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Diurnal Concentrations and Variation of Carbon Monoxide in Indoor and Outdoor Air of Residential Homes in Western Sierra Leone

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Abstract

It is widely known that more than half of the world's population use biomass fuels (wood, charcoal, dung) as household energy source, and hence, face significant and diverse range of toxic pollutants. In Sierra Leone, more than 90% of the population relies on biomass fuels. We carried out daytime measurements and observe variation of carbon monoxide (CO) in kitchen and outdoor locations in households that burn wood and charcoal fuels in Western Sierra Leone, during a survey that was conducted in September, 2011. Maximum time average 15 mins, 30 mins, 1 hr and 8 hrs concentrations in indoor and outdoor locations were computed. Mean concentrations decreased in the order, 15 mins to 30 mins to 1 hr and 8 hrs, in the two locations for households that burn wood and charcoal. About 87% and 67% of 8 hrs CO concentrations in kitchens with charcoal and wood stoves were in excess of world health organization (WHO) guideline. Approximately 66% and 63% of 1 hr CO concentrations were not different in the same environments. None of the corresponding outdoor locations had values that are said to be critical to human health. Evidence of greater variation in the maximum time average mean CO concentrations in kitchens with charcoal stoves relative to those using wood was observed. Behavioral patterns in homes burning charcoal coupled with the burning conditions were ascribed to the observed variation. The proportion of the short time and acute CO concentrations in kitchens is a cause for concern for humans from the stand point of improved human health.

Keywords: indoor air, outdoor air, biomass-fuel, carbon monoxide, Sierra Leone

1. Introduction

Studies on indoor air pollution (IAP) in relation to human health have been the subject of intense examination over the past decades. It continues to be an integral component for epidemiologists and public health officials given that people spend greater portion of their time in an indoor environment. It is well established that IAP from burning biomass fuel (wood, charcoal, crop residue, animal dung *etc*) in traditional unvented cook stoves release a host of indoor air pollutants including carbon monoxide (Bhattacharya et al., 2002; Taylor & Nakai, 2012a). Elevated exposures to these air pollutants are commonly found in the kitchen environments where little dispersion of air often takes place. Such high levels of exposures have been implicated in a broad range of adverse health effects. Even though, the mechanisms by which these pollutants affect human health is not entirely known, nevertheless though, exposure to biomass fuel smoke has been associated with several diseases in epidemiological studies (Liu et al., 2007; Regalado et al., 2006). The health related problems resulting from indoor air pollutants are quite pervasive because exposed groups are in proximity to the source. The World Health Organization (WHO) has included IAP from burning biomass fuels as one of the top ten global health risks that is responsible for about 2.7% of the global burden of diseases (Smith et al., 2004). Conservative estimates indicated that exposure to indoor air smoke from biomass fuels is responsible for about 1.6 million annual premature deaths of children worldwide for lower respiratory infections (Ezzati & Kammen, 2002; WHO, 2002).

Studies that have focused on indoor air quality resulting from burning biomass fuels in developing countries have reported high levels of indoor air pollution that often exceeds air quality guidelines (Dasgupta et al., 2006; Fullerton et al., 2009; Taylor & Nakai, 2012a). Two studies looked at biomass fired places as a source of ambient air pollution (Borrego et al., 2010; Gustafson et al., 2008). Others have focused on intervention programs to reduce indoor air pollution (Ezzati & Kammen, 2002; Naeher et al., 2000) through the use of vented efficient stoves and relatively cleaner fuels aimed at reducing human health impact. Nevertheless, the use of clean fuel is quite expensive for poorer families in developing countries that bear the utmost burden of biomass fuel smoke. The present report was part of a broader study that investigated the prevalence of acute respiratory infections in women and children potentially caused by smoke from wood and charcoal stoves in Western Sierra Leone (Taylor & Nakai, 2012c). As evidence of CO association with ARI prevalence is not yet fully resolved in the wider literature, the results that this paper seek to publish were not reported earlier (Taylor & Nakai, 2012c). Consequently this report attempt to explain daytime CO concentrations in kitchen and outdoor locations in households that burn wood and charcoal; compare the levels with the WHO guidelines; examine the degree of variation in the two fuels and relationship between the short time and long time levels.

