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Indoor Air Pollution in Rumuewhera Community in Obio-Akpor Local Government Area of Rivers State, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author OPK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author TGL managed the analyses of the study. Author OPK managed the literature searches. Both authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Indoor air pollution arising from the use of biomass fuel for cooking is a serious health issue in Nigeria especially in rural communities. This study investigated the levels of Carbon monoxide (CO), $PM_{2.5}$ and PM_{10} released during morning and evening cooking sessions in 17 households in Rumuewhara community in Obio/Akpor LGA, Rivers State Nigeria. This was to ascertain indoor air pollution concentrations in rural households categorized in the terms of fuel type (Firewood, Kerosene and LPG) and kitchen configuration. In the morning cooking session, mean and standard deviation of CO, $PM_{2.5}$ and PM_{10} concentration levels from households using LPG (8.78 $\pm$ 5.20 ppm, 25.5 $\pm$ 6.65 µg/m^3 and 39.38 $\pm$ 13.28 µg/m^3) were observed as lower than those from other households using biomass fuels (36.78 $\pm$ 19.44 ppm, 270.16 $\pm$ 159.44 µg/m^3 and 419.82 $\pm$ 247.29 µg/m^3 for firewood). The mean concentrations of CO, $PM_{2.5}$ and PM_{10} during cooking sessions in firewood kitchens are clearly higher than the standard limits of WHO and Health Canada due to the fuel type, kitchen configuration and ventilation habit. With correlation coefficients, r = -0.537, P=.03; r = -0.583, P=.01 and r = -0.566, p=0.02; there is a statistically significant and strong negative correlation between Relative Humidity vs CO, $PM_{2.5}$ and PM_{10} respectively. The use of biomass fuels for household cooking should be discouraged in favour of LPG or kerosene due to the high concentration of indoor air pollutants it

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generates. To reduce the effects of biomass fuels, well-positioned Chimneys should be incorporated into houses to limit the accumulation of indoor air pollutants in the cooking area.

Keywords: Indoor air pollution; biomass fuel; rural communities; cooking fuel.

1. INTRODUCTION

Worldwide, it is estimated that about 35.9% of the population use solid fuels as their primary cooking fuel; resulting in high levels of Indoor air pollution [1]. In developing countries, susceptibility to indoor air pollution is caused by burning traditional biomass fuels (wood, coal, charcoal, cow dung, and crop wastes). These biomass fuels are commonly used indoors in open fires or poorly-functioning stoves. Consequently, there are high levels of air pollution to which women, especially those in charge of cooking, and their young children, are most vulnerable. The aftermath of such inefficient combustion is a critical environmental health problem predominantly affecting the poor rural population in many developing countries [2].

Smoke entering the home from surrounding houses, forest burning, farmland and domestic waste, kerosene lamps use, factory and automotive emissions are other sources of indoor air pollutants in developing countries[3]. More than 2 million fatalities per year in large regions of the less developed countries are caused by Indoor Air Pollution (IAP) from biomass fuel combustion in open fires and local stoves. This can be considered a major avoidable risk criterion for respiratory and cardiac illnesses.\

According to the WHO report on non-communicable illnesses, 35% of chronic obstructive pulmonary disease (COPD) may well be prevented through a healthy indoor environment [4].

More than 80% of the Sub-Saharan Africa population depend on traditional biomass as the primary fuel for cooking. If the energy access policies for poor countries, particularly in Africa, do not improve drastically, there will be little (if any) reduction in the number of people dependent on polluting solid fuels and kerosene [4].

In low- and middle-income economies, where many residents are at the bottom of the energy ladder, the major burden of household air pollution is present. Most of the regional difference in fuel types used is dictated by local availability. Wood is for instance, the most widely used biomass fuel worldwide [5].

In Nigeria, 56% of households use firewood as the primary source of energy in cooking, resulting in over 50 million tons of firewood consumed per year, producing large amounts of indoor air pollution. Rural women are the most exposed, but they often unaware of the resulting negative impacts of over 79,000 fatalities per year [6].

While many people equate air pollution with the urban outdoor conditions, some of the largest amounts of indoor air pollution currently exist in rural areas. Biomass fuel, in the form of wood fuel, is the primary source of energy in rural communities. Rural dwellers are also vulnerable to the risks associated with smoke pollutants from incomplete combustion of biomass fuels used in cooking, heating and lighting.

Most people spend over 80% of the time indoors and are exposed to indoor air pollutants in building materials, cleaning liquids and other factors such as ventilation, temperature, humidity, energy sources of fuel contribute to the level of pollutants in the home environment. The prolonged exposure to CO and $PM_{2.5}$ often leads to acute and chronic respiratory and cardiac diseases [7, 8].

World Health Organization (WHO) estimates that about 3 billion people use open fire or traditional stoves that are fuelled by kerosene and solid fuels, globally (World Health Organization, 2018). These cooking methods are wasteful, and utilize fuels and innovations that create increased levels of Indoor air pollution or contamination with a range of health-damaging toxins, counting little sediment particles that enter straight into the lungs. People from low socio-economic background are forced to use solid fuels as these are available easily in rural areas at a lower cost [5]. This results to deforestation with global effects leading to biodiversity loss, extinction, changes to climatic conditions, desertification, and displacement of populations.In residences with ineffective ventilation , indoor smoke can be 100 times higher than satisfactory levels for fine particles.

Household air pollution causes noncommunicable diseases including stroke, ischaemic heart disease, chronic obstructive pulmonary disease (COPD), pneumonia and lung cancer [9,10]. Exposure is especially high among women and youthful children, who spend a lot of time in the household kitchen. Nearly 4 million individuals die prematurely per year from disease due to household air pollutants from inefficient cooking methods using polluting stoves combined with solid fuels and kerosene [11].

De la Sota et al. [8], suggested that in addition to the pollution source (i.e., cooking stove and/or fuel), effective interventions aimed at improving household air quality can include ventilation methods and building materials.

Abiem et al. [12] in their study of indoor air pollution from domestic fuels, indicated that the mean concentrations of CO, H_2S, NO_2 and SO_2 in a semi-modern kitchen using kerosene for cooking in selected villages were below the overall acceptable limits [10-35 ppm (1-hour average), 0.06 ppm (8-hour average), 1.20 ppm (1-hour average) and 0.01-0.14 ppm (24-hour average) respectively] set by the United States Environmental Protection Agency (USEPA). Mixed wood species reported the highest values followed by Parkia biglobosa (African locust bean) wood and Prosopis Africana wood with the lowest values. Although there were no major variations in the concentration of these gasses in the local kitchens in all the selected villages, they were all significantly higher than the recommended National Ambient Air Quality Standard. The study reveals that the use of kerosene fuel in a good stove and a well-ventilated kitchen is safer for an average cooking time of 1 hour, whereas the use of fuelwood as a source of energy in a poorly ventilated environment is the major cause of indoor air pollution in the rural areas of Makurdi L.G.A. Constant consumption of these pollutants has harmful effects on human health.

