Researchjournali's Journal of Public Health

Vol. 3 | No. 6 July | 2017

Exposure Levels To Fine Particulate Matter And Carbon Monoxide From Solid Biomass Fuel Use In Rural Western Kenya

Carol Munini Munyao

Tutorial Fellow, Department of Natural Resources, Moi University P.O. Box 3900-30100, Eldoret, Kenya

Dr. Gelas Muse Simiyu

Senior Lecturer, Department of Environmental Biology and Health, University of Eldoret, P.O. Box 1125-30100, Kenya

Dr. Kipkorir K. G. Kiptoo

Senior Lecturer, Department of Environmental Biology and Health, University of Eldoret, P.O. Box 1125-30100, Kenya

Dr. John Chelal

Lecturer, Department of Agriculture and Biotechnology, Moi University, P.O Box 3900-30100, Eldoret, Kenya

Researchjournali.com

Exclusive Journal publishing house

ABSTRACT

Globally, six million deaths annually are attributed to exposure to Indoor air Pollution (IAP) in developing countries due to pneumonia, chronic respiratory diseases and lung cancer, with the overall disease burden in Disability Adjusted Life Years (DALYs) exceeding the burden from outdoor air pollution by five-fold. In Kenya, respiratory infections account for 12% of annual deaths. This is due to overreliance on traditional biomass fuels which account for 90% of rural households and 70% of urban households as their primary cooking fuel. The objective of this study was to assess exposure levels to particulate matter (PM) and carbon monoxide (CO) from biomass fuel use in improved stoves and traditional stoves in Western Kenya region. The data was collected through continuous real-time monitoring of personal exposure levels for a period of 24 hours using CO monitors. Algorithms were used to estimate long term and short-term personal exposure of particulate matter from kitchen concentration levels. Data analysis was undertaken by first categorizing pollution data and exposure concentrations into three microenvironments then ANOVA done to test for their variations from WHO stipulated safe standards. At 95% CI, Maximum Daily Intake (MDI) of $PM_{2.5}$ was significantly higher using crop residues compared to wood fuel. Maximum daily intake using mud rocket stove was 889.889 $\mu g/m^3$ and 311.725 $\mu g/m^3$ using wood and crop residue fuels, respectively. Daily exposureof $PM_{2.5}$ using Chepkube stove was 442.354 $\mu g/m^3$ and 3518.6 $\mu g/m^3$ using firewood and crop residues fuels, respectively. Three-stone stove produced the highest daily exposure of 3646.5 $\mu g/m^3$ and 2768.5 $\mu g/m^3$ using crop residues and firewood fuels, respectively. Household indoor PM and kitchen concentrations associated with biomass fuel combustion in the study area exceeded WHO indoor safe limits of 25 $\mu g/m^3$ in the short term and 10 $\mu g/m^3$ in the long term and are in the hazardous range for human health. The extremely high kitchen $PM_{2.5}$ concentrations suggest that mud rocket stove and Cheprocket stoves cannot be an intervention for health effects of $PM_{2.5}$ which are of most interest in Household air pollution (HAP). Consequently, it is recommended that programs aiming to reduce exposure to CO and PM2.5 should focus on measures that result in larger reductions of PM2.5 emissions especially during burning and peak periods.

Keywords: Indoor air pollution, Exposure, Particulate Matter, Carbon Monoxide, Chepkube, Mud rocket stove

1. INTRODUCTION

Indoor air pollution associated with combustion of solid fuels in households in developing countries is now recognized as a major source of health risks. Use of open fires with simple solid fuels, biomass, or coal for cooking and heating exposes an estimated 2 billion people worldwide to concentrations of particulate matter and gases that are 10 to 20 times higher than health guidelines for typical urban outdoor concentrations (Rehfuess *et al.*, 2006). Although biomass makes up 10 to 15 percent of total human fuel use, indoor exposures are likely to exceed outdoor exposures on a global scale (Rehfuess *et al.*, 2006).

World Health Organization estimates that particulate matter emissions are responsible for approximately 800,000 premature deaths each year, making it the 13th leading cause of death globally (Anderson *et al.*, 2012). It is estimated that approximately 3% of cardiopulmonary and 5% of lung cancer deaths are attributable to PM globally. Results emerging from a recent study indicate that the burden of disease related to ambient air pollution may be even higher up to 3 million deaths annually (WHO, 2014). Most of PM emission quantification studies look at particulate matter from all sources, and therefore the premature deaths, morbidities, and associated costs incurred from biomass combustion emissions would be proportional to their contribution to national PM levels.

Young children living in developing countries and exposed to solid biomass fuels have a 2 to 3 times greater risk of developing acute lower respiratory tract infection (ALRI) compared with those living in households using cleaner fuels or suffering less exposure to smoke (Smith *et al.*, 2000). In children under 5 years, the mortality attributable to ALRIs is estimated to be over 2 million deaths per year in developing countries (Rudan *et al.*, 2004). The first finding of indoor cooking smoke to be associated with childhood pneumonia and bronchiolitis was in Nigeria (Sofoluwe, 1968), however not until 1980s when this finding was followed by reports from other areas in Africa (Shah *et al.*, 1994). A cohort study in rural Kenya found that the amount of IAP a child is exposed to directly correlate with the risk of developing pneumonia (Ezzati & Kammen, 2001).

