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Abstract

Purpose: This study investigated the impact of increased levels of indoor air pollution (IAP) caused due to biomass burning using different technologies in the rural households of Western, Kenya. A comparative assessment of the impact of traditional cookstoves (TCS) and improved cookstoves (ICS) coupled with the characteristics of kitchen was conducted to estimate the $PM_{2.5}$ and CO concentrations in the micro-environments of kitchen and living area of the households.

Methodology: The study incorporated both extensive and intensive real-time indoor air quality (IAQ) monitoring during the two cooking sessions of the day. A multi-stage sampling technique was used in this study and the total target population was 383; where 204 households were selected as the sample size for HH survey and 56 households were selected for indoor air pollution monitoring. Influence of the different types of kitchen characteristics; enclosed, semi-enclosed and open was also comprehensively analyzed to measure its impact on the IAQ. Both UCB-PATS instrument and CO loggers were launched in kitchens for 24 hours. The Kitchen Performance Test (KPT) was applied to demonstrate the effectiveness of stove interventions on household fuel consumption. The pollutant concentrations were reported in terms of 24-h, 1-h peak cooking and long-term time scales. Data was analyzed using Statistical Packages for the Social Sciences (SPSS). Multiple regression analysis was undertaken to evaluate the association between pollutant concentration and kitchen characteristics and to determine a set of variables that best predict the pollutants. Units of analysis included means, standard deviations, minimum values, median values and maximum values and IQR. Spearman's rank correlation coefficients (r) were used to assess the relationship between mean daily kitchen CO concentrations and kitchen $PM_{2.5}$ concentrations in order to determine whether all kitchen $PM_{2.5}$ concentrations were as a result of biomass combustion or there were other microenvironment $PM_{2.5}$ sources. One-way ANOVA was used to compare the quantified fuel use from different stoves and further multiple tests of mean separation were done according to Tukey's test of significance at $p < 0.05$.

Findings: The results of the study highlighted that households with improved cookstoves that included the Cheprocket and mud rocket stoves consumed 1.5 kg/day (95% CI: 1.3, 5.8) and 1.3 kg/day (95% CI: 1.2, 5.9) less fuel than households with three-stone stoves respectively. The multiple regression models indicated that well ventilated kitchens ($\beta = 2.556$, SE = 1.646, $p = .036$) using ICS, with cemented floors ($\beta = -.091$, SE = .026, $p = .001$) using Chepkube stove and higher number of windows ($\beta = -4.475$, SE = 2.841, $p = .031$) using Cheprocket stove; ($\beta = -.446$, SE = .042, $p = .030$) using rocket stove; ($\beta = -.045$, SE = .010, $p = .000$) using Chepkube stove were associated with lower kitchen $PM_{2.5}$ concentrations. The study concludes that usage of ICS coupled with efficient designing of the kitchen can improve the overall IAQ of the household along with immense health benefits.

Recommendation: Overall, the study emphasized the need of more user education for improved stoves users for behavioural change to reduce PM and CO kitchen concentrations and exposure.

Keywords: *Indoor air pollution, Improved Cookstove, Particulate Matter, Exposure, Chepkube, Mud rocket stove.*

1.0 INTRODUCTION

The dependence on biomass burning has its origins since ancient times, especially in the developing countries. Biomass fuels are the predominant form of energy in Kenya, used by 90% of households (UNEP, 2003). Households in Kenya, like in other countries, have been reported to consume a mix of different fuel types. In urban areas the mix comprises of biomass in the form of charcoal and fossil fuels such as kerosene and LPG. In rural areas, the mixture comprises of wood and farm and crop residues (Bates, 2005). Biomass fuel demand in Kenya is seen as likely to grow since alternative cleaner commercial energy options for cooking still remains inaccessible to the majority of the potential market. According to Mugo and Gathui (2010), there is an estimated wood fuel deficit of 57.2% in Kenya, which is above Food and Agricultural Organisation (FAO) Critical Scarcity level of 35%. The high deficit is contributed by the use of low efficiency combustion stoves such as traditional three stones, whose level of efficiency can be as low as 15% (Straif *et al.,* 2006). Use of inefficient biomass combustion stoves has significant social, health and environmental implications. Among the social implications include drudgery, physical burden and opportunity costs of spending several hours per day gathering fuelwood (Ochieng *et al.*, 2013; Jyoti, 2011; WHO & UNDP, 2009). Use of biomass fuels on traditional stoves is associated with higher emissions of products of incomplete combustion (PICs) (Quinn *et al.,* 2008; UNEP & WMO, 2011). Biomass fuels also have environmental implications such as land degradation, deforestation and ecosystem degradation in specific areas (Berrueta *et al.,* 2008; Geist & Lambin, 2002; Kirubi *et al.,* 2000; Mugo et al., 2010).

