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Deriving Optimal Mean Indoor Concentration Threshold Levels of $PM_{2.5}$ and VOC for Detecting Respiratory Symptoms among Pregnant Women in Ndola and Masaiti, Zambia

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Abstract

The burden of air pollution-related morbidity and mortality in developing countries will continue if limited air monitoring and lack of air quality standards continue. This paper focuses on deriving optimal mean indoor threshold concentration levels of particulate matter ($PM_{2.5}$) and volatile organic compounds (VOCs) for detecting respiratory symptoms among pregnant women in Ndola and Masaiti, Zambia.

The study involved 1,170 consenting pregnant women in a cross-sectorial study using a standard questionnaire. Lung function tests were conducted and indoor $PM_{2.5}$ and VOCs monitored in houses.

Biomass was the main cooking fuel. Indoor air quality monitoring results during cooking and daily average were 501(411, 686) µg/m^3 and 393 (303,578) µg/m^3 respectively for $PM_{2.5}$ and 340(318,360) ppb and 343(320, 363) ppb respectively for VOCs. Significant differences in the distribution of $PM_{2.5}$ (p-value = 0.001) and VOC (p-value = 0.017) between rural and urban areas were observed. Mean indoor $PM_{2.5}$ and VOC varied significantly by cooking activity in both rural (p-value < 0.001) and urban (p-value < 0.001) areas. Similarly, fuel type for $PM_{2.5}$ at p-value = 0.005 but no significant difference for VOC at p-value = 0.779. However, there was a significant association between mean indoor VOC and forced vital capacity (FVC). Mean indoor $PM_{2.5}$ was significantly higher in households that presented with respiratory symptoms than those without respiratory symptoms for both rural (p-value = 0.011) and urban areas (p-value < 0.001). Exposing a pregnant woman to mean indoor $PM_{2.5}$ of 418µg/m^3 in rural areas and 372.3µg/m^3 in urban areas increased the risk of having at least one respiratory symptom. Statistically significant associations were observed between mean indoor $PM_{2.5}$ and respiratory symptoms.

Household air pollution levels in Zambian homes are high. Therefore, systematic PM and VOCs monitoring is critical in order to develop strategies and policies relating to improvement of air quality and respiratory health.

Keywords: Air pollution, Biomass, Particulate matter, Volatile organic compounds, Spirometry

1. INTRODUCTION

Currently, developing countries are increasingly experiencing a double burden of infectious and chronic diseases (Boutayeb, 2006) partly due to environmental conditions (Sclar et al. 2005; Zulu et al. 2011) which are compromised by the increasing presence of poor air quality resulting from the use of unprocessed cooking fuels such as wood, charcoal, cow dung and crop residues. These cooking fuels produce pollutants such as respirable suspended particulate matter (RSPM) that is of major significance as it significantly affects the cardiovascular and respiratory health of individuals (Pope and Dockery, 2006). Animal studies have shown that wood smoke causes immune suppression in the respiratory system (Thomas and Zelikoff 1999; Zelikoff 1994) and several previous studies elsewhere have also documented an association between exposure to biomass (wood smoke) and incidence of tuberculosis,

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after taking smoking into account (Perez-Padilla et al. 2001; Mishra et al. 1999; Gupta and Mathur 1997).

Other than particulate matter, woodsmoke is also a source of volatile organic compounds (St. Helen et al., 2011) which include a variety of chemicals, some of which may have short- and long-term adverse health effects (Chikara, 2009) on the exposed. World Health Organization observed that large magnitude of volatile organic compounds exposure is a health risk to individuals who face chronic and daily exposures to household air pollution (WHO, 2014). Other research findings elsewhere also indicate that exposure to volatile organic compounds from second hand smoke can double the estimated lifetime excess risk of cancer death, however, the increased risk from exposure to household woodsmoke could even be far greater than this due to the higher exposure concentrations and longer exposure times (St. Helen et al., 2011).

Acceptable levels of fine particulate matter with an aerodynamic diameter of up to 2.5 mm (PM2.5) in inspired air have been documented by the World Health Organization (WHO, 2006). These levels are predominantly based on studies of environmental pollution and outdoor air and suggest that air quality should be maintained at not higher than a maximum 24 h average concentration of 25 μm^3 $PM_{2.5}$ in order to avoid adverse health effects. Previous studies in Asia (Kurmi et al, 2008) of biomass burning in homes have recorded $PM_{2.5}$ concentrations over 2000 μm^3 and similar levels have been documented in some areas of Africa (Rumchey et al 2007; Ezzati and Kammen 2001).