Evidence exists that implicates exposure to biomass fuels smoke to adverse effects on different birth outcomes (Sram *et al.*, 2005). Babies of mothers using open wood fires in Zimbabwe were found to be on average 72 grams lighter compared with babies born to mothers using cleaner fuels (Mishra *et al.*, 2004). Still in Zimbabwe, a report suggested that exposure to biomass fuels smoke in young children contributed to chronic nutritional deficiencies including anemia and stunted growth (Mishra & Retherford, 2007).

Major concern of particulate matter is the free radicals, hydrocarbons (PAHs, benzene, and styrene), aldehydes, and phenols, specifically carcinogenic or toxic compounds, that these particles can carry into an individual's lungs and blood stream because they are proven to cause cancer (Naeher *et al.*, 2007). It is important to note that while these chemicals are proven to cause cancer, both in human and animal models, very little research has been done to study the health effects and levels of exposure of these compounds when exposed via wood smoke (EPA, 2008).

In summary, short-term (hours or days) exposure to elevated particulate matter levels is linked to a variety of negative health outcomes including increased deaths from respiratory and cardiovascular causes, increased number of heart attacks specifically in individuals with previous underlying heart conditions, increased hospitalizations for asthma and respiratory causes among children, increased hospitalizations for cardiovascular disease, increased severity of asthma attacks among children, increased mortality, increased medication usage, decreased lung function and inflammation of lung tissue among healthy individuals (American Lung

Association, 2008). Long term exposure to elevated levels of particulate matter has been linked to higher rates of lung cancer, decreased lung function among children and teenagers, overall lung damage, increase risk of cardiovascular morbidity and mortality, and decreased life expectancy. Adults with chronic lung conditions such as asthma, chronic bronchitis and emphysema, individuals with cardiovascular disease, and individuals with diabetes are at higher risk of these problems (Brook *et al.*, 2010).

Respirable particulate matter is now considered the single best indicator pollutant for assessing the overall health-damaging potential of most kinds of combustion, including that of biomass. Exposure to $PM_{2.5}$ from the combustion of wood, charcoal, agricultural residues, and dung was implicated as a causal agent of respiratory and eye diseases including cataracts, blindness, and possibly conjunctivitis in developing countries in the 90s (Ellegard, 1996). Associations between exposure to household air pollution and increased incidence of chronic bronchitis in women and acute respiratory infections (ARI) in children have been documented (Ezzati & Kammen, 2001; Akunne *et al.*, 2006; WHO, 2007; Smith *et al.*, 2007; Lim *et al.*, 2012; Burnett *et al.*, 2014). A high correlation has been shown between biomass smoke exposure and acute respiratory infection in children of rural Kenyan households (Ezzati *et al.*, 2000).

Carbon monoxide binds to hemoglobin in preference to oxygen and thus reduces oxygen delivery to key organs, which may have important implications for pregnant women, with developing fetuses being particularly vulnerable (Bruce *et al.*, 2004; Bruce *et al.*, 2008). Breathing CO can cause headache, dizziness, vomiting, nausea and in severe cases may lead to unconsciousness or death. Exposure to moderate and high levels of CO over long periods of time has also been linked with increased risk of heart disease. People who survive severe CO poisoning may suffer long-term health problems (Bruce *et al.*, 2004; Bruce *et al.*, 2008; Smith *et al.*, 2007). Given the high burden of disease attributable to biomass fuel use, there is considerable interest in the design of interventions, such as improved biomass stoves which reduce exposure to indoor biomass smoke.

CO poisoning is a major public health problem and may be responsible for more than half of fatal poisoning in many countries and gives significant percentage of all poisoning deaths (Raub, 2000). Moderate carbon monoxide exposure has been reported to cause neurotoxic effects and impairment of higher functions. The central nervous system effects include reduction in visual perception, manual dexterity, learning, visual perception, driving performance and attention level (Raub, 2002). Acute CO poisoning leads to disorientation, confusion, coma and death. Survived patient will developed delayed neuropsychiatric impairment within 2 to 28 days after poisoning and slow resolution of neurobehavioral consequences (Raub, 2000). Table 1 shows symptoms of acute poisoning based on COHb levels.

Table 1: Symptoms of Acute Poisoning Based on COHb Levels

COHb %	Symptoms
10	Asymptomatic and may have headache
20	Dizziness, nausea, dyspnoea

30	Visual disturbance
40	Confusion, syncope
50	Seizures and coma
>60	Cardiopulmonary dysfunction and death

Source: WHO, 2014

Chronic CO poisoning due to biomass use is widespread and far more prevalent than is generally supposed. Prolonged exposure to this insidious poison, even at very low levels, is capable of producing various residual health effects. The incidence of such unpleasant effects is far higher than previously believed by the medical and public health community (WHO, 2014). However there are inadequate controlled human studies, ambient population-exposure studies or occupational studies to give reliable information regarding effects of low chronic CO exposure (Raub, 2002). Sub-acute or chronic CO poisoning presents with less severe symptoms and patient may be misdiagnosed as having other illness such as flu, viral infection and depression (Smithline *et al.*, 2003). Symptoms such as headaches, vertigo, nervousness, palpitations and neuromuscular pain that are found in chronic poisoning can also be found in individuals who have been acutely poisoned by CO (Smithline *et al.*, 2003).