Mohammadi and Mohammadi [13] in their report carried out a systematic analysis to determine the impact of biomass smoke on the prevalence of Acute Respiratory Infections (ARI) in children and strategies to mitigate indoor air pollution, emphasizing recent findings in developed countries. The findings showed that exposure to biomass smoke raised the incidence of ARI in children [range; 1.00-3.89 (CI 95 percent 0.92 – 28.25); median = 1.99]. Their study suggested that to reduce the incidence of ARI and associated morbidity and mortality, short term interventions such as use of effective stoves and keeping children away while cooking would be useful. In the long term, strategies should be advanced for changing to cleaner fuels including LPG and electricity with low pollutant, which may require investment in setup as well as economic development.

Aunan, Hansen, Liu and Wang [14] found that the ambient $PM_{2.5}$ concentration in the rural villages was similar to that in the urban areas. Also, the 24-hour mean personal exposure to particulate pollution ($PM_{2.5}$) was similar for urban and rural participants in total. However, they found indications of enhanced exposure levels in certain sub-groups, such as biomass users, women, and family cooks. Their study revealed that while villagers were strongly concerned about risks of air pollution coming from nearby factories, they were largely unaware of the problem of Household Air Pollution.

In their research on household air emissions from multiple forms of rural kitchens and their emission assessment; Sidhu, et al. [15], found out that average concentrations of $PM_{2.5}$, CO, percent relative humidity (percent RH) and temperature (T) were 549.6 µg/ m^3, 4.2 ppm, 70.2 percent and 20 °C respectively in five different types of kitchens. The largest concentrations of CO and $PM_{2.5}$ were observed in indoor cooking households (CO: 9.3 ppm; $PM_{2.5}$: 696.5 µg/m^3), followed by outdoor cooking households (CO: 5.8 ppm; $PM_{2.5}$: 539.5 µg/m3). The concentration of $PM_{2.5}$ and CO ranged according to the form of fuel and the maximum concentration was found in kitchens of cow dung cakes, followed by agricultural residue >> firewood >> biogas >> Liquefied Petroleum Gas (LPG). The findings showed that the concentration of contaminants differed with the type of kitchen, fuel type and kitchen location.

Lim et al. [16] In their study on the effects of mechanical ventilation on indoor air quality and occupant health status in energy-efficient homes, stated that Energy Efficient Households had a generally consistent interior temperature and relative humidity level, and the ventilation rate was linked to the daily risk of eye tiredness, allergic rhinitis, and atopic dermatitis symptoms.

This research evaluated the indoor air pollution levels from biomass fuel, kerosene and LPG. The study provides a baseline data for subsequent estimations of Indoor air pollution in

Rumuewhara community. This study demonstrated the presence of CO, $PM_{2.5}$ and PM_{10} at concentrations which may impact women and young children due to exposure during cooking in rural communities. The result of this study should also help governments in formulating and generating modalities of enforcing appropriate environmental policies to improve air pollution practices and clean fuel intervention programme for different stakeholders in the society. The study de-emphasizes focus of air pollution control policies on only urban air and emissions from the energy, industries and transport sectors, and suggests the various ways by which environmental norms and standards can be improved.
The study will also serve as reference material for future works in this line of study.

2. METHODOLOGY

2.1 Research Design

This research is an experimental study of selected households in Rumuewhera community in Obio / Akpor local government area in Rivers State of Nigeria to quantify indoor air pollution exposures in homes with traditional and improved cooking stoves.

The Research work was done using a non-probability Purposive sampling technique, realizing that a probability statistical technique cannot be used to determine the size of the sample.

The Research design was done on the basis of knowledge of the research problem to allow selection of appropriate households for inclusion in the sample using expert judgment. The households in this study were selected based on particular variables of interest – characteristics of cooking fuel and kitchen type.

2.2 Study Area

The study area, Rumuewhara is a local community in Obio / Akpor local government area in Rivers State of Nigeria. It is characterized by compact and closely built houses at an average distance of 1m from each other. The inhabitants are mainly low income and mid-income level indigene and non-indigenous households. It is located between latitudes 4°52'N and 4°54'N and longitudes 7°02'E and 7°04'E [17].

It has a tropical wet climate with lengthy and heavy rainy seasons and very short dry seasons occurring between the months of December and January. The month of September has the highest rainfall occurrence of an average of 367mm while the month of December is the driest with an average of 20mm rainfall.

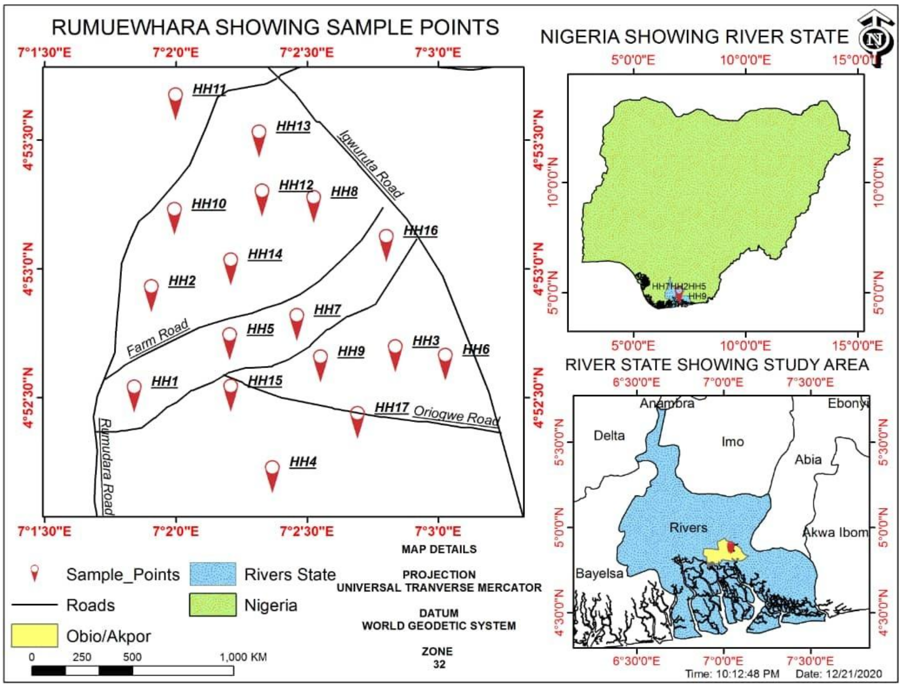

Fig. 1. Map of the study area

2.3 Methods of Data Collection

34 sampled measurement levels of Particulate Matter (PM2.5 and PM10), Carbon monoxide (CO), were taken inside the kitchens during cooking periods in the morning and evenings in 17 households within Rumuewhara area of Obio/Akpor Local Government Area from the 7th to 15th November 2020.

The Households were selected for monitoring based on the energy type used for cooking and the type of kitchen. The concentrations of Carbon monoxide (CO), Particulate Matter ($PM_{2.5}$, PM_{10}) were measured simultaneously with the appropriate equipment. The readings were taken for one-hour during morning and evening cooking sessions at intervals of 5-minutes.

Requisite control measures and precautions were taken to ensure data integrity. The tools and equipment were calibrated before use to ensure measurements are in conformity with manufacturers specifications. The concentrations of pollutants were measured at respiratory level which is between 0.4m and 2.0m above ground level in a bid to determine the representative concentration that household occupants are exposed to. The measurements were registered in a field data sheet and notebook with household code names to guide against error of ambiguity.

