were made using a passive diffusive sampler. A Saltzman colorimetric method using a spectrometer calibrated at 540 nm was employed to analyze the mass of NO₂ on the collection filter that was then subjected to a mass transfer equation to calculate the level of NO₂ for the 24 hours of sampling time. Structured questionnaire was used to collect relevant household information. Analysis of variance and multiple regression analysis were used to isolate determining factors contributing to the variation of NO₂ concentration.

Results

A total of 17,215 air sample measurements were made during the study period. Wood and crop were principal source of household energy. Biomass fuel characteristics were strongly related with measured indoor NO₂ concentration in both one-way and two way ANOVA. In a multiple regression analysis, highland setting, any one purpose having fire mainly cooking, cooking of at least four traditional food items, and involving at least one time fire use in each day were related to high level of NO₂ indoor concentration. A household being in a highland was a major predictor of indoor air pollution after controlling for the above factors. The volume of the housing unit, the presence of kitchen and window did not show significant difference in NO₂ concentration that can be any of practical use. Measured NO₂ over five times were not much different to explain the effect of sampling time.

Conclusions

High level of NO₂ concentration was observed in homes with under-five children. Agro-ecology, frequency of fire activity, frequency of cooking, and time of cooking were strong predictors of NO₂ concentration. However, agro-ecology only remained independently to explain the major variation in NO₂ concentration.

Background

Biomass fuel is the primary source of household energy in developing countries. Fifty two percent of the global population and more than 90% of rural homes in developing countries use solid biomass fuels for cooking, heating, and lighting purposes [1]. Biomass fuel, also designated as unprocessed or dirty solid biofuel, mainly includes firewood, animal dung, agriculture residues and plant leaves.

Indoor air pollution is considered as one of the leading risk factor causing high burden of diseases and of premature deaths in developing countries [2]. WHO and UNDP in their joint communiqué have recognized that IAP is a silent and unprotected killer among rural women and children who spend much of their time in the kitchen [3]. The burden of diseases that could be associated with IAP is high in individual developing nations. Smith estimated that IAP in India accounted for 4.2-6.1% of the total national burden of disease, this being a major public health concern, which other wise close to half million premature deaths could have been saved annually [4]. He further indicated that the burden of diseases among children and mothers due to IAP accounted 6.3%-9.2%, which is a significant proportion, given the critical roles of these population sectors in reference to biomass fuel handling. Women and under five children constituted about 60% of the national population, who often bear two thirds of the total national diseases burden in developing countries.

The health risk to direct exposure to biomass combustion is visible in the presence of the overwhelming practice of cooking in poorly ventilated and crowded single dwellings in developing countries [5-7]. Proximate factors related to socio-economic status like income education, and use of biomass fuel were highly associated with the level of IAP [4,6,8,9]. Despite the prevailing knowledge that exposure to biomass combustion products is high [6-7,10-17], quantitative studies on factors affecting the level of IAP are limited in developing countries [11].

Biomass fuel in the form of firewood, agricultural residues and animal dung is the primary source of household energy in Ethiopia [18,19]. The majority of rural homes

have only one room for all types of household activities including cooking, with no functional ventilation outlets and use traditional unvented stoves. Studies in Ethiopia showed high level of exposure to indoor air pollution [20-22] that exceeded the WHO one hour and eight hours guideline values [23]. However, those studies have limitations in sampling; either used grab sampling [20] or sample size were too small [21, 22] to be generalized to a larger population. In addition, these studies purposefully concentrated to associate only unvented stoves with use of traditional fuels.

Considering the likely of high exposure to IAP on the background of high rate of respiratory infections among under-five children [24], and cognizant of the paucity of studies addressing the problem, this study was undertaken to assess the effect of household factors on IAP using a daily monitoring of indoor air NO₂ in a larger study population in the Ethiopian context. The study has great relevance to achieving the Millennium Development Goal 7 (MDG 7) through the provision of adequate research data.

Materials and Methods

A longitudinal study was conducted to assess the level of indoor air pollution, by measuring NO₂ level, in rural households over a period of two years (March 2000-April 2002).