The national deaths attributable to respiratory infections are at 12% annually (WHO, 2007). There is a high correlation between the amount of indoor air pollution a child is exposed to and the risk of developing respiratory infections (Ezaati & Kammen, 2001). Use of traditional biomass fuels such as wood, dung, and crop residues is widespread in rural Kenya. According to GoK (2002), 90% of rural households and 70% of urban households rely on biomass as their primary cooking fuel. Since much of the cooking is carried out indoors in environments that lack proper ventilation, millions of people in the country, primarily poor women and children face serious health risks. In Kenya, efforts to address the overall health risks associated with solid biomass fuels use among rural women and children are currently done through promotion of improved biomass stoves such as Mud Rocket Stove (MRS) and Cheprocket stove among others.

There is limited knowledge in Kenya on exposure levels from indoor air pollution and therefore household air pollution remains a major cause of morbidity and mortality due to overreliance of solid biomass fuels for domestic cooking in rural areas. High poverty levels in these areas do not allow the communities to move up the energy ladder to cleaner fuels or adopt improved energy technologies therefore larger population remains exposed. Worse still, cooking is a daily activity implying that household air pollution is a lifetime challenge to women who are the main domestic cooks and young children always accompanying them during cooking remain exposed. Although there have been efforts to reduce household air pollution through introduction and promotion of improved cook stoves by mainly non-governmental organizations in Kenya, systematic evaluations to assess whether these programs have achieved the intended efforts are lacking. There has been no performance testing of exposure reduction potential of Cheprocket stove disseminated in the Elgon sub-county through VI-agro forestry project in 2012 and therefore associated health risks unknown. Absence of this information hinders proper planning by the county governments on public health issues. The main objective of this study was to assess exposure levels of particulate matter and carbon monoxide from biomass fuel use in improved stoves and traditional stoves in Western Kenya region.

This study is essential because it would provide information on the effectiveness of improved biomass stoves in reducing fuel use and both kitchen concentrations and personal exposures of PM and CO using different biomass fuels. Finding from this study could assist planners and policy makers on mitigation of household air pollution in Kenya. Planning opportunities to be derived from this study include formulation of a domestic biomass utilization policy that would enhance energy accessibility, control health burden from household air pollution and minimize environmental stress from biomass smoke. Finally, enhancement of the household air quality would make a significant impact on the rural economies by reducing disease burden especially on women and children thus improving their health and minimizing costs spent on hospital bills.

2. MATERIALS AND METHODS

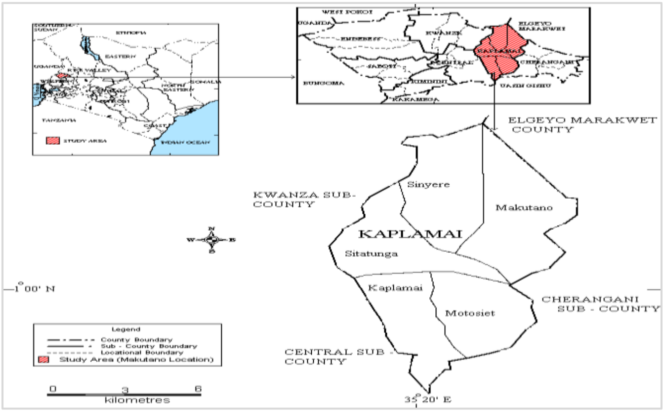
2.1 STUDY SITE

This study was undertaken in two Counties in the Western region of Kenya. They included the Trans Nzoia and Bungoma Counties.

2.1.1 POSITION AND LOCATION OF TRANS NZOIA COUNTY

Trans Nzoia County is one of the forty seven (47) counties in Kenya and it has three sub-counties. The county approximately lies between latitudes 0° 52´ and 10° 18´ North of the equator and longitudes 34° 38´ and 35° 23´ East of the Great Meridian as indicated in Figure 1. The County covers an area of 2,495.6 km^2 which forms 0.42% of the total land area of the Republic of Kenya (GoK, 2013a).

Figure 1: Trans Nzoia County indicating Location of Kaplamai Sub-county

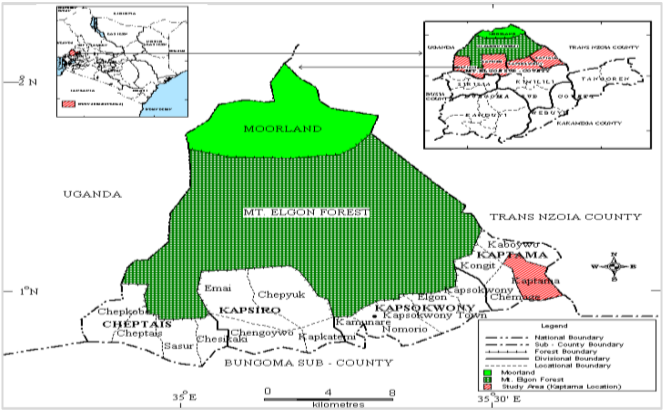


Source: Moi University, 2017

2.1.2 POSITION AND LOCATION OF BUNGOMA COUNTY

Bungoma County lies between latitude 0° 28' and latitude 1° 30' North of the Equator, and longitude 34° 20' East and 35° 30' East of the Greenwich Meridian as indicated in Figure 2. The County covers an area of 3032.4 km^2 (GoK, 2013b).