2. Methodology

2.1 Study Area

The study was conducted in fifteen small settlements spanning from Kent to Lower Allen Town in Western Sierra Leone during a survey that has been described in (Taylor & Nakai, 2012c). Households with wood stoves were identified in the western rural area but those with charcoal stoves were in peri-urban areas of Freetown. As similar sociocultural and demographic settings (household variables, such as, kitchen type, ventilation condition *etc*.) are quite similar for most of these communities. Detailed information has been described earlier in (Taylor & Nakai, 2012a). In summary households in the rural area burn wood in simple stove arranged in tripod in kitchens separated from the main house, but households in the peri-urban areas burn charcoal in the locally made stove in kitchens that are not separated from the dwelling house. Every kitchen has a main door and window that is normally opened for cooking activities. Eight households using a wood stove and six using charcoal stove were monitored in the two locations for CO.

2.2 Carbon Monoxide Measurement

Real-time monitoring of carbon monoxide was made using CO gas detector (EL-USB-CO, Lascar, Ohio, USA) with a procedure previously described in (Taylor & Nakai, 2012a; Taylor & Nakai, 2012b). The CO monitor is fitted with an electrochemical sensor and data logging chamber. The sensor operates by CO molecules entering a detection cell via a capillary with additional details described in (Keil et al., 2010). Direct monitoring was made concurrently in the kitchen and outdoor locations during the day for 12-hrs in the selected households. Measurements were made at a height of 1 m above ground in the two locations to simulate the respirable height. A distance of 1.5 m away from the cooking stove was chosen in the kitchen location to reflect a reasonable distance of CO exposure, and outdoor monitoring was made opposite the kitchen door 4-5 m from the fire place inside the kitchen.

2.3 Data Analysis

CO concentrations for the kitchens and outdoor locations were time averaged. Using the time average concentrations, the arithmetic means were calculated. Table 1, provides detailed information about the different times used for calculation from which the maximum 8 hrs, 1 hr, 30 mins & 15 mins averages were computed for comparison with WHO guidelines. The coefficient of variation (defined as the ratio of the standard deviation to the mean) was determined to explain the variation among the time averaged values and t-test was used to compare time averaged concentrations. Scatter plot was used to assess how the variables (short time and long time) measurements relate to each other and correlation coefficients were determined for the kitchen and outdoor environments, respectively to determine the strength and direction of association.

Table 1. Diurnal periods from which maximum time averaged concentrations were computed in kitchens and outdoor locations for homes burning wood and charcoal, respectively