Study setting, indoor air sampling and analysis for nitrogen dioxide

The study was conducted in rural villages of Meskan and Mareko districts in south central Ethiopia. The presence of a Demographic Surveillance System facilitated the conduct of the longitudinal study. All study villages were under surveillance for other health related studies since 1986. Indoor air samples for nitrogen oxide were taken in 3300 homes with under five children. Households with children were selected because of a related study that is investigating the association between indoor air pollution and child health. NO₂ was detected using a modified colorimetric Saltzman method. Detail description of the study area, sampling procedures, air sample location, and the analytical method is available elsewhere [25].

Factors used to assess the variation in indoor nitrogen dioxide

Structured questionnaire was used to collect household firing characteristics just immediately after air sampling. Data were collected by experienced surveillance enumerators who received special training for the purpose of this study. The main variables collected using the questionnaire included type of household fuel, purpose of having fire, type of cooked food and its timing. The physical dimensions (radius, axis, and wall height) of the study homes were taken at the beginning of the study as part of the routine surveillance activity in the study area.

Data analysis

Data were entered and cleaned using the EPI INFO (version 6.04; Center for Diseases Control and Prevention, Atlanta, GA, USA and World Health Organization, Geneva, Switzerland). Consistency and completeness of each questionnaire was checked at all times of data collection, entry and analysis. The data set was exported first to dbf and then to SPSS files (version 14.0; SPSS Inc., IL, USA) for the statistical analysis.

After data exploration, the original data set of indoor air NO₂ concentration was transformed into log₁₀ to meet the assumptions of ANOVA. In addition, box plots and stem plots were used to observe the relevance of outliers when comparing mean values of NO₂ by certain categorical variables. Variables describing firing events were categorized in such way to avoid multiple responses. These variables included purpose and time of fire events, and type of cooked food.

Descriptive statistics and analysis of variance (both one way ANOVA and univariate General Linear Model) were employed for the detection of any difference and change in the dependent variable, NO₂ indoor level, in the presence of biomass fuel characteristics. Individual mean values of NO₂ of relevant categorical variables were subjected to multiple pair wise comparisons using post-hoc Tukey method to find out the relative differences between any two mean values of NO₂.

A multiple linear regression (Enter method) was run to find out the relative importance and predicting power of household characteristics after checking assumption of normality and multicollinearity. Categorical variables were recoded into respective dummy variables for this purpose while maintaining the dependent variable as log of NO₂ concentration. In addition, time variable and housing characteristics (calculated volume, presence of window and kitchen) were used for multiple linear regression analysis and repeated ANOVA in order to explore their effect on indoor NO₂ concentration. Descriptive and inferential statistics mainly were used to present the findings. Further details on data management and data quality control are available elsewhere [25].

Results

The study was conducted for 2 years period involving a total of 17215 indoor air samples in 3300 households with no refusal of participation.

Characteristics of fuel use

About 98% of air samples were taken at a time of fire events in households. Biomass fuel in a form of wood, crop residues, and cow dung were largely used in 71%, 65%, and 32% of samples, respectively. Other type fuels that were seasonally used include eucalyptus dry leaves, corncobs, and leaves of false banana in 2.6% of households (Table 1). The use of all firing, whether it is for cooking or not, took place mainly indoor.

Cooking, lighting, heating, and insect repellent were indicated as the purpose of having fire events in households in the last 24 hours during the time of air sampling (Table 2). Cooking foods and heating the space, in 98% and 35% of the samples, respectively, were the major activities for the fuel use. The use of biomass smoke for insect repellent was observed in about 13% of samples. Cooking and heating activities simultaneously took place in one third of the samples, while other activities in combination were rarely practiced, in less than 2% of the samples.

Studied households had the practice of fire use three times a day. There were fewer activities at night that required the use of respective biomass fuels. Respondents in 73% of the samples perceived that firing at home took place relatively longer in the evenings than other times (data not indicated).

With regard to cooked food items, cabbage cooking, traditional coffee ceremony, bread and local staple diet (locally called “Kocho”) baking were the usual type of traditional foods that were prepared in over 65% of samples for the last 24 hours just during indoor NO₂ sampling. A traditional flat bread (locally called “Injera”) and its accompany sauce (locally called “Wat”) were rarely cooked, and only observed in less than 10% of the samples. Over 90% of cooking activities took place in the mornings and evenings, while this was insignificant for the nights (Table 3). Other rarely cooked traditional food items indicated were pea and bean roasting and boiling (locally called “Kolo” and “Nifro”),

boiling of milk, cucumber cooking and maize boiling in less than 5% of the samples (result not indicated in a Table).

