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Air Quality and Acute Respiratory Illness in Biomass Fuel using homes in Bagamoyo, Tanzania

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Abstract: Respiratory Diseases are public health concern worldwide. The diseases have been associated with air pollution especially indoor air pollution from biomass fuel burning in developing countries. However, researches on pollution levels and on association of respiratory diseases with biomass fuel pollution are limited. A study was therefore undertaken to characterize the levels of pollutants in biomass fuel using homes and examine the association between biomass fuel smoke exposure and Acute Respiratory Infection (ARI) disease in Nianjema village in Bagamoyo, Tanzania. Pollution was assessed by measuring PM_{10}, NO_2, and CO concentrations in kitchen, living room and outdoors. ARI prevalence was assessed by use of questionnaire which gathered health information for all family members under the study. Results showed that PM_{10}, NO_2, and CO concentrations were highest in the kitchen and lowest outdoors. Kitchen concentrations were highest in the kitchen located in the living room for all pollutants except CO. Family size didn't have effect on the levels measured in kitchens. Overall ARI prevalence for cooks and children under age 5 making up the exposed group was 54.67% with odds ratio (OR) of 5.5; 95% CI 3.6 to 8.5 when compared with unexposed men and non-regular women cooks. Results of this study suggest an association between respiratory diseases and exposure to domestic biomass fuel smoke, but further studies with improved design are needed to confirm the association.

Keywords: Biomass fuels, kitchen, cooking, pollution, acute respiratory infections.

Introduction

Biomass fuels are the human earliest source of energy with their invention history dating back to the adoption of fire thousands of years ago. Parallel with their economic development, developed countries have managed to shift from biomass fuel use to cleaner energy. Such shift has never been realized in developing countries. It is estimated that around 2 billion people in the world use biomass fuels as their main source of domestic energy [1]. In Tanzania, the Ministry of Energy and Minerals (MEM) estimates that biomass-based fuel accounts for more than 90% of primary energy supply in the country [2]. Majority of the people depending on these fuels are the poor of the poor living mainly in rural and sub-urban areas.

Biomass fuels are at the low end of the energy ladder in terms of combustion efficiency and cleanliness [3]. They are usually burnt in open fires or poorly functioning stove often indoors. Under these conditions, high volumes of a number of health-damaging air pollutants such as PM_{10}, CO, Nitrogen oxides, Sulphur oxides, formaldehyde, polycyclic aromatic hydrocarbons and other organic matter are generated [4]. Since people in rural areas of developing countries spend many hours a day cooking, exposure to these high levels is considerable, especially among women and children [5].

Exposure to the pollutants present in smoke is widely believed to be a risk factor for a number of health damages such as Acute Respiratory Infections (ARI), Chronic Obstructive Pulmonary Disease (COPD), asthma, low birth weight, cataract and blindness [6]. Strong association has been documented between biomass fuel use and increased incidences of COPD in women and acute respiratory infections in children [6]. The World Bank (WB) estimates that indoor air pollution from biomass combustion is responsible for almost 50% of the burden of total disease in geographically developing countries [7].

In the wake of epidemiological evidence on the association between biomass fuel use and negative health effects, attempts of air quality monitoring in homes

cooking on biomass fuels in developing countries have started being made and pollution levels have been reported. However, such studies are still few and have not been replicated to Tanzania. We therefore conducted a study to measure pollution levels in homes using biomass fuel for cooking and assess the association between biomass fuel smoke exposure and ARI in rural village in Tanzania.

Method

Study Area

The study took place between March 8 and April 20, 2004 in Bagamoyo district in Tanzania. Bagamoyo district is located on the north-eastern side of Coast Region, approximately 70 kilometers north of Dar es Salaam, the capital of Tanzania. The district lies between 6 and 7 degrees south of the equator and between 38 and 39 degrees east. The altitude range is 0 and 480 meters above sea level. Bagamoyo has a characteristic typical tropical climate with an average temperature of 28^0C. Wood fuel is the main source of energy for cooking. Body warming is uncommon as the district is characterized by high temperature and humidity due to its closeness to the sea. Cooking is thus the only source of biomass fuel pollutants exposure to the people. Use of charcoal is common only among the office-working class which mostly works for the Bagamoyo District Council and a few tourist hotels present in the area.