The households were divided into 3 categories on the basis of cooking fuel:

(i) Firewood
(ii) Kerosene, and
(iii) Liquified Petroleum Gas (LPG)

2.3.1 Equipment

Particulate Matter was measured using an Aeroqual PM_{10} / $PM_{2.5}$ Portable Particulate Monitor (Serial No: 5003-24D5-001). The particulate monitoring equipment measures $PM_{2.5}$ and PM_{10} simultaneously and in real-time and is a continuous reading device in addition to being an automatic direct reading meter in mg/m^3. Carbon monoxide, CO was measured using an Aeroqual Series 500 Portable Indoor Air Quality Monitor in ppm. Temperature and Relative Humidity were measured using a handheld Extech Thermo-Hygrometer EN150 (Serial No: Q006095). The Extech EN150 is a compact Hygro-Thermometer with UV Light Sensor for indoor and outdoor conditions. Its' built-in UV sensor measures UV light level, natural sunlight measurements, Temperature, Humidity etc.

The instruments were well calibrated as their proper functionality had a critical bearing on the variables under investigation so as to guide the study in achieving its purpose.

2.4 Methods of Data Analysis

The statistical methods used in this research consisted of descriptive statistics of percentage, mean, minimum, maximum, range and standard deviation of the measured concentrations in the monitored households. Other statistical methods that were employed include Kruskal-Wallis test on Vassarstat [18] and Spearman rank correlation in order to determine the significant difference or relationship between measured parameters. The quantitative data analysis was done on SPSS application and Microsoft Excel. Bar charts were also used to analyze and compare mean concentrations of CO, $PM_{2.5}$ and PM_{10} with WHO and Health Canada standards.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Mean 1-hr morning and evening cook time pollutant concentrations

A summary of the measured air pollutant parameters and the meteorological conditions for morning and evening is shown in Tables 1 and 2 respectively.

The Kitchen Configurations and location in Study Area is shown in Fig. 1.

K1 - Inside House
K2 – Attached
K3 - Separate Enclosure, 4ft from house
K4 - Open Area, 12ft from house

3.1.2 Comparison of 1-hr mean morning and evening CO concentration with 1-hr WHO / Health Canada Limits

Fig. 3 illustrates a comparison of 1-hr Mean morning and evening CO concentration with World Health Organisation (WHO) / Health Canada limits of 25ppm for the various households with fuels types – Firewood (F), Kerosene (K) and LPG (G).

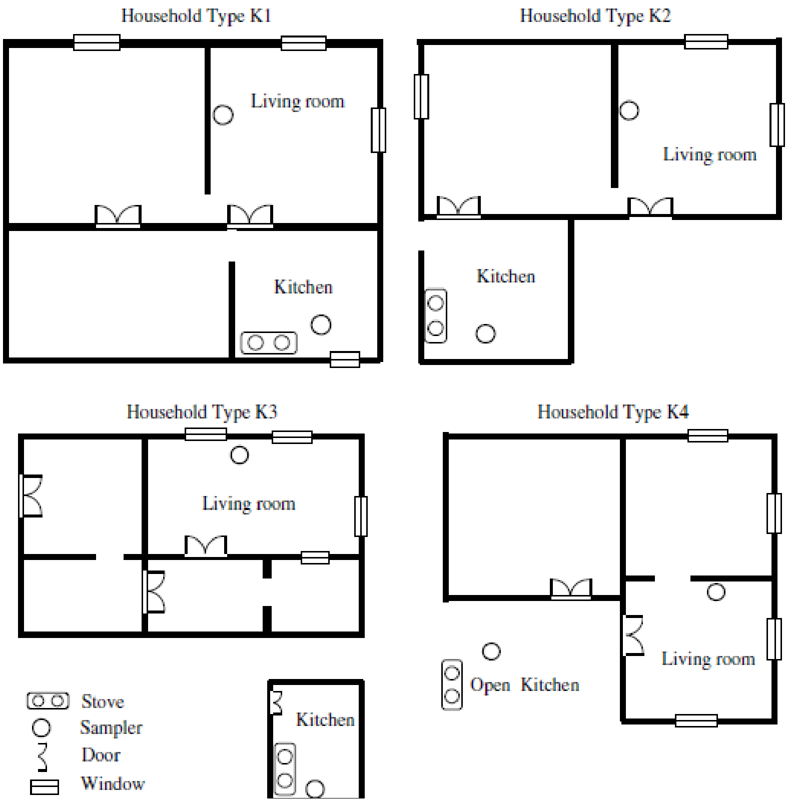

Fig. 2. Sample kitchen configurations in study area [7]

Table 1. Mean morning concentrations of measured parameters in monitored households

Household	Cooking Fuel	Kitchen Configuration	Temp ^{0}C	Rel. Humidity (%)	CO (ppm)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)
HH1	Firewood	Separate Enclosure, K3	29.72	80.23	56.15	340.25	533.92
HH2	Firewood	Attached, K2	29.65	78.54	37.63	208.17	329.50
HH3	Firewood	Separate Enclosure, K3	31.56	73.80	51.27	341.00	595.67
HH4	Firewood	Separate Enclosure, K3	29.62	80.10	53.75	391.00	454.17
HH5	Firewood	Attached, K2	27.48	89.74	9.11	560.17	867.25
HH6	Firewood	Open Area, K4	30.12	81.05	22.29	35.50	46.50
HH7	Firewood	Separate Enclosure, K3	29.48	75.58	7.78	92.92	109.42
HH8	Firewood	Attached, K2	30.04	75.54	38.14	257.50	417.83
HH9	Firewood	Attached, K2	29.48	80.37	54.94	204.92	424.08
HH10	Kerosene	Attached, K2	29.75	88.16	3.45	47.33	62.42
HH11	Gas	Attached, K2	29.92	82.20	6.30	30.58	48.33
HH12	Gas	Separate Enclosure, K3	30.16	83.75	0.99	28.50	43.75
HH13	Kerosene	Attached, K2	29.48	86.24	20.10	268.33	322.75
HH14	Kerosene	Inside House, K1	30.29	80.91	11.38	58.00	102.92
HH15	Kerosene	Separate Enclosure, K3	31.09	87.45	11.67	41.08	57.92
HH16	Gas	Inside House, K1	28.93	86.07	11.07	15.75	19.67
HH17	Gas	Inside House, K1	28.54	84.90	5.11	27.17	45.75
WHO					25	-	**50
Health Canada					25	100	

Table 2. Mean evening concentrations of measured parameters in monitored households