Homes	**Location**	**Periods from which maximum daytime measurements made for the reported periods**			
		15 mins	***30 mins***	***1 hr***	***8 hrs***
WH-[1]	Kitchen	16:39-16-54	16:27-16:57	16:00-17:00	11:00-19:00
	Outdoor	13:30-13:45	13:30-14:00	13:00-14:00	08:00-16:00
WH-[2]	Kitchen	14:43-14:58	14:28-14:58	14:00-15:00	08:00-16:00
	Outdoor	15:01-15:16	15:01-15:31	15:00-16:00	09:00-17:00
WH-[3]	Kitchen	18:30-18:45	18:30-19:00	18:00-19:00	11:00-19:00
	Outdoor	16:43-16:58	16:28-16:58	16:00-17:00	11:00-19:00
WH-[4]	Kitchen	11:45-12:00	11:30-12:00	11:00-12:00	11:00-19:00
	Outdoor	10:01-10:16	10:01-10:31	10:00-11:00	09:00-17:00
WH-[5]	Kitchen	07:15-07:30	07:01-07:31	07:00-08:00	07:00-15:00
	Outdoor	08:01-08:16	08:01-08:31	08:00-09:00	08:00-16:00
WH-[6]	Kitchen	17:33-17:48	17:19-17:49	17:00-18:00	11:00-19:00
	Outdoor	17:08-17:23	17:01-17:31	17:00-18:00	11:00-19:00
WH-[7]	Kitchen	07:01-07:16	07:01-07:31	07:00-08:00	07:00-15:00
	Outdoor	16:01-16:16	16:01-16:31	16:00-17:00	11:00-19:00
WH-[8]	Kitchen	10:01-10:16	10:01-10:31	10:00-11:00	09:00-17:00
	Outdoor	14:14-14:29	14:01-14:31	14:00-15:00	09:00-17:00
CK-[1]	Kitchen	12:01-12:16	12:30-13:00	12:00-13:00	07:00-15:00
	Outdoor	14:25-14:40	14:25-14:55	14:00-15:00	07:00-15:00
CK-[2]	Kitchen	14:36-14:51	14:29-14:59	14:00-15:00	11:00-19:00
	Outdoor	11:01-11:16	11:00-11:30	11:00-12:00	11:00-19:00
CK-[3]	Kitchen	16:17-16:32	16:17-16:47	16:00-17:00	11:00-19:00
	Outdoor	07:00-07:15	07:00-07:30	07:00-08:00	11:00-19:00
CK-[4]	Kitchen	13:01-13:16	13:01-13:31	13:00-14:00	07:00-15:00
	Outdoor	13:01-13:16	13:01-13:31	13:00-14:00	11:00-19:00
CK-[5]	Kitchen	14:02-14:17	14:02-14:32	14:00-15:00	08:00-16:00
	Outdoor	14:21-14:36	14:06-14:36	14:00-15:00	07:00-15:00
CK-[6]	Kitchen	12:00-12:15	12:00-12:30	12:00-12:30	10:00-18:00
	Outdoor	11:40-11:55	11:29-11:59	11:00-12:00	11:00-19:00

Times reported are in Greenwich Meridian Time (GMT)

WH - represents homes using wood

CK - represents homes using charcoal

Numbers in parenthesis represents home number

3. Results

Summary statistics for the maximum measured CO concentrations at 15 mins, 30 mins, 1 hr and 8 hrs in indoor (kitchen) and outdoor air are presented in Table 2. Evidence from the Table 2 showed great spread of the data around the mean values in the two locations for the stated measured times. For instance, mean 1-hr CO concentrations in kitchens with wood ranged from 12.1 to 82 ppm and ranged from 11 to 141 ppm in kitchens with charcoal stoves. Similarly, mean 1-hr CO concentrations varied from 0.8 to 8.4 ppm in the outdoor location in compounds with kitchens with wood stoves and ranged from 2.1 to 10.6ppm in a similar outdoor location for those with charcoal stoves. The maximum 8-hr CO concentrations in kitchens with wood and charcoal stoves were 37.6ppm and 82.0ppm, respectively. There is no significant variation in the mean maximum CO concentrations between wood and charcoal locations for the different times measured Table 2. Kitchens with charcoal stoves have relatively higher coefficient of variation, CV; (defined as the ratio of standard deviation to its mean, a measure of the variability of data relative to its mean) to those with wood stoves. A similar trend was observed in the outdoor location except for 1-hr and 8-hrs CO concentrations, respectively.