Air Pollution Sampling

We randomly selected one hundred homes in Nianjema village in Bagamoyo for pollutants monitoring. We identified three microenvironments namely kitchen, living room and outdoor environments, and used them in the monitoring exercise. Depending on the kitchen location, we subsequently classified kitchen microenvironment into three categories which are living room kitchen, separate house kitchen and outdoor kitchen. We then measured levels of PM_{10}, NO_2 and CO in all these microenvironments.

(a) PM_{10} Sampling

We measured PM_{10} concentration by use of a digital LD-3K fine dust monitor (Sibata Scientific Technology Ltd). The LD-3K monitor is a light scattering method portable dust measuring device which measures the mass concentration of fine particles floating in the air by the strength of scattered light.

We measured Particle concentration in the kitchen during cooking and when cooking was off for two hours and 1 hour respectively. We placed samplers in the kitchen at about 1.5 metre away from the stove and 1metre high so as to capture the average particle concentration and avoid damage of the sampler. We conducted similar measurement for outdoor PM_{10} concentration for 30 minutes by placing the sampler outside the kitchen at a distance far enough not to be affected by the particles emitted in kitchen. We also monitored for one hour for PM_{10} concentration in the living rooms of those houses whose cooking was exclusively done outdoors.

Particle concentration was recorded in the form of counts per minute (CPM) for every 30 seconds of measurement and we converted CPM to mass concentration units by multiplying the number of CPM by the K value. We estimated the K value by use of simultaneous measurement data taken from the first two homes of our measurement exercise using PM personal sampler as described in [8]. Cumulative household PM concentrations were then obtained as a sum of each record made by the monitor in each household.

(b) CO sampling

Due to shortage of equipment and focus of the study on place where exposure to pollutants from biomass fuel occur, we carried out CO concentration measurements in the kitchen and outdoor environment only. We measured CO levels by the use of a CO detector tube connected to a pump. We took our measurements at the beginning of cooking and 30 minutes later and we read CO concentration directly on the tube.

(c) NO_2 sampling

For the same reason as for CO, we took samples of NO_2 in the kitchens and outdoor environment only. Sampling was made over 24 hours a day using NO_2 badges developed by Yanagisawa and Nishimura [9]. We fixed the badges inside the kitchen and in the household compound and left them for 24 hours. We also took blank samples, by exposing the badges for a few seconds far from the kitchen, to help in the calculation of concentration. Upon collection, we packed the sample badges, labeled and then put them into air tight containers containing ice blocks before we transported them from the survey area for refrigeration. After completion of the survey, samples were shipped to Tokai University in Japan for laboratory analysis.

We conducted laboratory analysis of NO_2 samples for concentration according to the sampler manufacturer's protocol. Briefly, we first removed the filter papers and put them into test tubes. We then added 10ml of azodye-forming reagent (Saltzman reagent) into the test tubes and shook gently for a while. 30 minutes later, we set the test tubes onto the auto-analyzer for analysis and added Nitrite standard solution into the test tubes. The auto-analyzer then drew on a chart absorbance graphs I for samples under analysis and I_o for blank samples. The 24 hours concentration of NO_2 was then calculated by the formula:

$$M = K_{OG} * T * A * fNO_2 \quad \text{.....Equation 1}$$

Where M is the value of NO_2 (moles) absorbed by filter, K_{OG} is the overall mass transfer coefficient based on the gas phase (0.14cm/sec), T is the monitoring time (86400 sec), A is surface area of filter badge (9.88cm^2) and fNO_2 is NO_2 concentration in ppb.

After substituting the above values into the equation and relating the absorbance I to the standard nitrite concentration in azodye-forming reagent the equation above was reduced to:

$$fNO_2 = \frac{10^{-7} * \alpha}{4.9710 * 10^{-9} * I} \quad \text{.....Equation 2}$$

Where a is the difference between I and I_0

Health Information

We gathered health data by use of questionnaire. We asked chief (regular) cooks who mostly happened to be wives of the households' heads to explain on the health status of the people living in their households with respect to ARI. We first asked the cooks whether there were any members of their families who were suffering from coughs. If the answer was yes, we additionally asked the cooks to explain if the sick were breathing faster than usual with short and rapid breathing. We defined People who suffered from cough accompanied by rapid breathing as being suffering from ARI.