Household	Cooking Fuel	Kitchen Configuration	Temp ^{0}C	Rel. Humidity (%)	CO (ppm)	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)
HH1	Firewood	Separate Enclosure, K3	29.68	77.51	28.49	438.67	831.58
HH2	Firewood	Attached, K2	29.35	81.93	4.27	368.25	593.83
HH3	Firewood	Separate Enclosure, K3	31.20	71.88	188.56	635.33	1,087.25
HH4	Firewood	Separate Enclosure, K3	29.55	85.48	29.52	230.42	290.67
HH5	Firewood	Attached, K2	30.16	76.91	29.43	247.67	432.08
HH6	Firewood	Open Area, K4	29.02	81.45	36.45	171.75	212.17
HH7	Firewood	Separate Enclosure, K3	29.59	76.28	49.70	384.50	538.75
HH8	Firewood	Attached, K2	30.61	80.65	8.81	146.08	198.08
HH9	Firewood	Attached, K2	31.20	75.57	11.10	198.25	282.67
HH10	Kerosene	Attached, K2	30.53	85.34	7.61	50.33	78.92
HH11	Gas	Attached, K2	31.13	86.89	8.64	38.58	49.75
HH12	Gas	Separate Enclosure, K3	31.28	85.98	1.42	16.92	27.33
HH13	Kerosene	Attached, K2	30.70	86.33	13.30	185.17	214.08
HH14	Kerosene	Inside House, K1	30.53	80.08	10.08	50.58	85.33
HH15	Kerosene	Separate Enclosure, K3	31.22	81.24	8.23	39.17	54.33
HH16	Gas	Inside House, K1	29.58	81.74	5.70	16.67	20.92
HH17	Gas	Inside House, K1	29.55	83.38	3.79	32.58	69.67
WHO					25	-	**50
Health Canada					25	100	

*** WHO 24-h average for PM_{10}*

3.1.3 Comparison of 1-hr mean morning and evening PM2.5 concentration with Health Canada limit

Fig. 4 illustrates a comparison of 1-hr Mean morning and evening $PM_{2.5}$ concentration with Health Canada limit of 100 µg/m^3 for the various households with fuels types – Firewood (F), Kerosene (K) and LPG (G).

3.1.4 Comparison of 1-hr mean morning and evening PM2.5 concentration with WHO interim-target-1 recommendation

Fig. 5 illustrates a comparison of 1-hr Mean morning and evening PM2.5 concentration with WHO Interim-Target-1 recommendation for household combustion limit of 35 µg/m3 for the various households with fuels types – Firewood(F), kerosene (K) and LPG (G).

3.1.5 Correlations between CO, $PM_{2.5}$ and PM_{10}

Table 3 presents the correlations between CO, $PM_{2.5}$ and PM_{10} while the Scatter plots of the cook time concentrations of CO vs $PM_{2.5}$, CO vs PM_{10} and PM_{10} vs $PM_{2.5}$ are shown in Figs. 6, 7 and 8 respectively.

3.2 Discussion of Findings

3.2.1 Mean concentration of CO, PM2.5, PM10 at monitored households

From the tables 1 and 2, it is observed that HH3, with firewood as the cooking fuel, had the highest mean CO concentration of 188.56 ppm, mean $PM_{2.5}$ concentration of 635.33 µg/m^3, mean PM_{10} concentration of 1,087.25 µg/m^3 in the evening.

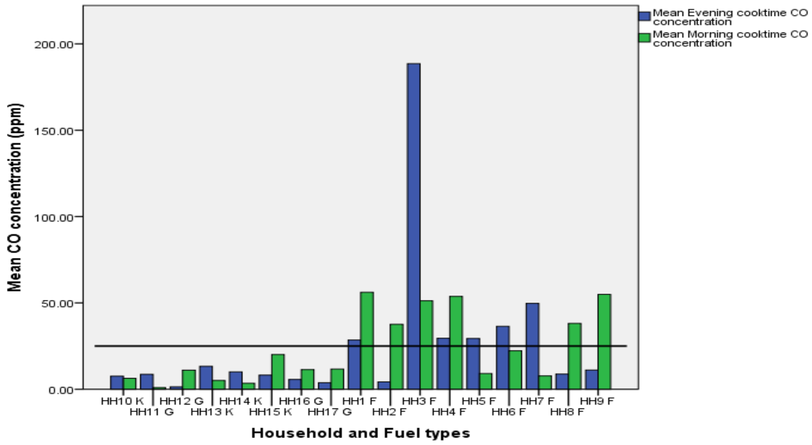

Fig. 3. Comparison of 1-hr mean morning and evening CO concentration with 1-hr WHO / Health Canada limits

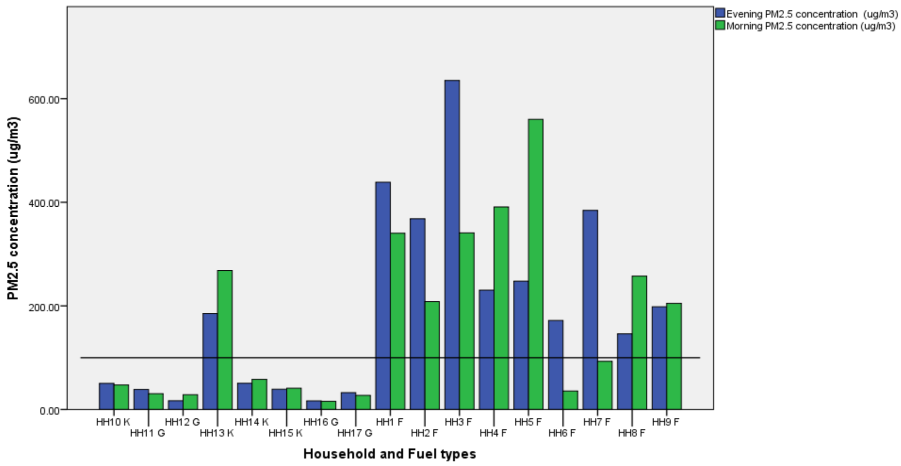

Fig. 4. Comparison of 1-hr mean morning and evening $PM_{2.5}$ concentration with Health Canada limit

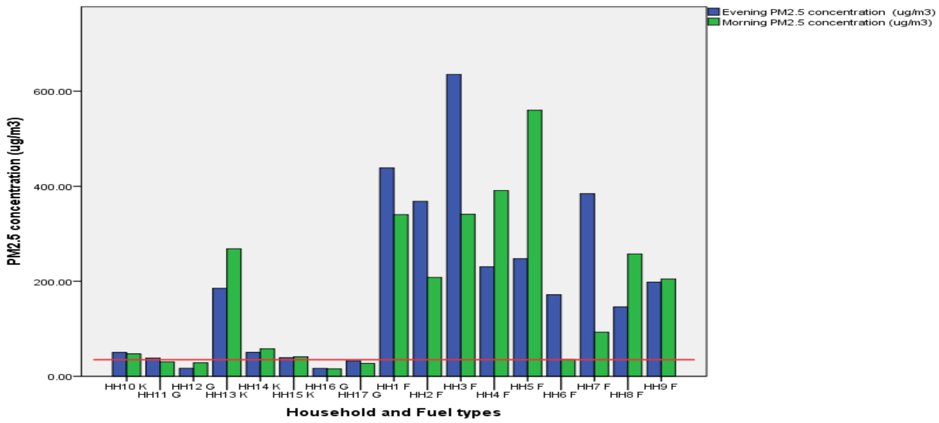

Fig. 5. Comparison of 1-hr Mean morning and evening $PM_{2.5}$ concentration with WHO Interim-target-1 recommendation