Table 2. Summary statistics for measured maximum time averaged CO concentrations

		Kitchens using Wood					Kitchens using Charcoal					
		{Concentration (PPM) n=8}					{Concentration (PPM) n=6}					
Location	**Duration**	**Mean**	**SD**	**Min**	**Max**	**CV**	**Mean**	**SD**	**Min**	**Max**	**CV**	***p*-value**
Kitchen	15 mins	54.7	30.6	15.2	86.5	0.5	83.1	75.0	15.1	209.0	0.9	0.207
	30 mins	49.9	29.4	13.3	88.1	0.5	62.9	44.5	13.5	112.0	0.7	0.277
	1-hr	42.3	27.4	12.1	82.0	0.6	58.6	48.1	11.0	141.0	0.8	0.242
	8-hrs	19.3	9.8	8.5	37.6	0.4	29.0	29.9	5.7	82.0	1.0	0.237
Outdoor	15 mins	5.0	2.4	1.0	7.5	0.4	7.8	5.5	3.2	18.4	0.7	0.138
	30 mins	4.5	2.2	0.8	6.8	0.4	6.4	4.1	2.6	14.0	0.6	0.158
	1-hr	4.6	2.4	0.8	8.4	0.5	5.4	2.9	2.1	10.6	0.5	0.302
	8-hrs	2.7	1.5	0.4	4.6	0.5	3.5	1.8	0.6	6.1	0.5	0.215

SD is standard deviation; Min is minimum; Max is maximum; CV is coefficient of variation

Temporal profiles for 12 hrs daytime measurements in one of the kitchens with the highest long time diurnal mean for either fuel are presented in Figures 1 & 2, respectively. From Figures 1& 2, it was observed that short time exposure can reach more than 100ppm during daytime exposure. A considerable buildup of prolonged CO concentration could be observed in the temporal profiles. The positive relationship observed between short time (15 mins) and long time (8hrs) CO measurements was plausible for kitchens with wood stoves and charcoal stoves, respectively; and the same could be said for outdoor air. Although the sample size is relatively quite small, the correlation coefficient derived indicated a good positive relationship between short time versus long time measurements in kitchens with wood stoves but very strong in those with charcoal stoves, Figure 3 (a&b), respectively. In outdoor air, a similar observation was made with much stronger relationship in outdoor air of homes using wood than charcoal, Figure 3 (c&d), respectively. It is reasonable to suggest that the positive association between short time and long time CO measurement is an indication that biomass (wood and charcoal) is an undisputable main source of human exposure to indoor air pollution especially CO indicator in kitchen. It further suggests that either short time or long time CO measurement in kitchens could be used to assess human exposure in epidemiological studies.

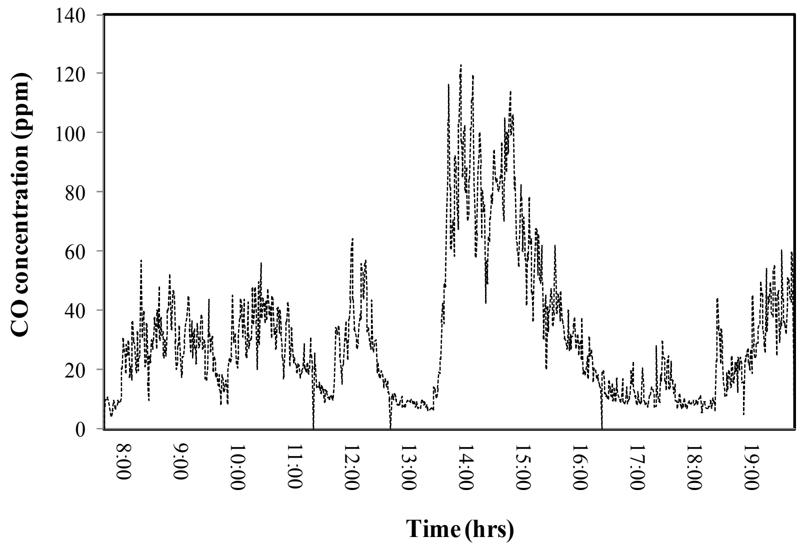

Figure 1. Diurnal temporal profile for a single household kitchen burning wood. Monitoring took place between the hours of 7:20 in the morning and 19:45 in the evening over 1 min interval