Despite indoor air quality being an important environmental condition, many countries in sub-Saharan Africa lack air quality standards and household air pollution monitoring is limited (Petkova et al 2013). Zambia for instance does not have an indoor air pollution monitoring program; therefore, no attention is paid to issues relating to household air pollution. Collective evidence from short-and long-term household air quality monitoring studies demonstrates that pollution levels in developing countries often exceed international guidelines. Biomass burning in poorly ventilated houses in developing countries exacerbates levels of indoor air pollutants. Despite the health risks that exposure to indoor air pollution presents, air quality programs, particularly in sub-Saharan Africa are not a priority. This therefore explains why indoor air pollution in developing countries still remains a major environmental and public health concern (Bruce et al, 2000) especially among the women and children who bear the heaviest burden of the problem due to longer times spent indoors. However, there has been a paucity of information describing biomass fuel use and exposure levels in Zambia. It is for this reason that we conducted a study to evaluate household air pollution levels using $PM_{2.5}$ and VOCs as indicators in rural and urban houses of Masaiti and Ndola so as to determine the optimal threshold for detecting respiratory symptoms among the exposed women.

2. METHODS

A cross sectional study among pregnant women recruited during antenatal visits was implemented in the rural district of Masaiti and urban district of Ndola in Zambia. Masaiti, is predominantly rural with a population of about 95,580 while Ndola being part of Zambia's copper mining region, has a population of 455,194 according to 2010 Census and mainly urban. An initial sample size based on online estimate calculator was adjusted by taking into account population of expected pregnancies (n = 10,863) in Masaiti and Ndola, the design effect and nonresponse rate of 10% giving a sample size of 1,210. Respondents were enrolled using a two stage sampling method. The Tropical Diseases Research Centre (TDRC) Ethics Committee approved the study and permission to conduct research in Masaiti and Ndola health facilities was granted by the Zambia Health Research Authority.

Data Collection

A structured questionnaire was used to capture background information and respiratory symptoms. Spirometry was conducted among the respondents and indoor air quality monitoring was conducted in their houses.

Monitoring of indoor $PM_{2.5}$ and VOCs

Particulate matter of aerodiameter of 2.5μm^3 and volatile organic compounds were monitored using Foobot (China), an air pollution measurement devise recommended for detecting pollution due to biomass emissions (Sousan et al., 2017; Klepeis et al., 2001; Utkarshani et al., 2017). Household air quality monitoring was conducted in all houses where a member of the family of consenting age was present at the time of the visit. The Foobot was kept in the house for 24hours and continuous monitoring apportioned before cooking, during cooking and after cooking period after which the daily average reading was obtained.

Lung function tests

Lung function tests were conducted among all the pregnant women using spirobank G (Italy). Disposable turbines were used for mouth pieces to avoid cross infections among the respondents. The spirometry parameters of interest were forced vital capacity (FVC), forced expiratory volume (FEV1) in one second and this is the volume delivered in the first second of an FVC maneuver. The ratio FEV1/FVC was also recorded and the spirometry test interpretation was based on the American Thoracic Society (ATS) standards.

Statistical Analysis

Statistical Package for Social Sciences (SPSS version 16.0) for windows, Chicago: SPSS Inc. was used in data analysis. Descriptive statistics were performed. Mean concentrations, median distributions and standard deviations were calculated for PM2.5 and VOCs in micrograms (μg/m^3) and parts per billion (ppb) respectively. Comparisons of distributions of $PM_{2.5}$ and VOCs between health endpoints or rural and urban areas were analyzed using Manny Mann Whitney U test. Comparisons across more than two variables of interest were conducted using Kruskal Wallis test. Analyses for associations were conducted using multivariate methods and significance was set at 0.05%. Associations between indoor PM2.5 and VOCs were evaluated using relative risk ratios to determine the risk of having respiratory symptoms among women from households with varying levels of indoor air pollutants. A two-tailed p-value <0.05 was considered as statistically significant.

3. RESULTS

General characteristics

The study recorded a response rate of 96.7% giving a sample size of 1,170 pregnant women of which the majority (91.2%) were married with more than half (54.6%) having attained secondary and only close to a third (30.0%) primary education. More than two thirds (69.6%) of the participants were unemployed and were mainly housewives. About less than one fifth (19.7%) of the participants reported alcohol use and only 3.1% constituted reports of cigarette smoking.