Table 3. Correlations between CO, $PM_{2.5}$ and PM_{10}

			Mean cooktime CO concentration	**PM2.5 concentration (ug/m3)**
Spearman's rho	Mean cooktime CO concentration	Correlation Coefficient	1	.554**
		Sig. (2-tailed)	.	0.001
		N	34	34
	PM2.5 concentration (ug/m3)	Correlation Coefficient	.554**	1
		Sig. (2-tailed)	0.001	.
		N	34	34
			Mean cooktime CO concentration	PM_{10} concentration (ug/m3)
Spearman's rho	Mean cooktime CO concentration	Correlation Coefficient	1	.555**
		Sig. (2-tailed)	.	0.001
		N	34	34
	PM_{10} concentration (ug/m3)	Correlation Coefficient	.555**	1
		Sig. (2-tailed)	0.001	.
		N	34	34
			PM_{10} concentration (ug/m3)	$PM_{2.5}$ concentration (ug/m3)
Spearman's rho	PM_{10} concentration (ug/m3)	Correlation Coefficient	1	.984**
		Sig. (2-tailed)	.	0
		N	34	34
	PM2.5 concentration (ug/m3)	Correlation Coefficient	.984**	1
		Sig. (2-tailed)	0	.
		N	34	34

***. Correlation is significant at the 0.01 level (2-tailed)*

For CO; 6 out of 9 Firewood-using households registered higher readings than WHO/Health Canada standards, Kerosene readings fall within the standards while Gas as expected had the lowest readings. The lowest mean morning concentrations of CO were observed in 11 households – HH5, HH6, HH7, HH10, HH11, HH12, HH13, HH14, HH15, HH16 and HH17. A minimum CO concentration of 0.99 ppm was recorded in HH12 and a maximum reading of 56.15 ppm in HH1.

Similarly in the evening, 11 households – HH2, HH8, HH9, HH10, HH11, HH12, HH13, HH14, HH15, HH16 and HH17, registered lower concentrations than specified by WHO. The minimum reading of 1.42 ppm was in HH12 and a maximum reading of 188.56 ppm in HH3. This maximum reading in HH3 may be attributed to the type of fuel (mixture of saw-dust and firewood). These 11 readings in the morning and 11 readings in the evening were below the World Health Organization (WHO) and Health Canada limits.

The mean morning concentration of $PM_{2.5}$ ranged between 15.75 – 560.17 µg/m^3 while the mean evening 1-hr $PM_{2.5}$ ranged between 16.67 –

635.33 µg/m^3. The highest morning and evening mean concentrations were observed in HH5 and HH3 respectively. These were found to be above the WHO interim-target-1-recommendation for household fuel combustion for $PM_{2.5}$ of 35µg/m^3 and above the 1-hr average (short-term exposure) of 100 µg/m^3 of Health Canada.

The mean morning concentration of PM_{10} ranged between 19.67 – 867.25 µg/m^3 while the mean evening concentration of PM_{10} ranged between 20.92 – 1087.25 µg/m^3. The highest morning and evening mean concentration of PM_{10} were observed in HH5 and HH3 respectively. These were multiple folds above the WHO and USEPA 24-hr limits of 50 µg/m^3 and 150 µg/m^3 respectively.

The Ordinal Kruskal-Wallis test for k=3 and n_a=9, n_b=4, n_c=4 for morning CO concentrations gave *p*=.0164 and mean ranks as 12.1, 7.3 and 3.8 for Firewood, Kerosine and LPG respectively. While for Evening CO concentrations, *p*=.0168 and mean ranks as 12, 7.8 and 3.5 for Firewood, Kerosine and LPG respectively.