Statistical Analysis

We subjected the data on levels of PM_{10}, NO_2 and CO and family size to descriptive statistics, ANOVA and Pearson regression for statistical analysis. We estimated effect of exposure to biomass fuel smoke on prevalence of ARI by an unadjusted odds ratio. We used one's presence in the kitchen during cooking as an exposure factor. For that matter, chief cooks and children under age 5 were regarded as the exposed since they are the ones who were always in the kitchen during cooking. We treated the remaining family members (non-cooks) as unexposed

Results

In a hundred homes we selected, we were able to monitor pollution in only 83 homes. We obtained CO data for all 83 homes but due to equipment failure we were able to get data from 75 homes for PM_{10} and 64 homes for NO_2. All selected houses used wood fuel for cooking. The number of houses with respect to the kitchen location is shown in Table 1. Most families used kitchen located in the living room of the house in which they live. The mean number of family members within each home for the entire sample was 6.

Table 1: Distribution of kitchen location in relation to pollutants sampled

Location	*Number of houses*			
	All	*PM_{10}*	*NO_2*	*CO*
Indoors (in living room)	48	40	37	48
Indoors (in separate house)	11	11	9	11
Outdoors	24	24	18	24

Pollution levels

Table 2: PM_{10} concentration ($\mu g/m^3$) in various microenvironments

	Kitchen (cooking)	*Kitchen (off-cooking)*	*Outdoor*	*Indoor*
Mean	656.2	96.1	40.1	44.6
SD	549.1	152.3	4.7	12.6
Min	29.0	9.4	6.1	12.6
Max	2565.1	611.3	74.0	214.8

PM_{10} Concentration in various locations is shown in Table 2. The highest of all PM_{10} concentrations was in kitchen. In this microenvironment, PM_{10} varied from 29.0 to 2656.0µg/m^3 when cooking was going on and from 9.4 to 611.3µg/m^3 when cooking was off. The average concentration during cooking was almost 7 times higher than that measured when cooking was not in progress. The second highest level was observed in living room (indoors) with outdoor microenvironment marking the lowest concentration. Concentration decreased dramatically in indoor and outdoor microenvironments in comparison to that in the kitchen. Mean outdoor and indoor PM_{10} concentrations were 40.1±4.7 and 44.6±12.6 µg/m^3 respectively. PM_{10} concentration in kitchens during cooking was significantly higher ($P<0.05$) than indoor and outdoor levels. However, PM_{10} levels in kitchen when cooking was not in progress were statistically ($P>0.05$) the same as those measured indoors and outdoors. There were high variations within microenvironments with higher variation observed in kitchen than in ambient and living room settings.

Table 3: PM_{10} concentration ($\mu g/m^3$) measured during cooking in different kitchen locations.

	Indoors (in living room)	*Indoors (in separate house)*	*Outdoor*
Mean	791.1	576.2	428.6
SD	638.9	413.9	334.7
Min	65.7	108.9	29.0
Max	2565.1	1289.2	1533.8

PM_{10} levels during cooking in relation to kitchen location are shown in Table 3. Kitchens located in living rooms had the highest average level of PM_{10} (791.1 µg/m^3) followed by kitchen located in a separate house, which had an average PM_{10} concentration of 576.2µg/m^3. Outdoor kitchen had the lowest average level which stood at 428.6µg/m^3. PM_{10} concentrations in kitchen located in living room were statistically ($p<0.05$) higher than those measured in outdoor kitchens. Surprisingly cooking indoors in a kitchen in separate house was found to be statistically the same ($p>0.05$) in pollution level as both cooking in living room and outdoors.

Pollutant emissions vary greatly throughout cooking. Since it is believed that exposure to high episodic levels of

PM_{10} is an important determinant factor of acute negative health effects, peak episodes of PM_{10} concentrations during cooking stratified per kitchen location are reported in Table 4. Almost all households experienced for 30 seconds of measurements episodic maximum levels higher than 1000µg/m^3. Three quarter of all the homes exhibited an intense PM_{10} concentration peak which varied from 3200 to 10000µg/m^3. These levels are very high and are typical exposure scenarios of cooks and other people residing in rural areas of developing countries.