Exposure variables

Only less than 5% of the women reported not being involved in cooking duties during pregnancy. Table 1 summarizes the fuel and kitchen types in the population and biomass was the main fuel used in cooking. Findings further indicate the various types of cooking environments with enclosed (43.2%) and separate room (43.3%) being the most used cooking environments. A large proportion of households in rural area cook outdoor compared to the urban area.

$PM_{2.5}$ and VOCs monitoring

Table 2 is the indoor $PM_{2.5}$ and VOC concentration index for the entire study population measured before cooking, during cooking and after cooking. Daily average concentration levels for $PM_{2.5}$ varied between 79μg/m^3 and 921μg/m^3 while VOC concentration levels ranged from 245 ppb to 393 ppb. Findings presented in table 3 showed a significant difference in the distributions of $PM_{2.5}$ (p value = 0.001) and VOC (p value = 0.017) between rural and urban areas. Concentration levels showed a median (Q_1, Q3) daily average of 441 (315,601) μg/m^3 in the rural area and 411 (303,556) μg/m^3 in the urban areas for the $PM_{2.5}$. VOC showed concentration levels of a median (Q1, Q2) daily average of 340 (320, 362) ppb in the rural area and 343 (320,365) ppb in the urban areas. Table 4 summarizes the median (Q_1, Q_3) distribution of $PM_{2.5}$ and VOC before, during and after cooking periods and results showed a significant difference across the three categories for both $PM_{2.5}$ (p value <0.001) and VOC (p value <0.001). The median (Q1, Q2) $PM_{2.5}$ concentration recorded for the study population during cooking activities and daily average were 501(411, 686) µg/m^3 and 393 (303,578) µg/m^3 while for VOCs during cooking was 340(318,360) ppb and daily average was 343(320,363) ppb. The maximum readings for $PM_{2.5}$ were obtained during cooking time which was not the case for VOC.

In table 5, distribution of pollutants ($PM_{2.5}$ and VOC) by fuel type and kitchen indicated a significant difference in mean indoor $PM_{2.5}$ distribution by fuel type (p value = 0.005). VOC (p value = 0.779) did not show any significant difference in the distribution by fuel type. Kitchen type did not show any significant difference in the $PM_{2.5}$ (p value = 0.124) and VOC (p value = 0.353) distribution.

Maternal respiratory symptoms

Table 6a summarizes the respiratory symptoms in the study population. Sputum production (45.9%) and nasal symptoms (45.6%) were the main symptoms among the respondents. There was statistically significant difference in some of the respiratory symptoms (Cough p value <0.001; nasal symptoms p value 0.034) between urban and rural dwellers with the rural recording higher proportions of the symptoms. Table 6b also summarizes the lung functions results, FEV1 (p value 0.015) and FEV1/FVC (p value <0.001) were statistically significantly different between rural and urban. The rural had a higher proportion of individuals with better FEV1 reading compared to the urban area, while for FEV1/FVC, it is the urban dwellers that had a higher proportion of individuals with a better lung function reading.

In table 7 results show that there was a higher mean indoor $PM_{2.5}$ concentration in both rural (p value = 0.011) and urban (p value <0.001) houses of mothers with respiratory symptoms compared to those without respiratory symptoms. Results further indicates that households of pregnant mothers presenting with a cough (p value <0.001), sputum production (p value = 0.046) and wheezing (p value = 0.001) had significantly higher mean indoor $PM_{2.5}$ concentration levels than mothers who didn't present with respiratory symptoms (table 8). Table 9 shows that there was a significant difference in the median distribution of indoor VOC (p value = 0.011) between households of pregnant mothers presenting with a normal FVC and those with an abnormal FVC. Table 10 shows that on average a $PM_{2.5}$ of 311.3µg/m^3 in rural and 297.6µg/m^3 in urban areas has no effect on maternal respiratory symptoms. Impliedly an additional $PM_{2.5}$ of 106.7µg/m^3 in rural areas and 74.7µg/m3 in urban areas marks the onset of respiratory symptoms among exposed pregnant women. Therefore, exposing a pregnant woman to an indoor mean concentration of 418µg/m^3 in rural areas and 372.3µg/m^3 in urban areas increases the risk of having at least one respiratory symptom. Therefore, the mean indoor $PM_{2.5}$ concentration increases with the increase in the number of maternal respiratory symptoms up to the fourth respiratory symptom as shown in fig.1. However, no association between the number of maternal respiratory symptoms and mean indoor volatile organic compounds was observed (fig. 2). Figure 3 illustrates the association between indoor air pollution and number of respiratory symptoms in rural and urban area in the same figure.