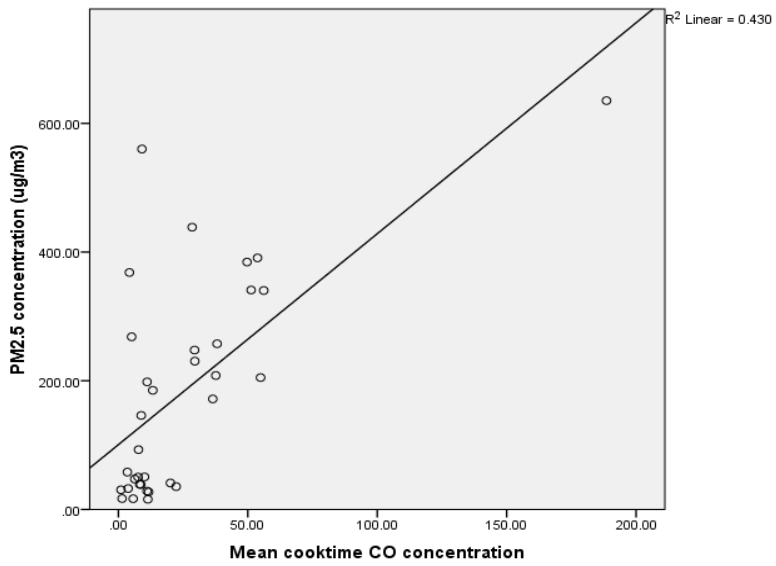

Fig. 6. Scatter plot of mean CO vs $PM_{2.5}$ concentrations

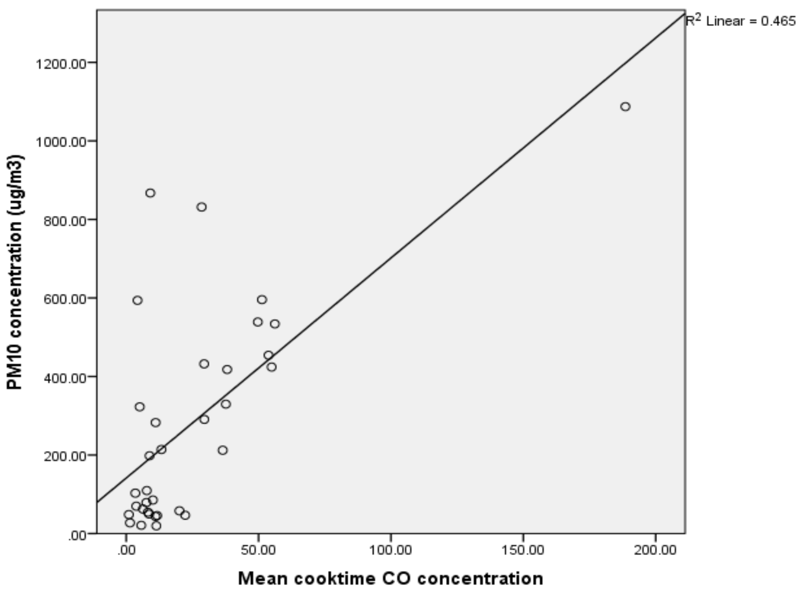

Fig. 7. Scatter plot of mean CO vs PM_{10} concentrations

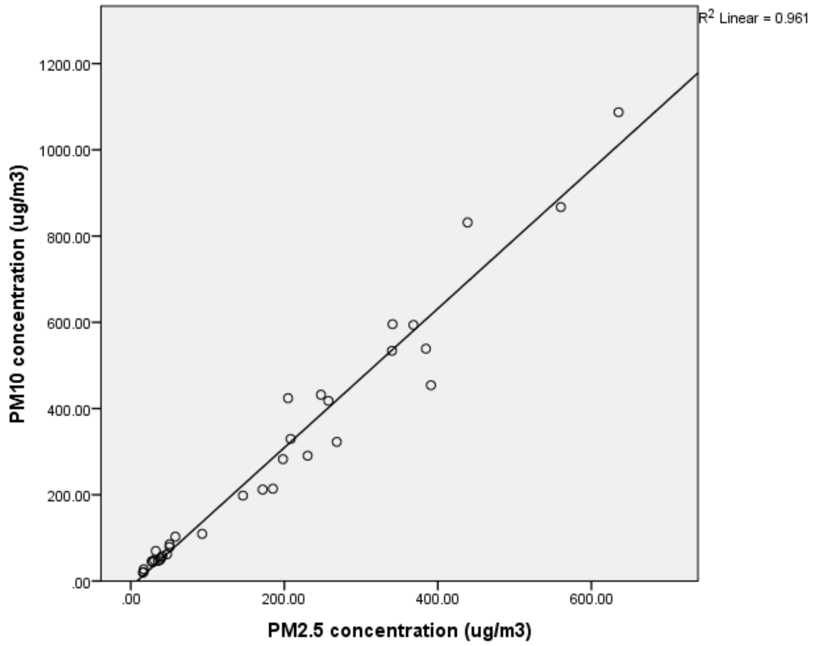

Fig. 8. Scatter plot of mean PM_{10} vs $PM_{2.5}$ concentrations

The Ordinal Kruskal-Wallis test for k=3 and n_a=9, n_b=4, n_c=4 for morning $PM_{2.5}$ concentrations gave *p*=.0065 and mean ranks as 12.1, 8.5 and 2.5 for Firewood, Kerosine and LPG respectively. While for Evening $PM_{2.5}$ concentrations, *p*=.0021 and mean ranks as 12.8, 7 and 2.5 for Firewood, Kerosine and LPG respectively.

The Ordinal Kruskal-Wallis test for k=3 and n_a=9, n_b=4, n_c=4 for morning PM_{10} concentrations gave *p*=.0058 and mean ranks as 12.3, 7.8 and 2.8 for Firewood, Kerosine and LPG respectively. While for Evening PM_{10} concentrations, *p*=.0021 and mean ranks as 12.8, 6.8 and 2.8 for Firewood, Kerosine and LPG respectively.

The Kruskal-Wallis test suggested that LPG was the best cooking fuel and firewood the worst.

3.2.2 Concentration of indoor air pollutants from firewood use

Nine households (HH1, HH2, HH3, HH4, HH5, HH6, HH7, HH8 and HH9) representing 52.94% of monitored households, were observed to use firewood as energy source for cooking in the mornings and evenings. Besides households HH5, HH6 and HH7, which recorded mean CO concentrations of 9.11 ppm, 22.29 ppm and 7.78 ppm respectively, all other households exceeded the CO limits of WHO and Health Canada in the morning cooking sessions. Whereas, in the evening cooking session, only HH2, HH8 and HH9 with CO concentrations of 4.27 ppm, 8.81 ppm and 11.10 ppm respectively were within the WHO and Health Canada CO limits of 25 ppm. Extreme CO concentration was observed in the evening session for HH3 due to their poor ventilation habit of not opening windows while cooking. None of the households that utilize firewood had an Inhouse K1 kitchen configuration as their kitchen were of the separate enclosure type, attached type or Open area type (for HH6). The Open area kitchen configuration for HH6 accounted for more ventilation and low recorded concentration levels of pollutants.

The mean and standard deviation for the morning $PM_{2.5}$ concentration was given as 270.16 $\pm$ 159.44 µg/m^3 while the evening $PM_{2.5}$ concentration had a mean and standard deviation of 313.44 + 158.08 µg/m^3. All households recorded evening $PM_{2.5}$ concentration level higher than the WHO and Health Canada limits.

The mean and standard deviation for the morning and evening PM_{10} were given as 419.82 $\pm$ 247.29 µg/m^3 and 496.34 + 303.04 µg/m^3 respectively. All households recorded higher values when compared with the 24-hr (exposure) for WHO and USEPA except household HH6 with a low mean morning PM_{10} concentration of 46.50 µg/m^3 due to an open area kitchen configuration. Extreme mean PM10 concentration of 1087.25 $\mu g/m^3$ was observed in HH3 due to poor ventilation habits in the evening and the use of saw-dust and firewood stove type.

3.2.3 Concentration of indoor air pollutants from kerosene use

The use of kerosene as an alternative source of cooking fuel was monitored in four households in the study. These households include HH10, HH13, HH14 and HH15 representing 23.53% of monitored households.

All the Four households recorded a low mean CO concentration in the morning (8.74 $\pm$ 7.66 ppm) and evening (9.81 $\pm$ 2.56 ppm) sessions with the highest concentration of 20.10ppm measured in household HH13 in the morning session.

All the Mean CO concentrations were within the stipulated CO limits of WHO and Health Canada in the morning cooking sessions.

The mean and standard deviation for the morning and evening $PM_{2.5}$ concentration for kerosene usage were given as 103.69 $\pm$ 109.99 $\mu g/m^3$ and 81.31 $\pm$ 69.44 $\mu g/m^3$ respectively. The highest morning and evening Mean $PM_{2.5}$ concentration were observed as 268.33 $\mu g/m^3$ and 185.17 $\mu g/m^3$ in household HH13 due to poor ventilation habits as windows were not being opened while cooking.

The mean and standard deviation for the morning and evening Mean PM_{10} concentration for kerosene usage were given as 136.50 $\pm$ 125.8 $\mu g/m^3$ and 108.17 + 71.86 $\mu g/m^3$ respectively.

The highest concentration of morning and evening Mean PM_{10} were observed as 322.75 $\mu g/m^3$ and 214.08 $\mu g/m^3$ respectively for kerosene usage in household HH13.

3.2.4 Concentration of indoor air pollutants from LPG (Gas) use

In this study, four households that utilized Gas for cooking were observed and these included HH11, HH12, HH16 and HH17 representing 23.53% of monitored households. The Mean morning and evening CO concentration were all within WHO, Health Canada and USEPA limits with a mean and standard deviation of 8.78 $\pm$ 5.20 ppm and 4.89 $\pm$ 3.05 ppm respectively.

The mean morning and evening $PM_{2.5}$ concentration for Gas usage had a maximum value of 30.58 $\mu g/m^3$ and 38.58 $\mu g/m^3$ respectively which were within 1-hr Health Canada limit of 100$\mu g/m^3$. Household, HH11 with the highest $PM_{2.5}$ concentration of 38.58 $\mu g/m^3$ slightly exceeded the WHO Interim-target-1-recommendation for household fuel combustion of 35 $\mu g/m^3$.

The Mean 1-hr morning and evening PM_{10} concentration had a mean and standard deviation for gas usage of 39.38 $\pm$ 13.27 $\mu g/m^3$ and 41.92 $\pm$ 22.25 $\mu g/m^3$ respectively.