Figure 2: Location of Mt. Elgon Sub-county in Bungoma County



Source: Moi university, 2017

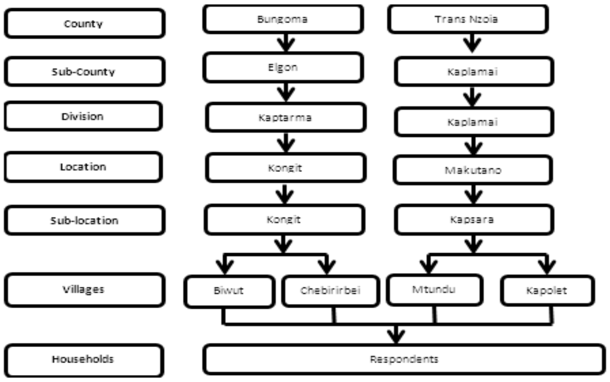
2.2 RESEARCH DESIGN

This research employed cross-sectional study design where there was quantification of personal exposure levels of improved biomass stoves users and traditional biomass stove users and comparing these levels against WHO safe limits. Both quantitative and qualitative research methods were applied. A systematic approach to the study design entailed sampling, data collection through pre-testing of emission meters, data categorization and analysis.

2.3 SAMPLING METHOD

A multi-stage sampling technique was used in this study as illustrated in Figure 3. Trans Nzoia and Bungoma Counties were selected purposively because both have major ecosystems where efforts have been made to promote biomass stoves aimed at ecosystem conservation and indoor air pollution reduction. Kaplamai Sub-county in Trans Nzoia county and Elgon Sub- county in Bungoma count were selected using cluster sampling method because in these sub-counties, divisions where stove promotion was undertaken are found. Kaptarma Division in Bungoma County and Kaplamai Division in Trans Nzoia County were selected. Cluster sampling method was employed to select one location and one sub-location in each sub-county based on their proximity to shopping centers for ease of electricity accessibility to charge the IAP meters batteries and adjacent to the forests. Kongit Location and Kongit sub-location in Bungoma County were selected while in Trans Nzoia, Makutano Location and Kapsara sub-location were selected. Cluster sampling method was used because Locations and Sub-locations have naturally occurring borders and groups were used rather than individuals.

Figure 3: Multi-stage Levels of Sampling Design



Stratified cluster sampling was used to select two villages were selected from each sub-location depending on whether training on ecosystem conservation such as on improved biomass stoves, or on tree planting was undertaken. Biwut and Chebirirbei villages were selected in Kongit sub-location, Bungoma County and Mtundu village and Kapolet village in Kapsara sub-location, Trans Nzoia County.

Selection of respondents from each village was done using random systematic sampling method where a list of all households in each village was given; top households were then picked according to the number attained after apportioning each village as per the sample population. The total sample population was 383 HH out of which 56 HH and 81 HH were from, Biwut and Chebirirbei villages, respectively, in Bungoma County while 115 HH and 131 HH were from Mtundu village and Kapolet village, respectively, in Trans Nzoia County. A total of 204 households were selected as the sample size for HH survey. The sample size was determined using sample size algorithm by Boyd and Manheim (2014) where a sample size is determined by the sample population size.

Selection of households for indoor air monitoring was done through quasi system where there was a predefined criterion from survey data. The criterion used was; first, the household must be using either Chepkube stove, or Cheprocket stove or rocket stove or three stone stoves and the household size to be above 7 members which was the main HH size recorded in both Counties from survey data. Same household size was used to reduce disparities among recorded emissions. Selected households had income levels ranging from 5000 to 30000 KShs per month and the occupation of household head was farming with farm size between one and five acres. A total of 56 HH were selected for indoor air pollution monitoring; 14 rocket stoves, 16 Chepkube stoves, 10 three stone and 16 Cheprocket.

2.4 DATA COLLECTION

2.4.1 PERSONAL EXPOSURE ASSESSMENT

CO personal monitors were worn by the women on the collar position, emulating the breathing zone. For $PM_{2.5}$, recorded kitchen concentrations were used to calculate personal exposures since the UCB-PATS instrument is too bulky to be worn on the neck. Monitoring arrangements were made with cooks in the households prior to the exercise, during which they were familiarized with the monitors and demonstrations done on how to wear the monitors, and where to keep them when sleeping. On the day of monitoring, the emission monitoring meters were placed in the early morning before cooking tasks begun. The sampling went on continuously for 24 hours, starting very early in the morning before the beginning of cooking tasks, and ending at the same time the following day.

After CO and $PM_{2.5}$ concentrations were obtained, a time-weighted average exposure concentration (EC) for each microenvironment was characterized by a specific activity pattern. There were three microenvironments. The first microenvironment (ME_1) was during peak periods; during fire lighting and when adding more fuel to fire, the second ME_2 was during fire burning duration and third ME_3 was when the fire was simmering or off. For short term (daily) personal exposure assessment, Equation 1 shown below was used.