Multinomial logistic Regression

The multinomial logistic regression shows that there was a statistically significant association between mean indoor $PM_{2.5}$ concentration levels and the number of maternal respiratory symptoms. However, mean indoor volatile organic compounds concentration levels did not show any significant association with the number of maternal respiratory health as shown in table 11.

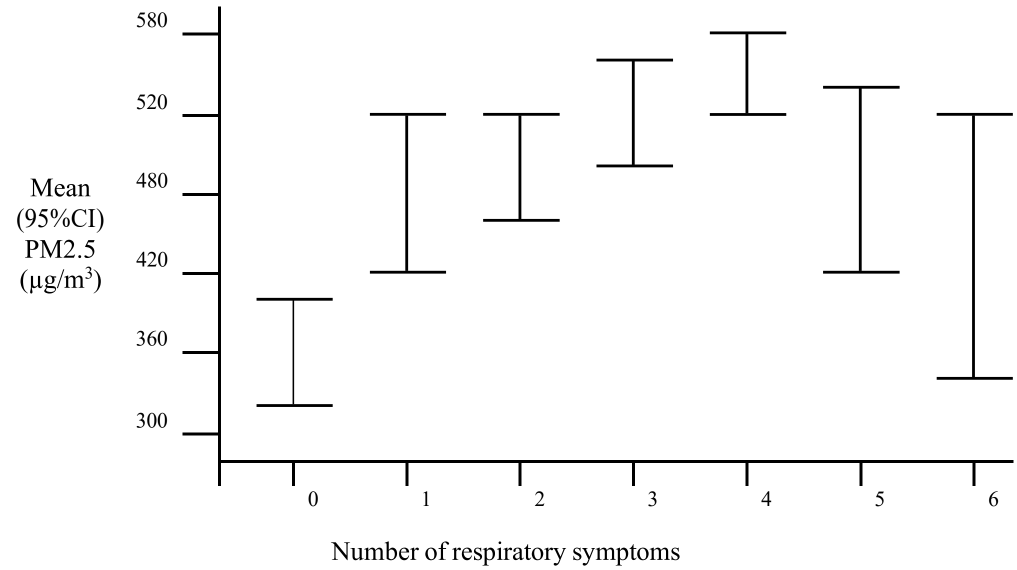

Figure 1: Association between mean (95% Confidence interval) indoor PM2.5 and number of maternal respiratory symptoms.

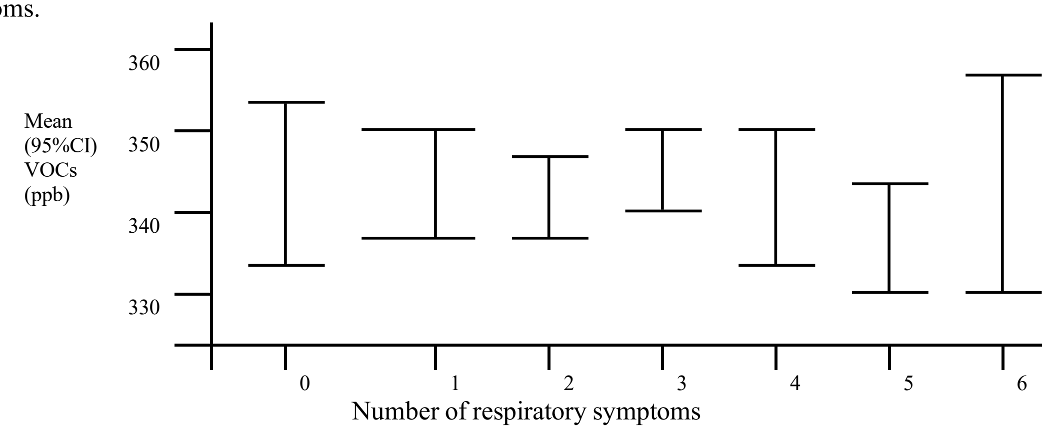

Figure 2: Association between mean indoor VOC and the number of maternal respiratory symptoms.