All Mean 1-hr PM_{10} concentration values were within 24-hr average limits for USEPA and NAAQS. Household, HH17 recorded the highest mean evening PM_{10} concentration of 69.67 $\mu g/m^3$ which was higher than the WHO 24-hr average of 50 $\mu g/m^3$.

Hence, it can be deduced that Gas is relatively the cleanest energy source out of the three fuel types monitored in this research.

3.2.5 Correlation between indoor CO, PM2.5 and PM10 concentrations

Scatter plots of the cook time concentrations of CO vs $PM_{2.5}$, CO vs PM_{10} and PM_{10} vs $PM_{2.5}$ were done to examine the relationship between CO, $PM_{2.5}$ and PM_{10} measured in the research area and are shown in Figures 5, 6 and 7 respectively.

From the plot of CO vs $PM_{2.5}$, r^2 = .43. This was further analyzed using spearman rank correlation in Table 3, which gave a correlation coefficient, r = .554 and p = 0.001. This shows that there was a strong correlation between CO and $PM_{2.5}$ during cooking session and $p < 0.05$ shows that there is a statistically significant linear relationship between CO and $PM_{2.5}$. A similar result was given by Parajuli et al. [2] who reported a strong correlation between CO and $PM_{2.5}$. Bartington et al. [19] also reported a strong correlation (r = 0.52) between CO and $PM_{2.5.}$

From the plot of CO vs PM_{10}, r^2 = .465. This was further analyzed using spearman rank correlation in Table 3, which gave a correlation coefficient, r = .555 and P = 0.001. This shows that there was a strong correlation between CO and PM_{10} during cooking session and $P < 0.05$ shows that there is a statistically significant linear relationship

Table 4. Correlations between meteorological factor (Temperature and Relative Humidity) and CO, $PM_{2.5}$, PM_{10}

			Mean Morning cooktime CO concentration	**Morning $PM_{2.5}$ concentration (ug/m3)**	**Morning PM_{10} concentration (ug/m3)**
Spearman's rho	Temp_Morning (^0C)	Correlation Coefficient	0.052	-0.076	-0.081
		Sig. (2-tailed)	0.844	0.771	0.757
		N	17	17	17
	RH_Morning (%)	Correlation Coefficient	-.522*	-0.346	-0.4
		Sig. (2-tailed)	0.032	0.174	0.112
		N	17	17	17
			Mean Evening cooktime CO concentration	Evening $PM_{2.5}$ concentration (ug/m3)	Evening PM_{10} concentration (ug/m3)
Spearman's rho	Temp_Evening (^0C)	Correlation Coefficient	-0.117	-0.179	-0.243
		Sig. (2-tailed)	0.656	0.491	0.347
		N	17	17	17
	RH_Evening (%).	Correlation Coefficient	-.537*	-.583*	-.566*
		Sig. (2-tailed)	0.026	0.014	0.018
		N	17	17	17

*. Correlation is significant at the 0.05 level (2-tailed).

between CO and PM_{10}. Similar study by De la Sota et al. [8] supported that there was an association between PM and CO emittance.

From the plot of PM_{10} vs $PM_{2.5}$, r^2 = .961. The spearman rank correlation analysis in Table 3, gave a correlation coefficient, r = .984 and p = 0. This shows that there was a very strong correlation between PM_{10} and $PM_{2.5}$ during cooking session and $p < 0.05$ shows that there is a statistically significant linear relationship between PM_{10} and $PM_{2.5}$. The coefficient of determination, r^2 = 0.961, shows that $PM_{2.5}$ statistically explained 96.1% of the variability in PM_{10}.

3.2.6 Effects of temperature and relative humidity on indoor CO, PM2.5 and PM10 concentrations

From the Table 4, it was observed that in the morning session, the correlation coefficient, r of temperature against CO, $PM_{2.5}$, PM_{10} was given as 0.052, -0.076 and -0.081 respectively. For the evening session, the correlation coefficient, r of temperature against CO, $PM_{2.5}$, PM_{10} was given as -0.117, -0.179 and -0.243 respectively. This showed that there was a small or weak correlation between Temperature and CO, $PM_{2.5}$, PM_{10}. All had a $p>0.05$, which indicated that there is no statistically significant linear relationship between Temperature and CO, $PM_{2.5}$, PM_{10}.

However, it was observed that in the morning session, the correlation coefficient, r of Relative Humidity against CO, $PM_{2.5}$, PM_{10} was given as -0.522, -0.346 and -0.4 respectively. This indicates that there was a strong negative correlation of relative humidity with CO whereas there was a moderate negative correlation with $PM_{2.5}$ and PM_{10}. For the evening session, the correlation coefficient, r of Relative Humidity against CO, $PM_{2.5}$, PM_{10} was given as -0.537, -0.583 and -0.566 respectively. This indicated that there was a strong negative correlation of relative humidity with CO, $PM_{2.5}$ and PM_{10}. In the evening session, all had a $p<0.05$, which indicated that there is a statistically significant linear relationship between Relative Humidity and CO, $PM_{2.5}$, PM_{10}.

4. CONCLUSION

Indoor air quality in rural communities is a function of the type of energy used for cooking, kitchen configuration and the time spent in cooking**.** For households where there is variability in cooking fuels, stove types, cooking locations and ventilation efficiency, all of these variables are significant. CO, $PM_{2.5}$ and PM_{10} concentrations were measured during morning and evening cooking sessions in 17 households in Rumuewhara, a rural area in the Obio/Akpor Local Government Area to ascertain indoor air pollution concentrations in rural households. The mean pollutant concentration levels were used in the analysis of the households in the terms of fuel type, kitchen configuration, and location of the kitchen. The CO and PM levels from LPG-using households were found to be lower than those from other households using biomass fuels. It was also noted the mean concentrations of CO, $PM_{2.5}$ and PM_{10} during cooking sessions from kitchens that use firewood are clearly higher than the standard limits of WHO and Health Canada.

Although the choice of cooking fuel can impact the contamination of indoor air, kitchen ventilation is also a critical factor for consideration. The use of highly polluting cooking methods puts human health at risk [20]. In the cooking and residential spaces, open or well-ventilated kitchens with well positioned chimneys limit the accumulation of Air pollutants. The current study indicates that even where biomass fuels are used, certain kitchen settings will provide reasonably safe conditions in terms of concentrations. These solutions are easier to adopt in the rural households, and it is more CO and PM cost-effective to follow such kitchen settings rather than turn to more costly renewable fuels to experience substantially cleaner air.