$MDI = (CA \times IR \times 24)/BW$ ………………………..Equation 1

Where;

MDI – Maximum daily intake

CA – contaminant concentration

IR – Inhalation rate (m^3/hr)

24 – hours/day

BW – body weight (kg)

Assumptions

- The age of primary cooks was 35 years old hence inhalation rate used was 1.62 m^3/hr as stipulated in EPA (2013) guidelines.
- Average body weight of an adult female is 60 kg.

For long term exposure assessments, these concentrations were then combined into a longer term average EC by weighting the EC by the duration of each exposure period using Equation 2 below.

$EC_j = \sum_{i=1}^{n}(CA_i \times ET_i \times EF_i) \times ED_j / AT_j$ ....Equation 2

Where:

EC_j (µg/m^3) = average exposure concentration for exposure period j;

CA_i (µg/m^3) = contaminant concentration in air in ME_i;

ET_i (hours/day) = exposure time spent in ME_i;

EF_i (days/year) = exposure frequency for ME_i;

ED_j (years) = exposure duration for exposure period j; and

AT_j (hours) = averaging time = ED_j x 24 hours/day x 365 days/year.

Assumptions

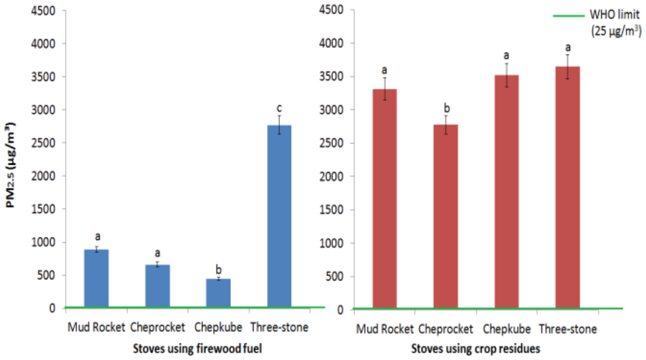
- ME_1 - Fire burning duration is an average 5 hours in a day
- ME_2 - Peak durations take period of 1 hour in a day
- ME_3 - Simmering period was assumed to be 4 hours
- For long-term exposures, it was assumed that cooks were exposed for 75% of their lifetime of 70 years hence exposed for a duration of 53 years
- Exposure frequency is 75% of a year; 273 days/year

3. RESULTS

3.1 SHORT-TERM $PM_{2.5}$ PERSONAL EXPOSURE

At 95% CI, Maximum Daily Intake (MDI) of $PM_{2.5}$ was higher using crop residues compared to wood fuel. Maximum daily intake using MRS was 889.889 $\mu g/m^3$ ($p = 0.000$) and (311.725 $\mu g/m^3$ ($p = 0.000$) using wood and crop residue fuels, respectively. Daily exposureof $PM_{2.5}$ using Chepkube stove was 442.354 $\mu g/m^3$ ($p = 0.000$) and 3518.6 $\mu g/m^3$ ($p = 0.000$) using firewood and crop residues fuels, respectively. Three-stone stove produced the highest daily exposure of 3646.5 $\mu g/m^3$ ($p = 0.000$) and 2768.5 $\mu g/m^3$ ($p = 0.000$) using crop residues and firewood fuels, respectively. While Cheprocket stove produced a daily exposure of 661.8 $\mu g/m^3$ ($p = 0.000$) and 1291.8 $\mu g/m^3$ ($p = 0.000$) using firewood and crop residues fuels, respectively as indicated in Figure 4.

Figure 4: MDI of $PM_{2.5}$ using Different Biomass Stoves



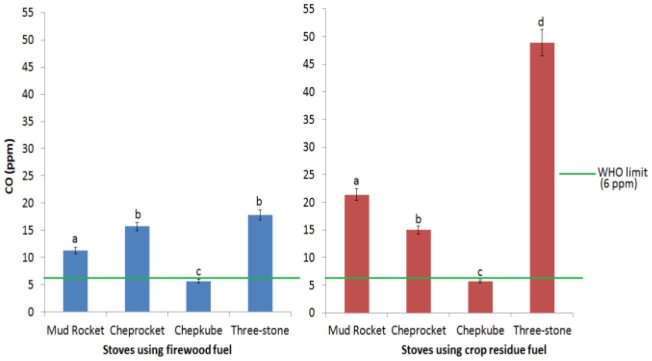
NB: Bars designated with same letter within a fuel type are not statistically different at $p < 0.05$ based on Tukey's test.

3.2 SHORT-TERM CO PERSONAL EXPOSURE

At 95% CI, cooks using three-stone stove had highest MDI of 48.886 ppm ($p = 0.000$) and 17.79 ppm ($p = 0.000$) using crop residues and firewood fuels, respectively while those using the Chepkube stove had the least

MDI at 5.713 ppm ($p = 0.000$) and 5.652 ppm ($p = 0.000$) using crop residues and firewood fuels, respectively as indicated in Figure 5.