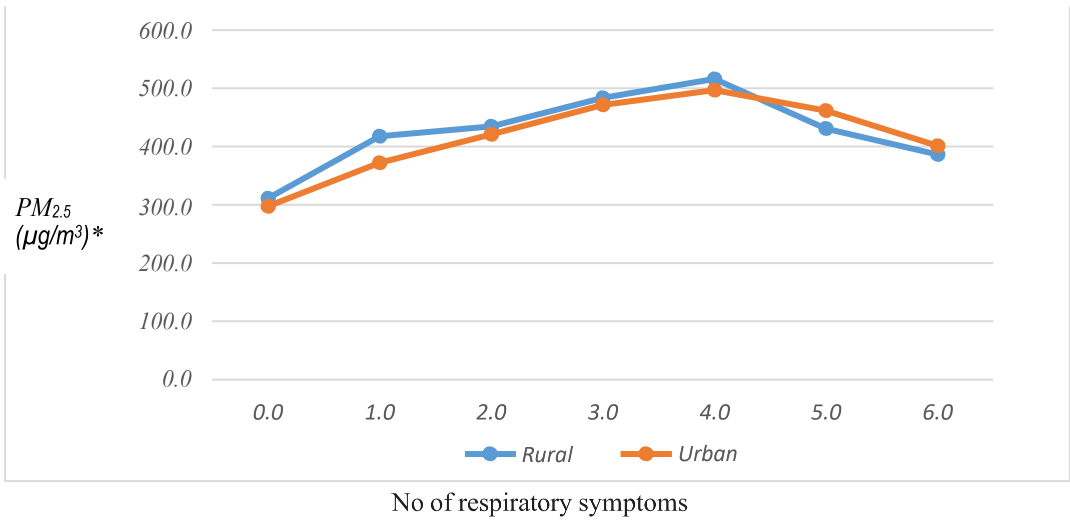

Figure 3: Number of maternal respiratory symptoms versus mean indoor concentration levels of particulate matter (micrograms) in rural and urban areas

$PM_{2.5}$ (µg/m^3) - Particulate matter aerodynamic of diameter of 2.5 micrograms per meter cubic*

*VOCs (ppb) ** - Volatile Organic Compounds in parts per billion*

Tables

Table 1: Cooking characteristics

Cooking characteristics	Total		Rural		Urban	
Fuel type	(n)	%	(n)	%	(n)	%
Biomass	(810)	69.2	(463)	96.3	(417)	60.5
Electricity	(145)	12.4	(12)	2.5	(107)	15.5
Combined (Biomass / electricity)	(215)	18.4	(6)	1.2	(165)	24.0
Kitchen type						
Enclosed	(505)	43.2	(205)	42.6	(310)	45.0
Separate room	(507)	43.3	(212)	44.2	(278)	40.4
Open space	(158)	13.5	(64)	13.2	(101)	14.6

Table 2: Indoor $PM_{2.5}$ and VOC concentration index apportioned before, during and after cooking.

Period	$PM_{2.5}$ ($\mu g/m^3$)	From	To	VOC (ppb)	From	To
Before cooking	Low	79	179	Low	245	320
	Moderate	180	344	Moderate	321	350
	High	345	664	High	351	383
During cooking	Low	335	432	Low	297	322
	Moderate	433	601	Moderate	323	353
	High	602	921	High	354	393
After cooking	Low	262	369	Low	272	333
	Moderate	370	535	Moderate	334	363
	High	536	855	High	364	393
Daily average	Low	26	328	Low	300	25
	Moderate	329	493	Moderate	326	355
	High	494	813	High	356	385

Table 3: Distribution of $PM_{2.5}$ and VOC between rural and urban

Pollutant	Rural (N = 481)	Urban (N = 689)	p value
	Median (Q_1,Q_3)	Median Q_1,Q_3)	
$PM_{2.5}$ (µg/m^3)	441 (315, 601)	411 (303, 556)	0.001
VOC (ppb)	340 (320, 362)	343 (320,365)	0.017

Table 4: Distribution of $PM_{2.5}$ and VOC concentrations before, during and after cooking periods

Period of Measurement	$PM_{2.5}$ (µg/m^3)		VOC (ppb)	
	Median (Q_1,Q_3)	p value	Median (Q_1,Q_3)	p value
Before cooking	244 (154,429)	<0.001	338 (315,358)	<0.001
During cooking	501 (411,686)		340 (318,360)	
After cooking	435 (345,620)		350 (328,370)	