The variation of fuel characteristics by ecological setting is presented in Table 4. There was a difference in the type of biomass fuel and its purpose of using. The use of wood predominated in the highland, while crop residues prevailed in the lowland. Heating of the housing space was more frequent (40%) in highland than the lowland (28%). Cooking of any three food times in three time intervals of the day were commonly practiced in 73% and 80% of samples, respectively.

Consistency of fire use events

We were not able to detect any difference in the time and frequency of fire use, type of fuel and type of cooked food items that occurred between the sampling time and prior one recall week to this time. We were at least able to know that a religious holiday related to “Romodan”, the Moslem fasting month, was implicated to be a factor for additional cooking food items such as vegetable and meat soup, which took place relatively longer than the usual days of cooking.

The level of NO₂ by the characteristics of fuel use

The relative difference in NO₂ concentration by proxy fuel factors affecting this level is indicated in Table 5. The concentration of NO₂ was found to significantly differ by type of fuel that was used at the time of NO₂ sampling. On the average (SD) households using wood had GM (SD) of 71.2 µg/m³ (2.8), for cow dung, 67.5 (2.9), and for crop residues 56.1 (2.7) µg/m³, which significantly differed from that of the former two fuel types (p<0.05). A single use of one type of biomass fuel during the sampling day also indicated similar magnitude of NO₂ concentration and same pattern of differences in NO₂ average values. Any combination of biomass fuel use did not significantly impact NO₂ concentration (data not shown).

The GM (SD) concentration of NO₂ representing a single purpose of having a fire in a household was 69.2 (2.7), any two purposes 57.1(2.9) and any three and above purposes 55.6 (2.8) µg/m³. Multiple comparisons indicated that high level of NO₂ was

related with only single purpose compared to combination of them ($p < 0.05$). The concentration of NO_2 had a declining linear trend from a single activity to combined activities (p -value for linear trend < 0.001). The combination of household activities related to cooking, lighting, heating, and repellent in a household, however, did not indicate any marked difference in indoor NO_2 concentration (data not shown).

Multiple food cooking was strongly related to NO_2 indoor level compared to any single food preparation ($p < 0.05$). An increasing linear trend to the number of cooked food was also observed (p -value for linear trend < 0.001). Coffee drinking, bread and “Kocho” baking are the usual types of food that were frequently cooked and responsible for the increased NO_2 level.

Generally, increased level of NO_2 was significant among households that frequently used firing ($p < 0.05$). One time of fire use per day was related to GM (SD) NO_2 of 30.8(3.34) $\mu\text{g}/\text{m}^3$, while this was 64.3 (2.79) $\mu\text{g}/\text{m}^3$ for any combination of timing of fire in reference to the morning, daytime, evening or at nighttime. NO_2 had an increasing trend to the frequency of cooking time (p -value for linear trend < 0.001).

Two-way ANOVA using univariate General Linear Model was used to investigate the changes in NO_2 in the presence of covariates related to household characteristics that were subjected under univariate analysis in one-way ANOVA. We found all household characteristics to affect NO_2 level. Interaction effect was significant between ecology with type of fuel, number of cooked food items, and frequency of fire use; number of food with frequency of cooking.

In a multiple linear regression, an overall association was found with ecology type, type of fuel, purpose of having fire, number of foods cooked per day, and time of having fire ($F(12,16862)=97.3$, $p < 0.005$) to explain an overall variations in NO_2 concentrations. Multiple linear correlation was significant at $r = 0.254$ ($p < 0.005$). Ecology (a household being in a highland), frequency of food items (cooking 4 and above food items), frequency of purpose of firing (any one purpose), and frequency of fire use (any 1 time)

emerged as better predictors of indoor concentration. Ecology, however, better explained the variation with a contribution of about 65% of the overall explainable variance after controlling for others (Table 6).

Level of NO₂ by time of measurement and housing structure

NO₂ measurement time variable and variables on housing (calculated volume, window, and kitchen) were extracted from 3300 housing units (>99% of all expected housing units) for analysis. The mean (SD) number of NO₂ measurements during our study period was 4.37 (1.90) per household, while the median was 5. Nearly seventy and 56 percent of the households had at least 4 and 5 measurements of NO₂, respectively. A repeated measure of ANOVA for households with five NO₂ measurements involving the five times indoor air sampling was performed in order to see the effect of sampling period across the two years study duration on measured indoor NO₂. There was a significant effect for time of sampling ($p=0.006$ ($F(4,8615) = 3.67$)). However, the effect size was less than moderate (Partial Eta squared = 0.002), implying that the observed difference in mean values of NO₂ concentrations among the five time periods was not practically meaningful. The compared five NO₂ measurements were GM (SD): 66.1(2.69), 65.9(2.78), 65.1(2.72), 63.0(2.79), 61.2(2.83) $\mu\text{g}/\text{m}^3$.