1.1 Improved Cookstove Use

An improved stove is a cooking stove which has been especially/specifically designed to use less fuel, cook food more quickly, and produce less smoke. One example of an improved stove is the Mud Rocket Stove (MRS) found in East Africa. Improved biomass stoves have been used in Kenya for the last three decades initially with the aim of reducing deforestation but recently; they are seen as a potential intervention to reduce HAP (Household Air Pollution) due to biomass fuels use. Kenya has experienced the highest level of improved stove distribution, with 700,000 stoves distributed within the last two decades compared with only 50,000 stoves in Tanzania (Mielnik & Goldemberg, 2000). However, there are countable designs of improved biomass stoves. Some stoves have varied names in different locations as indicated in table 1.

Table 1: Common firewood stoves in Kenya

Stove	Stove Type	Characteristics	Cost (KShs)	Producer
Three Stone	Traditional	Open fire with three stones that support cooking pot	None	Locally available
Chepkube	Traditional	Fixed stove made of clay with single or multiple burners fitted with an oven or food warming cavity, may also be fitted with hatchery for different models	300 – 1,000	Indigenous innovation by the larger Kalenjin women in the North Rift region

Cheprocket	Improved	Fire chamber built using bricks, has fireproof lining then outer walls made of bricks or mud. Also fitted with an oven or food warming cavity, may also be fitted with hatchery for different models	1,000 – 2,000	VI-agro forestry
Maendeleo/ Upesi/ Kuni mbili	Improved	Pottery cylinder (known as liner) which is built into a mud surround in the kitchen or onto a metal encasing	500 - 800	MoE, who have trained local producers
Brick Rocket	Improved	Fire chamber built using bricks, has fireproof lining then outer walls made of bricks.	1,000 – 2,000	Aprovecho. Promoted locally by GTZ
Mud rocket	Improved	Similar to brick rocket stove but the outer wall is made of mud	5,000 - 1,000	Aprovecho. Promoted locally by GTZ
Envirofit	Improved	Metallic stove. There are designs that use both charcoal and firewood	3,500 – 4,000	Aprovecho. Promoted by entrepreneurs

Source: Author

1.2 Indoor Air Quality

Concentration of pollutants emitted from indoor biomass burning depends on various factors such as kitchen characteristics, stove characteristics, type of fuel, quantity of fuel, method of cooking, time-activity profile and ventilation that strongly influence the indoor air quality (IAQ) of the household (Bartington et al., 2017). Three factors greatly determine exposure: firstly, pollutant concentration in the environment, secondly time spent breathing in polluted air and thirdly location and distance from pollution source (Nieuwenhuijsen, 2003). Pollution concentrations can therefore vary temporally and spatially. Exposure also varies from day to day and from subject to subject that is, within and between subject variability. Past burden of disease estimates for indoor air pollution (IAP) related to solid fuel combustion have relied on categorical exposure indicators such as use of comparison between solid biomass fuels to clean fuels such as LPG (Bruce *et al.*, 2004; Bruce *et al.*, 2008; Smith *et al.*, 2007).