Table 5: Distribution of indoor $PM_{2.5}$ and VOC by fuel types and kitchen types

$PM_{2.5}$ (µg/m^3)			
Fuel type	**N**	**Median (Q_1, Q_3)**	**p value**
Charcoal	622	417 (318, 598)	0.005
Wood	229	398 (291, 611)	
Crop Res.	29	338 (266,578)	
Electricity	119	361 (292, 493)	
Combinations	171	358 (298, 538)	
Kitchen type			
Enclosed	505	403 (308, 586)	0.124
Separate room	507	398 (303, 593)	
Open space	158	368 (293, 533)	
VOC (ppb)			
Fuel type			
Charcoal	622	343 (320, 363)	0.779
Wood	229	348 (323, 368)	
Crop Res.	29	338 (315, 369)	
Electricity	119	340 (325, 363)	
Combinations	171	340 (320, 360)	
Kitchen type			
Enclosed	505	340 (318, 362)	0.353
Separate room	507	343 (323, 365)	
Open space	158	339 (323, 365)	

Table 6a: presents the proportion of pregnant women with respiratory symptoms

Respiratory Symptom		**Total** (n)	%	**Urban** (n)	%	**Rural** (n)	%	**P value**
Cough	Yes	(334)	28.5	(99)	20.6	(214)	31.1	<0.001
	No	(836)	71.5	(382)	79.4	(475)	68.9	
Sputum	Yes	(537)	45.9	(231)	48.0	(312)	45.3	0.389
	No	(633)	54.1	(250)	52.0	(377)	54.7	
Wheezing	Yes	(356)	30.4	(162)	33.7	(202)	29.3	0.128
	No	(814)	69.6	(319)	66.3	(487)	70.7	
Breathlessness	Yes	(191)	16.3	(83)	17.3	(110)	16.0	0.602
	No	(979)	83.7	(398)	82.7	(579)	84.0	
Nasal Symptoms	Yes	(534)	45.6	(196)	40.7	(325)	47.2	0.034
	No	(636)	54.4	(285)	59.3	(218)	52.8	
Throat Symptom	Yes	(385)	32.9	(178)	36.9	(218)	31.6	0.072
	No	(785)	67.1	(303)	63.1	(471)	68.4	

Table 6b: Distribution of maternal spirometry results between rural and urban

Factor	Region	Median (Q_1,Q_3)	p value
FEV1	Rural	85 (76, 93)	0.015
	Urban	83 (76, 91)	
FVC	Rural	76 (69, 83)	0.744
	Urban	76 (69, 83)	
FEV1/FVC	Rural	89 (86, 108)	<0.001
	Urban	103 (96, 112)	

Table 7: Distribution of $PM_{2.5}$ between mothers with respiratory symptoms and those without respiratory symptoms for rural and urban areas

Pollutant	Region	Respiratory symptoms Absent	Respiratory symptoms Present	p - value
$PM_{2.5}$ ($\mu g/m^3$) (SD)	Rural	295.19 (60.6)	461.67 (19.0)	0.011
	Urban	280.28 (51.2)	437.91 (182.6)	001

Table 8: Distribution of $PM_{2.5}$ and VOC according to specific respiratory symptoms

		Median (Q_1,Q_3)	p value
Indoor $PM_{2.5}$			
Cough	Yes	438 (328, 618)	<0.001
	No	322 (278, 398)	
Sputum	Yes	418 (323, 613)	0.046
	No	363 (293, 538)	
Breathlessness	Yes	478 (31, 638)	0.822
	No	383 (302, 563)	
Wheezing	Yes	416 (314, 603)	0.001
	No	378 (298, 568)	
Nasal symptoms	Yes	383 (298, 576)	0.834
	No	403 (308,581)	
Throat symptoms	Yes	407 (308, 568)	0.778
	No	388 (298, 583)	
Indoor VOC			
Cough	Yes	343 (320, 363)	0.981
	No	340 (320, 363)	
Sputum	Yes	340 (320, 363)	0.322
	No	343 (320, 365)	
Breathlessness	Yes	345 (320, 363)	0.519
	No	343 (320, 363)	
Wheezing	Yes	340 (320, 363)	0.344
	No	343 (320, 363)	
Nasal symptoms	Yes	343 (322, 365)	0.155
	No	340 (320, 363)	
Throat symptoms	Yes	340 (320, 363)	0.391
	No	343 (320, 363)	