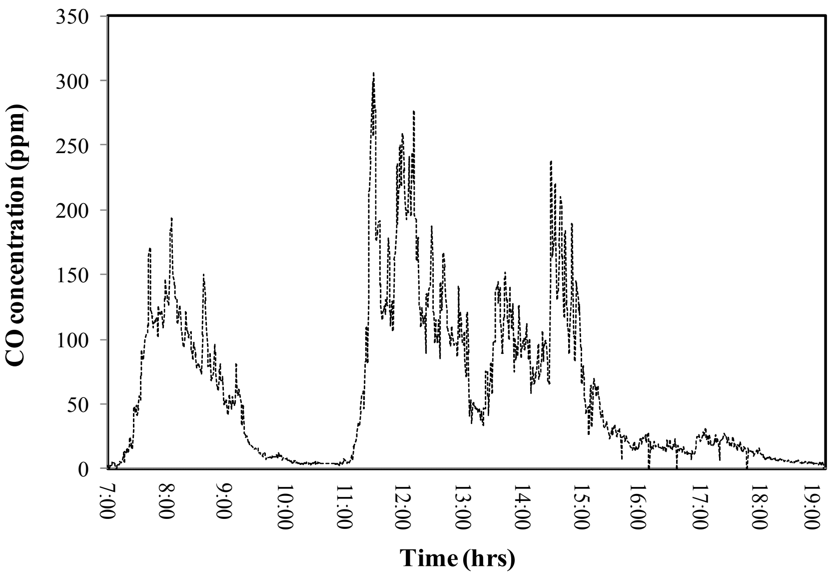

Figure 2. Diurnal temporal profile for a single household kitchen burning charcoal. Monitoring took place between the hours of 7:00 in the morning and 19:00 in the evening over 1 min interval

4. Discussion

There has been marked variation in the design and conduct of studies of indoor air pollution across the world which makes direct comparison with this study difficult. Due to the flexibility of our data, we compared the reported levels with previous studies. For instance, the maximum 8hrs time averaged concentration for kitchens using charcoal was quite similar to a previous study in Pakistan although lower than the same reported for users of wood stove in the same study (Siddiqui et al., 2009). But instantaneous peak concentrations (> 150 ppm) in this study are greater than what (Siddiqui et al., 2009) and (Khushk et al., 2005) reported in Pakistan for their peak levels. In the same study, 1hr mean CO concentration was higher than what the current study reported. The 30 mins CO concentrations in the kitchens in this study is higher than those reported for the same period in Tanzania (Kilabuko et al., 2007) but lower than outdoor levels for the same duration in the same study. The ambient 8 hrs CO concentrations for homes using charcoal as main source of energy was lower than the levels found near major traffic roads in Freetown, Sierra Leone and Lagos, Nigeria (Olajire et al., 2011; Taylor & Nakai, 2012b).