Figure 5: MDI of CO using Different Biomass Stoves



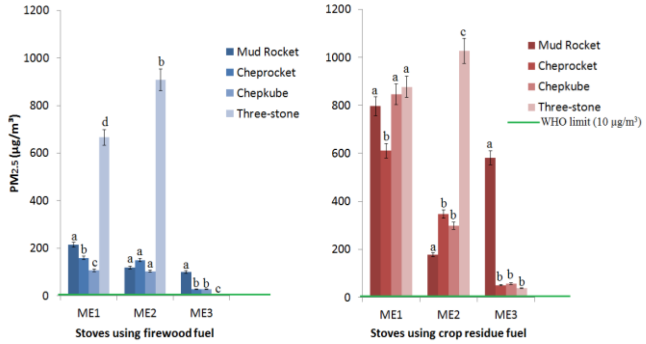
NB: Bars designated with same letter within a fuel type are not statistically different at $p < 0.05$ based on Tukey's test.

Maximum daily intake using mud rocket stove was 21.355 ppm ($p = 0.000$) and 11.264 ppm ($p = 0.000$) using crop residues and firewood fuels, respectively. Daily exposure using the Cheprocket stove was 14.980 ppm ($p = 0.000$) and 15.705 ppm ($p = 0.000$) using crop residues and firewood fuels, respectively.

3.3 LONG-TERM EXPOSURE OF $PM_{2.5}$

Three-stone stove recorded the highest overall chronic Exposure Concentration (EC) of 1941.873 µg/m^3, (ME_1 – 876.869 µg/m^3, ME_2 – 1026.990 µg/m^3, ME_3 – 38.014 µg/m^3, $p = 0.000$) and 1576.25 µg/m^3 (ME_1 – 665.735 µg/m^3, ME_2 – 908.061 µg/m^3, ME_3 – 2.454 µg/m^3, $p = 0.000$) using crop residues and firewood respectively, while Chepkube stove recorded the least EC at 235.959 µg/m^3 (ME_1 – 106.371 µg/m^3, ME_2 – 102.721 µg/m^3, ME_3 – 26.867 µg/m^3, $p = 0.000$) and 1201 µg/m^3 (ME_1 – 846.101 µg/m^3, ME_2 – 298.863 µg/m^3, ME_3 – 56.463 µg/m^3, $p = 0.000$) using firewood and crop residues respectively. Chronic exposures of $PM_{2.5}$ from all biomass stoves were significantly higher than WHO safe limit of 10 µg/m^3 as indicated in Figure 6.

Figure 6: Long-term $PM_{2.5}$ Exposure using Different Biomass Stoves



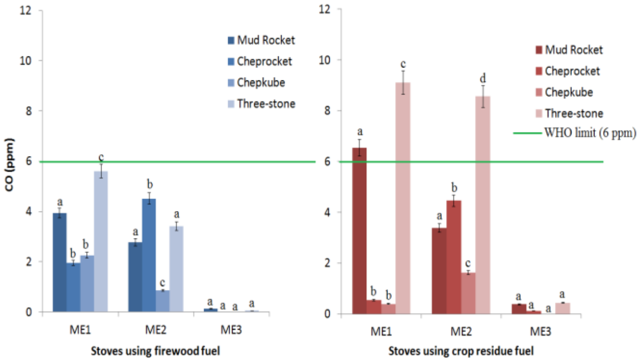
NB: Bars designated with same letter within a specific microenvironment (ME) are not statistically different at $p < 0.05$ based on Tukey's test.

Mud rocket stove had a long-term EC of 431.693 μg/m^3 (ME_1 – 213.988 μg/m^3, ME_2 – 118.353 μg/m^3, ME_3 – 99.352 μg/m^3, $p = 0.000$) and 1555.277 μg/m^3 (ME_1 – 796.357 μg/m^3, ME_2 – 177.567 μg/m^3, ME_3 – 581.353 μg/m^3, $p = 0.000$) using firewood and crop residues as fuels, respectively. Further, Cheprocket stove produced a long-term EC of 334.58 μg/m^3 (ME_1 – 159.140 μg/m^3, ME_2 – 149.207 μg/m^3, ME_3 – 26.233 μg/m^3, $p = 0.000$) and 1050.117 μg/m^3 (ME_1 – 652.635 μg/m^3, ME_2 – 346.463 μg/m^3, ME_3 – 51.019 μg/m^3, $p = 0.000$) using firewood and crop residues as fuels, respectively.

3.4 LONG-TERM EXPOSURE OF CO

Chronic CO exposure using MRS and three-stone stove using crop residue fuel were the highest at 10.303 ppm (ME_1 – 6.544 ppm, ME_2 – 3.386 ppm, ME_3 – 0.373 ppm, $p = 0.000$) and 18.119 ppm (ME_1 – 9.115 ppm, ME_2 – 8.568 ppm, ME_3 – 0.436 ppm, $p = 0.000$) respectively. The local innovation; Chepkube stove had the least chronic CO exposure concentrations at 3.116 ppm (ME_1 – 2.259 ppm, ME_2 – 0.857 ppm, ME_3 – 0 ppm, $p = 0.000$) and 2.006 ppm (ME_1 – 0.389 ppm, ME_2 – 1.617 ppm, ME_3 – 0 ppm, $p = 0.000$) using wood and crop residues as fuels, respectively as indicated in Figure 7.