A multiple linear regression was further performed to assess the relationship between the physical structures of the housing units and the log transformed indoor NO₂ concentration. The calculated volume of "Tukul" was linearly related with NO₂ concentration [$F(1,2897) = 12.16$ ($p < 0.05$), $R^2 = 0.004$]. The addition of window and kitchen variables in the Model also showed a statistical significance, but of only explaining less than 1% variations in NO₂ concentration ($R^2 = 0.006$).

Table 1: Type of fuel and its use pattern for the last 24 hours of indoor NO₂ sampling, Butajira, Ethiopia, 2000-2002 (n= 16899)

Type of fuel	All the time * # (%)	Mostly* # (%)	Little* # (%)	Not at all	Any use Sub total, %*
Wood	4905 (29.0)	3685 (21.8)	3347 (19.8)	4962 (29.4)	70.6
Crop residue	2716 (16.1%)	4926 (29.1)	3411 (20.2)	5846 (34.6)	65.4
Cow dung	63 (0.4)	349 (2.1)	4977 (29.5)	11510 (68.1)	31.9
Charcoal	5 (0.03)	7 (0.04)	30 (0.2)	16857 (99.8)	0.25
Kerosene	8 (0.05)	20 (0.12)	15 (0.09)	16856 (99.7)	0.26
Other fuel	21 (0.12)	31 (0.20)	387 (2.3)	16460 (97.4)	2.60

*Respondents judgment comparing with the usual days.

Table 2 Distribution of purpose of having fire and its timing during indoor NO₂ sampling, Butajira, Ethiopia, 2000-2002 (n= 16899)

Purpose of having fire	Morning # (%)*	Mid day # (%)*	Evening #(%)*	Night # (%)*	Total # (%)*
Cooking	15670 (98.9)	14583 (99.1)	16325 (98.8)	934(94.9)	16622 (98.4)
Lighting	668 4.2)	615 (4.2)	684 (4.1)	95 (9.7)	703 (4.2)
Heating	5529 (34.9)	5185 (35.2)	5718 (34.6)	331 (33.6)	5838 (34.5)
Insect repellent	1945 (12.3)	1527 (10.4)	2009 (12.2)	212 (21.5)	2122 (12.6)
Total use of fire	15836 (93.7)	14714(87.1)	16520 (97.8)	984 (5.8)	16899

*Percentages did not add up 100% due to multiple responses

Table 3: Usual type of food by time of cooking for the last 24 hours of NO₂ sampling Butajira, Ethiopia, 2000-2002 (n= 16622)

Type of food/time of having fire	Morning	Mid day	Evening	Night	Total # (%)*
“Injera”	994 (6.3)	961 (6.6)	1053 (6.5)	86 (9.2)	1089 (6.6)
“Wat”	969 (6.2)	967 (6.6)	1046 (6.4)	70 (7.5)	1067 (6.4)
“Gomen”	12886 (82.2)	12082 (82.8)	13388 (82.0)	777 (83.2)	13576 (81.7)
“Kocho”	3590 (22.9)	3348 (23.0)	3669 (22.5)	242 (25.9)	3744 (22.5)
“Bread”	10644 (67.9)	9910 (68.0)	11110 (68.1)	623 (66.7)	11279 (67.9)
Traditional Coffee service	12729 (81.2)	12100 (83.0)	13269 (81.3)	775 (83.0)	13448 (80.9)
Other food	1141 (7.3)	1098 (7.5)	1215 (7.4)	174 (18.6)	1240 (7.5)
Overall	15670 (94.4)	14583 (87.7)	16325 (98.2)	934 (5.6)	16622

* Percentages did not add up 100% due to multiple responses

Table 4: The characteristics of fuel by ecological setting, Butajira, Ethiopia, 2000-2002 (n=16899)