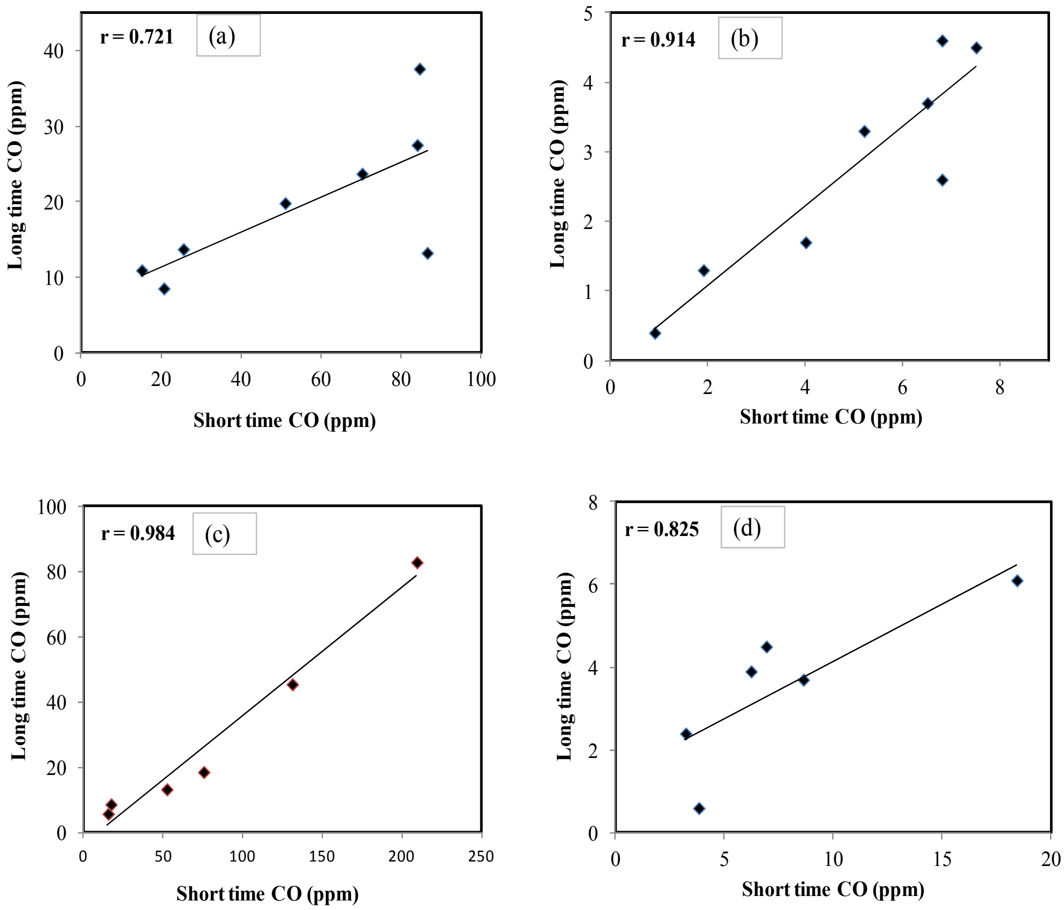

Figure 3. Scatter plot analysis between short time (15 mins) and long time (8 hrs) for (a) kitchens with wood stoves; (b) outdoor air in homes with wood stoves; (c) kitchens with charcoal stoves and (d) outdoor air in homes with charcoal stoves indicating respective correlation coefficients

Generally, the study revealed that kitchens using charcoal as the primary fuel had higher mean CO concentrations than those using wood; and similar observation was made in previous studies (Bhattacharya et al., 2002; Taylor & Nakai, 2012a; Zhang et al., 1999). The variability in mean CO concentrations was more apparent in kitchens using charcoal than wood by 48% for 15 mins; 19% for 30 mins; 25% for 1 hr and 75% for 8 hrs. Probable reasons for such difference could be the amount of fuel used, burning conditions of the flames or the observational practice of starting charcoal fires with plastics and or wood shavings that consequently releases additional pollutants from these different sources for periods when fires are started. Further, (Ezzati et al., 2000) reported that stove emissions usually show temporal variability for large parts of the day during burn period reaching instant peak periods of exposure that may have also accounted for the observed variation. Outdoor variation for 1 hr and 8 hrs CO concentrations was quite similar between homes that burn wood and charcoal probably due to slow dispersion of pollutants over a period of time.

In Sierra Leone, the use of biomass fuels (wood and charcoal) is quite ubiquitous (Amoo-Gottfried & Hall, 1999; Taylor & Nakai, 2012a; Taylor & Nakai, 2012c). This as well as the absence of chimneys to vent noxious pollutants away from the kitchen might have accounted for the high levels of CO concentrations reported in this study. The same exposure levels can be observed for greater parts of Sierra Leone with potential implication for women of reproductive age that are living in such hazardous conditions. From the temporal profiles in Figures 1 & 2, one could explain the contamination level of CO in such kitchens, which has the propensity of reaching up to more than 300 ppm that could be firmly attributed to one field observation. It was observed that cooks do not often extinguish flames from burning wood logs after cooking activity in the kitchen, rather burning logs would continue to smoulder (without flames) for some time until next activity in some cases. We found this observation consistent with a study of indoor air pollution conducted in Honduras (Clark et al., 2010).