Further research should be done to determine long-term levels of all pollutant like 24-hr mean level, annual mean and measured seasonal changes in Rumuewhara community.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX A

Data Entry

	Ranks for Sample			Raw Data for Sample		
count	A	B	C	A	B	C
1	17	2	4	56.15	3.45	6.30
2	12	10	1	37.63	20.10	0.99
3	14	8	7	51.27	11.38	11.07
4	15	9	3	53.75	11.67	5.11
5	6			9.11		
6	11			22.29		
7	5			7.78		
8	13			38.14		
9	16			54.94		
Reset	Calculate from Ranks			Calculate from Raw Data		

Mean Ranks for Sample		
A	B	C
12.1	7.3	3.8

H = 8.22
df = 2
P = 0.0164 *

Fig. A1. Kruskal Wallis Test on Mean Morning CO concentration (http://www.vassarstats.net/)

Data Entry

	Ranks for Sample			Raw Data for Sample		
count	A	B	C	A	B	C
1	14	7	4	340.25	47.33	30.58
2	11	13	3	208.17	268.33	28.50
3	15	8	1	341.00	58.00	15.75
4	16	6	2	391.00	41.08	27.17
5	17			560.17		
6	5			35.50		
7	9			92.92		
8	12			257.50		
9	10			204.92		
Reset	Calculate from Ranks			Calculate from Raw Data		

Mean Ranks for Sample		
A	B	C
12.1	8.5	2.5

H = 10.08
df = 2
P = 0.0065 *

Fig. A2. Kruskal Wallis Test on Mean Morning PM2.5 concentration (http://www.vassarstats.net/)

Data Entry

	Ranks for Sample			Raw Data for Sample		
count	A	B	C	A	B	C
1	15	7	5	533.92	62.42	48.33
2	11	10	2	329.50	322.75	43.75
3	16	8	1	595.67	102.92	19.67
4	14	6	3	454.17	57.92	45.75
5	17			867.25		
6	4			46.50		
7	9			109.42		
8	12			417.83		
9	13			424.08		
Reset	Calculate from Ranks			Calculate from Raw Data		

Mean Ranks for Sample		
A	B	C
12.3	7.8	2.8

H = 10.29
df = 2
P = 0.0058 *

Fig. A3. Kruskal Wallis Test on Mean Morning PM10 concentration (http://www.vassarstats.net/)

Data Entry

	Ranks for Sample			Raw Data for Sample		
count	A	B	C	A	B	C
1	12	5	7	28.49	7.61	8.64
2	3	11	1	4.27	13.30	1.42
3	17	9	4	188.56	10.08	5.70
4	14	6	2	29.52	8.23	3.79
5	13			29.43		
6	15			36.45		
7	16			49.70		
8	8			8.81		
9	10			11.10		
Reset	Calculate from Ranks			Calculate from Raw Data		

Mean Ranks for Sample		
A	B	C
12	7.8	3.5

H = 8.17

df = 2

P = 0.0168 *

Fig. A4. Kruskal Wallis Test on Mean Evening CO concentration (http://www.vassarstats.net/)

Data Entry

	Ranks for Sample			Raw Data for Sample		
count	A	B	C	A	B	C
1	16	6	4	438.67	50.33	38.58
2	14	10	2	368.25	185.17	16.92
3	17	7	1	635.33	50.58	16.67
4	12	5	3	230.42	39.17	32.58
5	13			247.67		
6	9			171.75		
7	15			384.50		
8	8			146.08		
9	11			198.25		
Reset	Calculate from Ranks			Calculate from Raw Data		

Mean Ranks for Sample		
A	B	C
12.8	7	2.5

H = 12.29

df = 2

P = 0.0021 *

Fig. A5. Kruskal Wallis Test on Mean Evening PM2.5 concentration (http://www.vassarstats.net/)

Data Entry

	Ranks for Sample			Raw Data for Sample		
count	A	B	C	A	B	C
1	16	6	3	831.58	78.92	49.75
2	15	10	2	593.83	214.08	27.33
3	17	7	1	1,087.25	85.33	20.92
4	12	4	5	290.67	54.33	69.67
5	13			432.08		
6	9			212.17		
7	14			538.75		
8	8			198.08		
9	11			282.67		
Reset	Calculate from Ranks			Calculate from Raw Data		

Mean Ranks for Sample		
A	B	C
12.8	6.8	2.8

H = 11.96

df = 2

P = 0.0025 *

Fig. A6. Kruskal Wallis Test on Mean Evening PM10 concentration (http://www.vassarstats.net/)

APPENDIX B

Table B1. Descriptive Statistics for FIREWOOD

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Mean Morning cooktime CO concentration	9	48.37	7.78	56.15	36.7844	19.43606
Mean Evening cooktime CO concentration	9	184.29	4.27	188.56	42.9256	56.50048
Morning $PM_{2.5}$ concentration (µg/m^3)	9	524.67	35.50	560.17	270.1589	159.44342
Evening $PM_{2.5}$ concentration (µg/m^3)	9	489.25	146.08	635.33	313.4356	158.08287
Morning PM_{10} concentration (µg/m^3)	9	820.75	46.50	867.25	419.8156	247.28813
Evening PM_{10} concentration (µg/m^3)	9	889.17	198.08	1087.25	496.3422	303.03865
Temp_Morning (^{0}C)	9	4.08	27.48	31.56	29.6833	1.04783
Temp_Evening (^{0}C)	9	2.18	29.02	31.20	30.0400	.79994
RH_Morning (%)	9	15.94	73.80	89.74	79.4389	4.65478
RH_Evening (%).	9	13.60	71.88	85.48	78.6289	4.10041
Valid N (listwise)	9					

Table B2. Descriptive Statistics for KEROSENE

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Mean Morning cooktime CO concentration	4	16.65	3.45	20.10	8.7400	7.66299
Mean Evening cooktime CO concentration	4	5.69	7.61	13.30	9.8050	2.55534
Morning $PM_{2.5}$ concentration (µg/m^3)	4	227.25	41.08	268.33	103.6850	109.98540
Evening $PM_{2.5}$ concentration (µg/m^3)	4	146.00	39.17	185.17	81.3125	69.44248
Morning PM_{10} concentration (µg/m^3)	4	264.83	57.92	322.75	136.5025	125.80321
Evening PM_{10} concentration (µg/m^3)	4	159.75	54.33	214.08	108.1650	71.86307
Temp_Morning (^{0}C)	4	1.61	29.48	31.09	30.1525	.70995
Temp_Evening (^{0}C)	4	.69	30.53	31.22	30.7450	.32665
RH_Morning (%)	4	7.25	80.91	88.16	85.6900	3.28377
RH_Evening (%).	4	6.25	80.08	86.33	83.2475	3.05197
Valid N (listwise)	4					

Table B3. Descriptive Statistics for GAS

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Mean Morning cooktime CO concentration	4	10.68	.99	11.67	8.7775	5.19744
Mean Evening cooktime CO concentration	4	7.22	1.42	8.64	4.8875	3.05338
Morning $PM_{2.5}$ concentration (µg/m^3)	4	14.83	15.75	30.58	25.5000	6.64976
Evening $PM_{2.5}$ concentration (µg/m^3)	4	21.91	16.67	38.58	26.1875	11.11916
Morning PM_{10} concentration (µg/m^3)	4	28.66	19.67	48.33	39.3750	13.26977
Evening PM_{10} concentration (µg/m^3)	4	48.75	20.92	69.67	41.9175	22.25039
Temp_Morning (^{0}C)	4	1.62	28.54	30.16	29.3875	.77629
Temp_Evening (^{0}C)	4	1.73	29.55	31.28	30.3850	.94891
RH_Morning (%)	4	3.87	82.20	86.07	84.2300	1.65185
RH_Evening (%).	4	5.15	81.74	86.89	84.4975	2.36463
Valid N (listwise)	4					

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