$PM_{2.5}$ - Particulate matter aerodynamic of diameter of 2.5 micrograms per meter cubic VOCs** - Volatile Organic Compounds in parts per billion; (SD) **- Standard deviation*

Table 9: Variations in the distribution $PM_{2.5}$ and VOCs between normal and impaired lung functions

Spirometry	**Pollutant**	**Normal LFT Median(Q_1, Q_2)**	**Abnormal LFT Median(Q_1, Q_2)**	**p value**
FVC	$PM_{2.5}$ µg/m^3	383 (293,578)	403 (307, 578)	0.117
	VOC ppb	338 (320, 358)	345 (320, 365)	0.011
FEV1	$PM_{2.5}$ µg/m^3	398 (303, 593)	385 (298,558)	0.219
	VOC ppb	343 (320,363)	340 (320, 363)	0.476
FEV1/FVC	$PM_{2.5}$ µg/m^3	393 (303, 578)	366 (262, 429)	0.321
	VOC ppb	343 (320, 363)	329 (314, 343)	0.197

LFT - Liver function Test FVC - Forced Vital Capacity FEV1 - Forced Expiratory Volume in 1 second FEV1/FVC - Ration of Forced Expiratory Volume in 1 second to Forced Vital Capacity

Table 10: No. of respiratory symptoms versus mean indoor $PM_{2.5}$ and VOC concentration levels in rural and urban settings

		Symptoms	Mean (SD)	95% C.I
Rural	PM2.5	0	311.3 (18.4)	(275.2,347.4)
		1	418.0 (23.8)	(371.2,464.8)
		2	435.0 (13.9)	(407.7,462.3)
		3	483.5 (14.2)	(455.6,511.4)
		4	516.2 (21.2)	(474.5,557.9)
		5	430.9 (29.3)	(373.3,488.4)
		6	386.6 (43.0)	(302.0,471.1)
	VOC	0	297.6 (8.9)	(280.2,315.0)
		1	372.3 (14.6)	(343.7,401.0)
		2	421.3 (11.3)	(399.2,443.4)
		3	471.7 (10.9)	(450.2,493.1)
		4	497.0 (20.2)	(457.2,536.7)
		5	462.0 (24.9)	(413.1,510.9)
		6	401.5 (50.8)	(301.8,501.2)
Urban	PM2.5	0	335.6 (6.3)	(323.2,347.9)
		1	336.6 (3.3)	(330.1,343.0)
		2	339.4 (2.1)	(335.3,343.5)
		3	344.1 (2.1)	(340.1,348.2)
		4	338.1 (3.0)	(332.3,343.9)
		5	338.4 (4.4)	(329.6,347.1)
		6	352.9 (8.5)	(336.2,369.5)
	VOC	0	346.1 (4.6)	(337.0,355.2)
		1	343.4 (2.4)	(338.8,348.1)
		2	342.2 (1.8)	(338.6,345.8)
		3	343.8 (1.7)	(340.4,347.1)
		4	342.0 (2.9)	(336.3,347.8)
		5	336.0 (3.5)	(329.2,342.9)
		6	347.3 ()	(335.0,359.5)

Table 11: Association between maternal respiratory symptoms (MRS) and household air pollution (PM2.5 and VOC).

		Number of respiratory symptoms						
	Variable	0	1	2	3	4	5	6
Rural	PM25	1	1.04* (1.00 - 1.08)	1.04** (1.00 - 1.08)	1.05** (1.01 - 1.09)	1.05*** (1.01 - 1.10)	1.04* (1.00 - 1.08)	1.03 (0.98 - 1.08)
	VOC	1	1 (0.93 - 1.08)	1.02 (0.95 - 1.09)	1.03 (0.97 - 1.11)	1.01 (0.94 - 1.08)	1.01 (0.94 - 1.09)	1.07 (0.97 - 1.19)
Urban	PM25	1	1.05*** (1.01 - 1.08)	1.06*** (1.03 - 1.09)	1.07*** (1.04 - 1.10)	1.07*** (1.04 - 1.11)	1.07*** (1.03 - 1.10)	1.05*** (1.02 - 1.09)
	VOC	1	0.99 (0.95 - 1.03)	0.98 (0.95 - 1.02)	0.99 (0.95 - 1.03)	0.98 (0.94 - 1.03)	0.96* (0.92 - 1.01)	1 (0.93 - 1.08)