Figure 7: Long-term CO Exposure using Different Biomass Stoves



NB: Bars designated with same letter within a specific microenvironment (ME) are not statistically different at $p < 0.05$ based on Tukey's test.

Chronic exposures to CO from all biomass stoves using firewood were significantly lower than WHO safe limit of 6ppm. However, long-term EC of CO using crop residues using mud rocket and three-stone stoves during burning period and 1-hour peak period for three-stone stove were significantly higher than the recommended daily limit of 6 ppm as indicated in Figure 7.

4.0 DISCUSSION

Personal exposures were much lower than kitchen concentrations. This finding is supported by Yamamoto *et al.* (2014) who reported that PM and CO personal concentrations were much lower than both indoor and outdoor concentrations. Both long-term and short-term exposure $PM_{2.5}$ concentrations were significantly higher than the stipulated WHO and EPA safe limits from all stove types. However, three-stone stove had the highest personal exposures followed by rocket stove then Cheprocket stove while Chepkube stove had the least PM personal exposures.

Higher kitchen concentrations of the pollutants due to reduced air circulation in to the stoves’ combustion chambers was the probable reason for cooks using improved stoves having higher exposures compared to those using the Chepkube stoves. The higher Long-term $PM_{2.5}$ exposures compared to short-term exposures implied that as the cooks age, the risk of getting upper and lower respiratory infects such as asthma and bronchitis, also increased. This is disastrous because at old age, most people cannot access medical cover in Kenya; enjoyed by the few individuals in formal employment, therefore medical bills are individually catered for, which may lead to early deaths and reduced lifespan as a result of the high poverty levels in these regions.

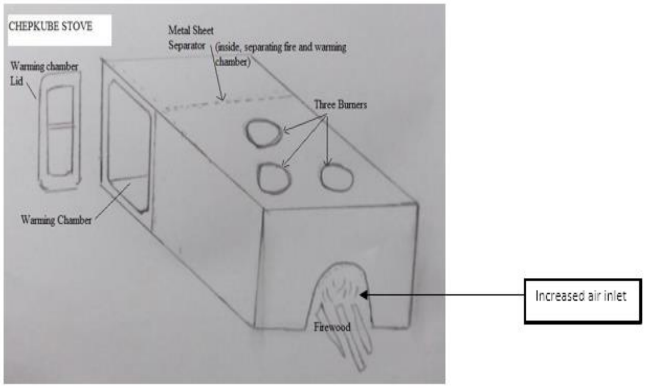
It was found that maximum daily intake of CO using different stoves were all above the daily safe stimulated limits of 6 ppm apart from Chepkube stove which had 5.6 ppm using wood as fuel and 5.7 ppm using crop residues as fuel. Average long-term peak exposures of CO were within WHO safe 60-minute limits of 30 ppm for all stoves. Peak exposures shown in the diurnal plots indicate that CO and PM exposures were higher when the cooks are near combustion sources or during lighting of fire although these exposures were only for a short duration. Pollution from biomass is episodic and peaks account for a substantial portion of an individual’s exposure therefore an intervention such as improved stoves; that does not reduce these peaks may not be sufficient on its own. Use of cleaner stoves is one of the options to reduce wastage in fuel and emissions. By focusing on technology alone, many other important aspects of kitchen characteristics are neglected, such as variety of cooking practices, kitchen construction material type and floor design, cultural norms, and spillover effects related to cooking such as space heating. The unexpected higher CO exposures from mud rocket stoves and Cheprocket stoves compared to Chepkube stove was contributed by high incomplete combustion due to poor air circulation in the firing chambers of the mud rocket stove and Cheprocket stoves since most of their air inlets were clogged with ash from previous fuel combustion as illustrated in Plate 1.

Plate 1: Mud Rocket stove in a Typical Kitchen

Source: Author

The height of MRS is low necessitating bending over above the fire during cooking leading to increased exposure. In addition, the high exposures of $PM_{2.5}$ was also as a result of the fuel type used; crop residues specifically maize stalks and maize cobs have low calorific value and hence produce higher amounts of ash and higher smoke levels during combustion. Chepkube stove has enlarged firewood and air supply opening that ensures adequate supply of air as indicated in Figure 8.

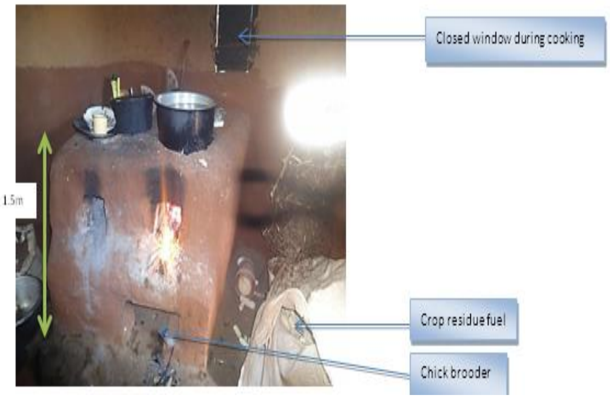
Figure 8: Schematic Illustration of the Chepkube Stove



Source: Author

The Cheprocket stove had relatively lower personal exposures compared to mud rocket stove because of its improved design with elevated height which reduces direct bending over above fire during cooking unlike for mud rocket stove as indicated in Plate 2.