Table 4: PM_{10} peak concentration (*µg/m^3*) recorded during cooking in different kitchen locations

	Indoors (in living room)	*Indoors (in separate house)*	*Outdoor*
Q1	3789.6	5207.2	3183.2
Q2	6482.4	7178.4	4979.2
Q3	7610.4	7585.6	6763.2
Max	10048.0	7969.6	9300.0

Q=Quartile

Concentrations of NO_2 and CO are indicated in table 5. Concentrations of NO_2 ranged from 2.0 to 206.0ppb and 0.6 to 58.7ppb in kitchen and outdoor environments respectively. The mean NO_2 concentration was 31.8ppb in kitchens and 6.8ppb outdoors. The levels in the two micro-environments were statistically ($p<0.05$) distinguishable with those measured in kitchen being higher by a margin of approximately 20 ppb. The CO levels in households' compounds were at the level that the equipment used in the study could not detect. The maximum CO concentration in kitchen was 38 ppm and minimum value was not detected. The mean CO concentration in kitchens was 15 ppm.

Table 5: NO_2 and CO levels in different micro-environments

	NO_2 (ppb)		*CO (ppm)*	
	Kitchen	*Outdoors*	*Kitchen*	*Outdoors*
Mean	31.8	6.8	15	ND
SD	35.2	12.7	13	N/A
Min	2.0	0.6	ND	ND
Max	206.0	58.7	38	ND

ND and N/A means not detected and not applicable respectively.

The results of NO_2 and CO measured in kitchen after stratification on the basis of kitchen location are shown in Table 6. The mean kitchen NO_2 concentrations in living room, in separate house, and outdoors were 23.2±23.3, 16.3±11.9, and 2.7±1.6ppb respectively. The mean CO concentrations were 13±8, 14±8, and 16±9ppm for kitchens in the living room, in a separate house, and outdoors respectively. The mean NO_2 concentrations decreased ($p<0.05$) significantly from cooking in the living room to cooking outdoors. This decreasing trend, however, was not observed in CO where the mean CO levels in different kitchen locations were almost the same.

Table 6: NO_2 and CO concentrations in different kitchen locations

	NO_2 (ppb)			*CO (ppm)*		
	Indoors		*Out-doors*	*Indoors*		*Out-doors*
	Living room	*Separate house*		*Living room*	*Separate house*	
Mean	23.2	16.4	2.7	13	14	16
SD	23.3	11.9	1.6	8	8	9
Min	2.9	2.1	2.0	2	7	ND
Max	206.0	109.6	58.7	33	29	38

Relationship between pollution levels and family size

Regression was carried out between family size and the levels of PM_{10} and CO measured in kitchen during cooking and with 24 hours NO_2 levels measured in kitchen to determine the effect of family size on pollution level found in kitchen. Regression results are shown in Table 7. A very weak positive relationship with family size was found for all the three pollutants (r = 0.04 to 0.20). The relationship was significant suggesting strongly that family size was not a determinant of the pollutants levels found in kitchen.

Table 7: Pearson correlation coefficients (R) between Family size and pollution levels in kitchen

	PM_{10}	*NO_2*	*CO*
Family size	+0.04	+ 0.04	+0.20

Association between biomass smoke exposure and ARI

Results of the effect of exposure to pollution from biomass fuel during cooking are summarized in Table 8. From the table the overall prevalence of ARI in the sample was found to be 29.76%. Prevalence for children under age 5 and cooks was 67% and 45% respectively. The overall prevalence of ARI was 54% for cooks and under 5 children combined and 17% for other members of the family. Unadjusted Odds Ratio (OR) for cooks and children combined vis-à-vis other members of the family was 5.5, 95% CI 3.6 to 8.5. The OR indicated that children under age 5 years and cooks combined were about six times more likely to suffer from ARI than men and non-cook women.

Table 8: Sample distribution and ARI prevalence (in brackets)

		Exposure			*Total*
		Yes		*No*	
		<5	*Cooks*		
Disease	Yes	49 (66.6%)	33 (45.2%)	57 (17.9%)	139 (29.8%)
	No	28	40	260	328
Total		77	73	317	467

OR (95% CI) = 5.5 (3.6 - 8.5)

Discussion

In this study, the means and standard deviation values for all the pollutants suggest two things: one, the data are log normally distributed, and two, there is high variation among data within groups. One reason for such a distribution which also explains on high variation observed in the study is the fact that the generation of pollutants in the environment is a complex process which does not appear to be sum of independent random events but depends on many factors such as emission source characteristics, weather, and architecture of the place in which the sources are used. The high variations observed during cooking may partly be explained by the architecture and location of kitchen and the quality of the fuel used.