Characteristics	Ecology type		Total # (%)*
	Highland, # (%)*	Lowland, # (%)*	
Type of fuel			
Only wood	6209 (73.5)	2183 (8.5)	8392 (52.1)
Only Crop residue	2180 (25.8)	5231 (68.4)	7411 (46.0)
Only dung	63 (0.7)	234 (3.1)	297 (1.8)
Total	8452 (52.5)	7648 (47.5)	16100
Purpose of having fire			
Cooking	8905 (98.6)	7717 (98.1)	16622 (98.4)
Lighting	304 (3.4)	399 (5.1)	703 (4.2)
Heating	3609 (40.0)	2229 (28.3)	5838 (34.5)
Insect repellent	360 (4.0)	1762 (22.4)	2122 (12.6)
Total	9031 (53.4)	7868 (46.7)	16899
Food frequency			
Any one food item	318 (3.6)	331 (4.5)	649 (4.0)
Any two food items	1022 (11.6)	1423 (19.2)	2445 (15.1)
Any three food items	6393 (72.9)	5433 (73.3)	11826 (73.1)
Any 4 & + food items	1040 (11.9)	224 (3.0)	1264 (7.8)
Total	8773 (54.2)	7411 (45.8)	16184
Frequency of having fire			
Any one time	147 (1.6)	175 (2.2)	322 (1.9)
Any two times	1088 (12.0)	1333 (16.9)	2421 (14.3)
Any three times	7386 (81.8)	6164 (78.3)	13550 (80.2)
Any four times	410 (4.5)	196 (2.5)	606 (3.6)
Total	9031 (53.4)	7868 (46.6)	16899

*Percentages did not add up 100% due to multiple responses

Table 5: NO₂ concentrations related to household characteristics in a bivariate analysis, Butajira, Ethiopia, 2000-2002 (n=16899)

Characteristics	n (*2)	NO ₂ mean (SD) (linear scale)*3 µg/m ³	log NO ₂ mean(SD) *3 µg/m ³	GM (SD) µg/m ³	Test of significance	X ² linear trend
Biomass fuel type (n=16076)*1						
Only wood	8379	107.6 (96.0)	1.85 (0.45)	71.2 (2.8)	P<0.05	P < 0.001
Only cow dung	297	110.8 (114.9)	1.83 (0.47)	67.5 (2.9)		
Only Crop residues	7400	86.3 (83.7)	1.75 (0.44)	56.1 (2.7)		
Total	16076	97.9 (91.6)	1.80(0.45)	63.7 (2.8)		
Purpose of having fire						
Any one activity	9271	103.0 (91.0)	1.84 (0.43)	69.2 (2.7)	P<0.05	P < 0.001
Any two activity	6666	91.7 (92.5)	1.76 (0.46)	57.1 (2.9)		
Any three and above	886	87.3 (85.2)	1.75 (0.45)	55.6(2.8)		
Total	16823	97.7(91.5)	1.80 (0.45)	63.4 (2.8)		
Type of foods cooked (n=16184)*1						
Any one food item	649	93.1 (92.5)	1.76 (0.45)	58.1 (2.9)	P<0.05	P<0.001
Any two food item	2445	84.0 (80.8)	1.74 (0.44)	54.7 (2.7)		
Any three food item	11826	99.5 (91.3)	1.81 (0.45)	65.3 (2.8)		
Any 4 food & above	1264	119.6 (108.9)	1.90 (0.43)	80.0 (2.7)		
Total	16184	98.5 (91.7)	1.81 (0.45)	64.3 (2.8)		
Time of having fire						
Any one time	325	58.5 (69.5)	1.49 (0.52)	30.8 (3.3)	P<0.05	P<0.001
Any two time	2414	84.6 (79.8)	1.75 (0.42)	56.2 (2.6)		
Any three time	13499	100.8 (93.3)	1.82 (0.45)	65.7 (2.8)		
Any four times	604	99.1 (90.0)	1.82 (0.42)	66.2 (2.6)		
Total	16842	97.6 (91.3)	1.80 (0.45)	63.3 (2.8)		

Table 6: Full Model of multiple linear regression of NO₂ with household fire use characteristics, Butajira, Ethiopia, 2000-2002 (n=16875)