Plate 2: Typical Cheprocket stove



Source: Author

Therefore, in judging the effectiveness of mud rocket and Cheprocket stoves, there needs to be a clear distinction between the presumed emissions reduction and actual exposure reduction. Improved stoves may improve emission reduction but not necessarily reduce exposure automatically due to kitchen and behavioral and characteristics as it was observed in this study. If improved stove users have to bend over above fire during cooking owing to stove height, although emissions may be reduced, exposure could be increased significantly.

Although less smoke may be produced after cooking, longer hours indoors especially in the evenings after supper chatting around fire meant higher exposures and health impacts resulting from pollutant concentrations already in the kitchens.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Household indoor PM and kitchen concentrations associated with biomass fuel combustion in the study area exceed WHO indoor safe limits and are in the hazardous range for human health. The extremely high $PM_{2.5}$ exposure suggest that MRS and Cheprocket stoves cannot be an intervention for health effects of $PM_{2.5}$ which are of most interest in HAP.

High reliance on traditional biomass fuels with low combustion efficiency contributed to high levels of products of incomplete combustion hence the high PM concentrations, which are more damaging to health.

Lack of kitchen practices such as removing ash from stoves regularly may lead to more emissions from improved stoves although they have superior combustion principles as witnessed with mud rocket stove. Further, if improved stove users cook with their windows closed, there would be high levels of indoor air pollution even if emissions are reduced.

5.2 RECOMMENDATIONS

- A more detailed should study to be undertaken to understand variations in human exposure from season to season.
- An epidemiological study to be carried out to assess the linkage between PM exposures and expiratory infections in the region

6. REFERENCES

Akunne, A. F., Louis, V. R., Sanon, M., & Sauerborn, R. (2006). Biomass solid fuel and acute respiratory infections: the ventilation factor. *International Journal of Hygiene Environmental Health*, *209*, 445 – 450.

Bruce, N., McCracken, J., Albalak, R., Schei, M. A., Smith, K. R., Lopez, V., & West, C. (2004). Impact of improved stoves, house construction and child location on levels of indoor air pollution exposure in young Guatemalan children. *Journal of Exposure Analysis and Environmental Epidemiology*, *14*, 26 – 33.

Bruce, N., Fullerton, D.G., & Gordon, S.B. (2008). Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. *Transactions of the Royal Society of Tropical Medicine and Hygiene Royal Society of Tropical Medicine and Hygiene*, *102*, 843 - 851.

Burnett, R.T., Pope, C. A., Ezzati, M., Olives, C., Lim, S. S., & Mehta, S. (2014). An Integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environmental health perspectives*, *122*, 397 - 403.

Ellegard A. (1996). "Cooking Fuel Smoke and Respiratory Symptoms among Women in Low-Income Areas in Maputo," *Environmental Health Perspectives*, 104, 980 - 985.

Environmental Protection Agency (EPA). (2013). Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual; Supplemental Guidance for Inhalation Risk Assessment, EPA, *OSWER*, 9285: 7 - 82

Ezzati, M., Saleh, H., & Kammen, D. M. (2000). The Contributions of Emissions and Spatial Microenvironments to Exposure to Indoor Air Pollution from Biomass Combustion in Kenya. *Environmental Health Perspective*, *108*, 833 – 839.

Ezzati, M., & Kammen, D. M. (2001). Quantifying the effects of exposure to indoor air pollution from biomass combustion on acute respiratory infections in developing countries. *Environmental Health Perspective*, *109*, 481 - 489.

Government of Kenya, (GoK). (2002). *Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small Scale Industries and Service Establishments*. Ministry of Energy (MoE), Nairobi.

Government of Kenya, (GoK). (2013a). *Trans Nzoia County Integrated Development Plan 2013 - 2017*. Trans Nzoia County government, 2013.

Government of Kenya, (GoK). (2013b). *Bungoma County Integrated Development Plan 2013 – 2017*. Bungoma County government, 2013.

Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., & Adair-Rohani, H. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990 - 2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*, *380*, 2224 - 2260.

Moi University, (2017). *Trans Nzoia and Bungoma county Maps*. Department of Geography, Moi university press, 2017.

Rehfuess, E., Mehta, S., & Pruss-Ustün, A. (2006). Assessing household solid fuel use: multiple implications for the Millennium Development Goals. *Environmental Health Perspective, 114*, 373 - 378.

Smith K. R., Diaz, E, Smith-Sivertsen, T., Pope, D., Lie, R. T., Diaz, A., McCracken, T.,Arana, B., Bruce, N. (2007). Eye discomfort, headache and back pain among Mayan Guatemalan women taking part in a randomized stove intervention trial. *Journal of Epidemiology & Community Health,* 74 – 79.

World Health Organization (WHO). (2007). *The Global Burden of Disease: 2004 Update*. Geneva: World Health Organization, 2008.

Yamamoto, S. S., Louis, V. R., Sié, A., & Sauerborn, R. (2014). Biomass smoke in Burkina Faso: what is the relationship between particulate matter, carbon monoxide, and kitchen characteristics? *Environmental Science and Pollution Research*, *21*, 2581 – 2591.