Kitchen location seemed to have an effect on levels of all the pollutants monitored except CO. PM_{10} and NO_2 concentrations were higher in indoor kitchens located in the living room, which by nature were poorly ventilated, compared to other locations. The other kitchen locations had a decreasing effect. The decreasing trend suggests that cooking outdoors can be safer as far as health effects are concerned. However, this should be taken with caution since the maximum intense peaks recorded in this study are high enough to trigger an acute health effect as the levels far exceed the current US Environmental Protection Agency (EPA) recommendation which calls that the average 24-hour PM_{10} levels should exceed 150µg/m^3 only once in 100 occasions. To well understand the effects of these peaks which recur frequently and the mechanism by which pollutants from biomass smoke trigger acute negative health effects, there is need for a case-crossover study to be conducted.

Family size was expected to have an influence on the level of pollution found in kitchen. It was thought that the higher the family size, the larger the amount of fuels used for cooking and hence the higher the pollution level. Results, however, showed that family level did not have any significant role on the levels in kitchen. Reducing family size cannot reduce pollution levels. Technological interventions or energy shift are therefore inevitable if pollution from biomass fuel combustion in kitchens is to be reduced.

The PM_{10} concentrations taken in kitchen in this study seem to be less than those reported by many similar studies in various countries but compare well with those reported in other countries in Africa. A study conducted in India in 1983 [10] reported kitchen area concentrations of PM_{10} for 15 minutes of cooking by biomass fuels in the range of 15800 µg/m^{3}and 18300 µg/m^3. A relatively broad study which measured PM_{10} kitchen concentration during whole period of cooking found PM_{10} kitchen concentration ranging from 4000-21000 µg/m^3 [11]. A study in Bolivia found a geometric mean kitchen concentration of 1830µg/m^3-h and 430µg/m^3-h during cooking in indoor and outdoor cooking villages respectively [5]. Studies in Africa observed relatively low PM_{10} concentrations in kitchens. A study conducted in Maputo, Mozambique and Lusaka, Zambia found concentrations in the kitchen ranging from 531 to 1038 µg/m^3 [12]. Another study in Mozambique which measured PM_{10} for entire period of cooking found a mean PM_{10} concentration of 1200 µg/m^3 [13]. A study in Zimbabwe found cooking by wood to be responsible for about 1998 µg/m^3 of particles produced in kitchen [14]. A study in Kenya for PM_{10} concentration from biomass fuel in kitchens in lowlands reported PM_{10} levels in kitchen ranging from 300 to 1500 µg/m^3 [15]. The results for lowlands in Kenya and those for Maputo and Lusaka are within the range observed in this study. A recent study conducted in Tamil Nadu region in India [16] also recorded the same results. Tamil Nadu, as it is for Bagamoyo, is a lowland area bordering sea. Low kitchen concentrations in this study can be attributed to characteristic high temperatures and humidity common in lowland areas.

NO_2 concentrations in kitchens were higher than those measured outdoors. The outdoor sample mean concentration was lower than those reported in studies conducted in developed countries [17-19].

The mean CO for the entire sample was below the WHO 15 minutes, 30 minutes and 1hour guidelines which are 87ppm, 52ppm and 26ppm respectively. CO concentrations in kitchen were less than that reported by WHO as common levels in developing countries kitchens [20]. The 15 ppm CO mean measured in kitchen in this study is within the range of 10 to 35ppm which is a marginal level in reference to potential or foreseeable problems in some situations. The range calls for family members to be advised of a potential health hazard to infants and small children, elderly people and persons suffering from respiratory or heart problems. However the mean concentration can be accepted as normal since the source of CO in this study area is unvented stove. The levels would be unacceptable if they originated from vented appliances.

Effect of biomass fuel pollution exposure as shown by odds ratio suggests that exposure to pollutants from combustion of biomass fuels is associated with increased ARI prevalence in the study area. Higher effect observed in this study can partly be due to failure to adjust for potential

confounders such as age and sex which may have strengthened the effect. However, higher prevalence in cooks and children under age 5 crudely suggests strong association. Although the results of this study suggest a relationship between exposure to biomass fuel smoke and ARI in children and cooks, further studies with improved study design are needed to confirm the association.

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