Fire use characteristics	Unstandardized Regression Coefficients	Std. Error of B	Standardized regression Coefficients	t-statistics	P-value	B 95% CI	
						Lower bound	Upper bound
(Constant)	1.694	0.020	-	85.145	0.000	1.655	1.733
Ecology	-0.157	0.007	-0.174	-20.901	0.000	-0.171	-0.142
Only wood	0.037	0.007	0.038	4.531	0.000	0.019	0.048
Only dung	0.092	0.026	0.027	3.596	0.000	0.042	0.143
Any 1 purpose	0.084	0.007	0.093	11.931	0.000	0.070	0.098
Any 3 purpose	0.024	0.016	0.012	1.533	0.125	-0.007	0.055
Any 1 time of having fire	-0.246	0.026	-0.075	-9.405	0.000	-.0298	-0.195
Any 3 times	0.038	0.010	0.034	3.977	0.000	0.019	0.057
Any 4 times	0.0071	0.020	0.003	0.356	0.722	-0.032	0.046
Any 1 food item	0.073	0.024	0.032	3.115	0.002	0.027	0.120
Any 2 foods	0.026	0.009	0.041	2.826	0.005	0.008	0.045
Any 3 foods	0.032	0.006	0.099	5.701	0.000	0.021	0.044
Any 4 foods	0.034	0.005	0.080	6.556	0.000	0.024	0.044

Dependent Variable: indoor concentration transformed to log 10; Most frequent category with greater R2 in univariate regression was considered to correct multicollinearity which was observed between wood and crop; any 1 and 2 purposes ; any 2 and 3 times of having fire per day

Discussion

Selected household characteristics affecting the level of indoor air pollution have their own role to meaningfully change the level of NO₂ in the context of our study area. Nearly all the study households used biomass fuel in a form of firewood, crop residues, and animal dung among which the first two predominated. The study setting is known to use wood most of the time through out the year, crop residues such as stocks of maize and barley during harvest times, and animal dung in summer times [26]. While biomass are relatively cheap, easily locally available, and routinely used, fossil fuel origin such as kerosene was only used to light the interior of housing units at night. The cost of kerosene is not bearable for rural residents to use it for cooking purposes like in urban settings. The use of biomass fuel as a primary source of household energy is consistent with other studies observed in other developing countries [1,8,17,20,27-28].

Biomass fuel was extensively used for cooking traditional foods compared to other purposes of having fire events. Cooking activity largely absorbed the largest share of household fuel use taking place in all times of the day. Heating ranked 2nd purpose, while only about a tenth of households used to repel mosquitoes at night. The use of heating indoor space predominated in colder villages, mainly in the highlands in 40% of the samples, while repelling mosquitoes prevailed in the lowlands, in 22% of the samples. It is evident from the data that home heating in the highland served an additional fuel use burden, which possibly contributed to the increased concentration of indoor NO₂ compared to the relative fuel use burden required for insect repellent in the low land. The extreme temperature difference might have contributed to the variation in the use of fuel for heating between the two ecological settings. Low temperature in early mornings and nights is a characteristic to highlands of Ethiopia, which is explained mainly by the difference in altitude. Villages in the lowland inherently possess a risk to malaria. Malaria has established its endemicity in the low lands of Ethiopia causing high diseases burden and mortality [29] and is a common cause of morbidity among ambulatory patients [24]. There is a cultural practice in the study area that established indoor firing repels mosquitoes.

Traditional foods that do not require a stock of for more than a day were routinely cooked. The cooking time was equally important in all cases of cooking which involved the mornings, middays and evenings. Traditional coffee and bread making mainly from maize flour and kale cooking are the features of daily food items that are traditionally practiced in the study area. Coffee in each household is served for a group of neighborhoods nearly on daily basis, which is a cultural heritage in Ethiopia. The relative time and cost of preparing these food items are a bit less than the local food item of “Injera” and its sauce called “Wat” that is widely used in other parts of Ethiopia, especially in the temperate and highland areas. The practice of “Injera and “Wat” is expensive and the raw material, locally called “Teff” is considered as a cash crop for the rural residents. There is a linear relationship between the number of cooked food items and frequency of cooking with the level of IAP. This is obvious given the increased respective amount of biomass fuels corresponding higher emission of other pollutants in addition to nitrogen dioxide.