*ciEform in parentheses *** p<0.01, ** p<0.05, * p<0.1*

4. DISCUSSION

This study is the first to evaluate household air pollution using PM2.5 and VOCs as indicators in Zambian houses. To the best of our knowledge it is the first study, to derive an optimal mean indoor $PM_{2.5}$ threshold for detecting onset of respiratory symptoms in Zambia among pregnant women that cook predominantly with solid fuel. The current study found high mean indoor $PM_{2.5}$ and VOCs concentration levels in both rural and urban areas of the study population. However, there seemed to be higher mean indoor concentration levels of $PM_{2.5}$ and VOCs in households that used biomass only compared to those that used electricity. This result is in accord with what is pertaining in sub-Saharan Africa and similar findings elsewhere indicate that particulate matter levels may be 10–50 times higher than the recommended standards in houses where solid fuels are used (Hulin et al., 2012). Our study also observed more respiratory symptoms among women from households where biomass only was used as cooking fuel compared to women from households that used electricity. This finding is consistent with research results in randomized control trials in rural Mexico (Romieu et al., 2009) that indicated that cleaner fuels were significantly associated with a reduction of respiratory symptoms among women.

We found that there was a significant association between mean indoor $PM_{2.5}$ concentration levels and onset of maternal respiratory symptoms. These findings are consistent with results elsewhere (Dominicini et al. 2006) indicating that even short-term exposure to $PM_{2.5}$ results increased risk for cardiovascular and respiratory hospital admissions and this is further confirmed by studies which indicate that even at relatively low levels respirable particulate exposure can increase respiratory symptoms and mortality (Kurma et al. 2015; Tielssch et al. 2014). Results in an Indian study also showed that increased respiratory symptoms are related to increased indoor concentration levels of $PM_{2.5}$ (Kumar, 2015). The gases and particles are said to be responsible for weak host defenses against respiratory infections which would further lead to an increased predisposition to respiratory infections. Inflammation of the airways and alveoli, resulting from the exposure to these pollutants, may be another mechanism increasing the severity of respiratory infections (Ezzati and Kammen , 2001)

A review of information relating to air pollution in Zambia indicate that there is paucity of such information because like in many countries in the sub-Saharan Africa, air monitoring is limited and there is a lack of air quality standards at national level. In our study, an indoor mean concentration of 418µg/m^3 in rural areas and 372.3µg/m^3 in urban areas was responsible for increasing the risk of having at least one respiratory symptom among pregnant women. This is comparable with previous studies conducted in Asia (Kurmi et al, 2008) stating that $PM_{2.5}$ concentrations in houses get as high as over 2000 mg/m3 and in some African countries like Zimbabwe and Kenya where indoor air pollution monitoring has been conducted (Rumchey et al 2007; Ezzati and Kammen 2001). The findings of our study show that indoor air pollution in our study population excessively exceed the WHO recommendations (WHO, 2005).

This finding is an indication that Zambian urban and rural women will continue to carry the burden of air pollution-related morbidity and mortality if no public health interventions are implemented to control the poor environmental conditions which are fueled by limited air monitoring and lack of air quality standards at national level. Our current study creates an important baseline for the implementation of systematic $PM_{2.5}$ data collection to enable air pollution-related respiratory health impact assessment among women predominantly using biomass for cooking. This will in turn help in the development of strategies and policies relating to air quality and respiratory health.

5. LIMITATIONS

There are number of limitations that we need to mention in this study and in the first instance we should note that women in the study were not selected randomly from the population, a cause and effect conclusion cannot be inferred. Exposure to $PM_{2.5}$ and VOC was a proxy measure as personal samplers were not used to determine levels of exposure. Duration and frequency of exposure to pollutants was not also assessed, conclusions relied on the respondents' feedback.

6. CONCLUSION

Household air pollution levels in Zambian homes are high. Further research work is required because the concentration levels that have been observed in this study are hazardous and are likely to have adverse health outcomes. Public health interventions should therefore be identified to reduce indoor concentration levels to less harmful standards. The process of reducing concentration levels of $PM_{2.5}$ is beyond the control of individuals and requires action by public authorities and health sector can play a pivotal role in leading a multi-sectoral approach to the prevention of exposure to air pollution by engaging and supporting other relevant sectors such as housing, industry and energy sectors in reducing the risk of indoor air pollution to respiratory health among women.

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