It is against this backdrop that the WHO set up indoor air quality CO guidelines to protect many disease outcomes such as coronary artery disease from acute ischemic heart attacks and fetuses from hypoxic effects. The guideline for 15 minutes exposures is 90 ppm, for 30 minutes is 50 ppm, 1 hr is 25 ppm and 8hrs is 9 ppm (WHO, 2010). Approximately 67% and 87% of the 8hrs CO concentrations were more than WHO guidelines for kitchens using charcoal and wood, respectively. About 63% and 66% of 1hr CO concentrations exceeded WHO guidelines for kitchens using wood and charcoal, respectively. Two of the six kitchens with charcoal stoves had a short time (15 mins) CO concentration that exceeded said guidelines. None of the kitchens with wood stoves exceeded the 15 mins threshold value but three had levels very close to the value (90 ppm). Also, none of the corresponding outdoor locations had values that exceeded ambient air quality guidelines for either fuel category. For kitchens burning charcoal, the home with a very high 15 mins CO had the same for the duration of 8 hrs among the homes. Reasons for such an observation might be explained in terms of continual build up of CO during the monitoring; and a probable explanation could be ascribed to low ventilation effect associated with superior construction materials. For kitchens burning wood, the home with the highest 15 mins CO did not reflect highest 8 hrs CO amongst the homes. It could be due to the poor construction of outdoor kitchens that somehow enhance penetration effect through cracks on the walls of the kitchen. Such assumptive observations would require further study where detailed diary of every activity would be taken and reported.

As one of the health concerns from CO exposure is fetal hypoxic exposure, the reported levels in this study would be a cause for concern for pregnant women. Although fetus development is a function of time, the impacts on sensitive group (pregnant women) could be significant. Reliable estimate of coronary artery disease in Sierra Leone is not known but our 1 hr short time exposure in the present study often exceeds air quality guidelines that could increase the risk of heart attacks in vulnerable group of people especially women and the elderly. Empirical evidence exists where associations between CO concentrations and health effects have been seen (although in these studies CO is probably acting as a surrogate for other pollutants (Sari et al., 2008; Yang, 2008). However, a previous report indicated an inconclusive relationship between CO exposure and cardiovascular disease during community population studies (Raub, 1999). But a recent study in Botswana, Southern Africa indicated possible health conditions that were reported by household members, and these include; dizziness, shortness of breath and cough, all of which were associated with high levels of CO (Verma et al., 2010). Another study conducted over a decade ago in Kenya Masai homes revealed high concentrations of CO that were linked to the health effects of the people (Bruce et al., 2002).

One major strength of this study is the use of realtime monitors to measure CO concentrations concurrently in kitchen (where the risk of exposure is high) and outdoor locations during the day. Again, it further insight into understanding the short time and instantaneous CO concentration levels in such rural communities. We hope that the information provided in this report would provide basic standard for intervention programmes tailored at reducing exposure levels especially in rural kitchens.

5. Conclusion

Based upon the data obtained in this study, maximum CO concentrations decreased with increase in the times monitored in both the kitchen and outdoor locations. Observed variation was evident among kitchens with charcoal stoves than wood stoves but no distinguishable variation in long time exposure (8 hrs) in outdoor locations was observed. Short time (15 mins) and instantaneous exposure in the kitchen provided critical information for health education and information. Unlike outdoor locations, measured concentrations for most of the different times exceeded the WHO guideline values in the kitchen.

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