Cooking and heating activities are the main household factors that led to the excess NO₂ concentration due to solid biomass fuel use in general, and in the highland areas in particular. Given the range of the purpose of biomass fuel use, cooking has been implicated as the main factor for the greater proportion of exposure to IAP in developing countries [6,30]. Biomass fuel emits in the order of 50 times more pollution during cooking compared to cleaner fuels [6], while the exposure magnitude of breathing in pollutants could be twice more for the same population [4]. The magnitude of the health risk due to biomass combustion can reach as much as 2-3 times greater compared to the risk among clean fuel users [6,7]. Indoor smoke from biomass fuel was attributed to loss of healthy life in the poorest countries of developing world due to known health outcomes such as ARI, ALRI, and chronic obstructive lung diseases [31]. We can speculate based on our findings that higher degree of exposure to indoor air smoke goes to mothers and children who often spend most of their time inside the same house and perform similar day-to-day activities. This implies that the attainment of morbidity and mortality reduction would be a challenge forward to attain MDG goals in developing countries.

Assumption of variation in indoor NO₂ concentration by time was certainly important given the possible differences in the exposure to various fuel characteristics among households. Our finding was able to detect mean differences as much 2-5 µg/m³ between any two NO₂ sampling intervals. Such difference, we believe, was due to large sample size, which otherwise could not have any practical difference due to the small effect on NO₂ variation. We can only say the seasonal variation in fuel characteristics might have affected the indoor NO₂ concentration as described by ecology. This was supported by our data that conclusively indicated variations of NO₂ were dependent on fuel characteristics.

Ecology, type of biomass fuel, the purpose and time of having fire and the frequency of cooked food items were all found to affect the level of indoor air in a bivariate analysis, while ecology came out as a single major actor in the multiple linear regression analysis after controlling for other factors. Factors other than ecology were important as well, but could not soundly impact the variance of NO₂ compared to ecology. The high level of NO₂ difference between the two ecological settings can only be explained by the difference in daily temperature that required the use of additional fire activities for heating the space in addition to the major cooking activity. Further data analysis indicated that the proportion of households in the highland ecology heating their space was about 1.5 times more than the lowland households. The time that required complete cooking of local foods could be extended to compensate the prevailing extreme temperatures. The high level of NO₂ in the highland areas can be also explained by high proportion of wood fuel use. Wood is at least better than crop residues and animal dung in the energy ladder [32] and provides energy efficiency, which in turn easily oxidizes indoor air nitrogen because of the relatively high combustion temperature.

The effect of housing volume was found to show little importance to affect IAP as measured by NO₂, which was against our hypothesis. Together with the presence of window and kitchen in the multiple linear Models, there was only very small proportion

of explainable variance in NO₂ concentration despite the statistical significance. The computed Model was not able to indicate a practical relevance in explaining the direction and strength of the association between the magnitudes of indoor air pollution and the physical housing characteristics in our study area. The significance difference, however, could be only explained due to large sample size that could have picked up small differences. We understood that our findings did not show of practical relevant differences. Rural housings due to their nature of construction allows easily the passage of indoor smoke through their thatched roof, open eaves and unplastered or partially plastered wall all together which strongly restricts the continued built up of indoor air pollutants, hence resulting in the relative increase of NO₂. It is very usual to visually observe the penetration of intense smoke through such structures during active cooking times in early mornings when there is good visual contrast (personal observation). Windows in the study area represent just a small hole, usually < 5% of the floor area, which are often closed due to the fear of wind drafts that is culturally believed to affect resident's health.

The major limitation of this study is acknowledged elsewhere (9 (5)). In conclusion, the type of biomass fuel, its purpose of using, the frequency of cooked food items, the time of having fire, the type of ecology setting were predictors of indoor NO₂ in the Ethiopian rural context. Ecology came out as a single strong predictor of NO₂ after controlling for others. The time series variation in NO₂ level was not important factor in determining the NO₂ pattern. The physical sub-structures of the housing unit could not stand alone to prove differences in NO₂. Further, personal exposure assessment linking with environmental data is highly recommended. Relating indoor NO₂ data with commonly seen childhood diseases, such as respiratory symptoms, is another area of significant relevance for a research given the high level of IAP.

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Author's contributions: Kumie A and Emmelin A were involved in the study protocol design development, data collection, data quality monitoring, data analysis and preparation of the manuscript. Berhane Y and Ali A were involved in analysis and editing draft manuscripts. Wahlberg S and Brändström D designed and supervised NO₂ data collection and laboratory analysis; Mekonen E was involved in supervising and monitoring lab data analysis. Worku A was involved mainly in data analysis and its data quality management. All authors contributed to revising the final manuscript.

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