In communities that heavily rely on solid biomass fuels, household emission of pollutants can also be a significant contributor to ambient air pollution (Lim *et al.*, 2012). As a result, these communities often suffer from elevated indoor and outdoor air pollution. Household concentrations and personal exposures to air pollutants resulting from solid biomass fuel combustion vary according to a hierarchy of factors such as fuel type, stove type, kitchen area ventilation, quantity of fuel used, age and gender of the exposed person, and time spent near the cooking area (Ezzati & Kammen, 2000). Indoor pollutant concentration alone does not determine the health risk, but rather the personal exposure. Apart from the high emissions that characterize burning biomass fuels in poorly functioning stoves, high levels of exposure result due to the

generally poor ventilation conditions in the kitchens where biomass fuels are burned. These conditions provide very high residence time for the pollutants.

1.3 Relationship between Kitchen Characteristics and Indoor Air Pollution

Women, who are primarily responsible for cooking in the developing countries, are exposed to high smoke concentrations over extended periods of time. Young children are also at risk if they are carried on their mothers' backs or are close to fires during cooking periods (Bruce *et al.,* 2004). The accurate, timely, and efficient assessment of exposures and their sources is therefore an important precondition for reducing and preventing adverse health effects. The most significant issue that concerns indoor air quality in household environments of developing countries is that of exposure to pollutants released during combustion of solid fuels, including biomass such as wood, dung, and crop residues used for cooking and heating. A majority of rural households burn these simple solid fuels in inefficient earthen or metal stoves, or use open pits in poorly ventilated kitchens, resulting in very high concentrations of indoor air pollutants. In many rural households of developing countries, it is common to find kitchens with limited ventilation being used for cooking and other household activities. Even when separated from the adjacent living areas, most offer considerable potential for smoke to diffuse across the house. Use of biomass for space heating creates additional potential for smoke exposure in living areas (WHO, 2007).

Other household characteristics such as kitchen location, ventilation, and kitchen structure are important in terms of air pollution exposures (Balakrishnan *et al.*, 2004). Interventions can only be complementary to changes in pollution source, for instance improved housing and ventilation, and behavioral changes. Pollution from biomass is episodic and peaks account for half of an individual's exposure (Ezzati & Kammen, 2001) therefore an intervention 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. The most common way to address this problem has been to promote the dissemination of more efficient biomass cooking technologies. However, by focusing on technology, many other important aspects of cooking are neglected, such as multiple fuel choices, variety of cooking practices, societal and cultural norms, spillover effects related to cooking, such as space heating and insect repellant. As such, we call for initiatives that focus on 'clean cooking,' where it is not just about having the technology, but using it too; thereby adopting a systems approach to improving cooking practices and harnessing the cross-sectoral linkages.

Another key aspect of reducing pollution during peak hours is assessing the levels of air pollutants to which people are exposed and how these levels vary with different kitchen characteristics. Respirable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) are commonly sampled components of biomass smoke and have been associated with a number of health issues (Balakrishnan *et al.*, 2004). However, few investigations into factors affecting air pollutant levels in households have been conducted in Kenya, a country that depends heavily on biomass fuels (WHO, 2006). Behavioral and cultural factors have also been shown to be predictors of exposure (Albalak *et al.,* 2001). Any evaluation of IAP intervention should therefore take into account kitchen characteristic factors. In Kenya, few studies such as Munyao *et. al,* (2017a) have compared exposures at different cooking periods from different solid biomass fuels and from the traditional Chepkube stove that is widely used in the North rift region and Western part of the country. The main objective of this study was to assess impact of intervention of biomass cookstove

technologies on fuel consumption and compare effects of kitchen characteristics on indoor air quality in rural settings of western, Kenya

2.0 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 comprises five constituencies namely Endebess, Cherangany, Saboti, Kwanza and Kiminini. The county borders the Republic of Uganda to the West, Bungoma and Kakamega Counties to the South, West Pokot County to the East and Elgeyo Marakwet and Uasin Gishu Counties to the South East. The County approximately lies between latitudes $0^{o} 52´$ and $10^{o} 18´$ North of the equator and longitudes $34^{o} 38´$ and $35^{o} 23´$ 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).
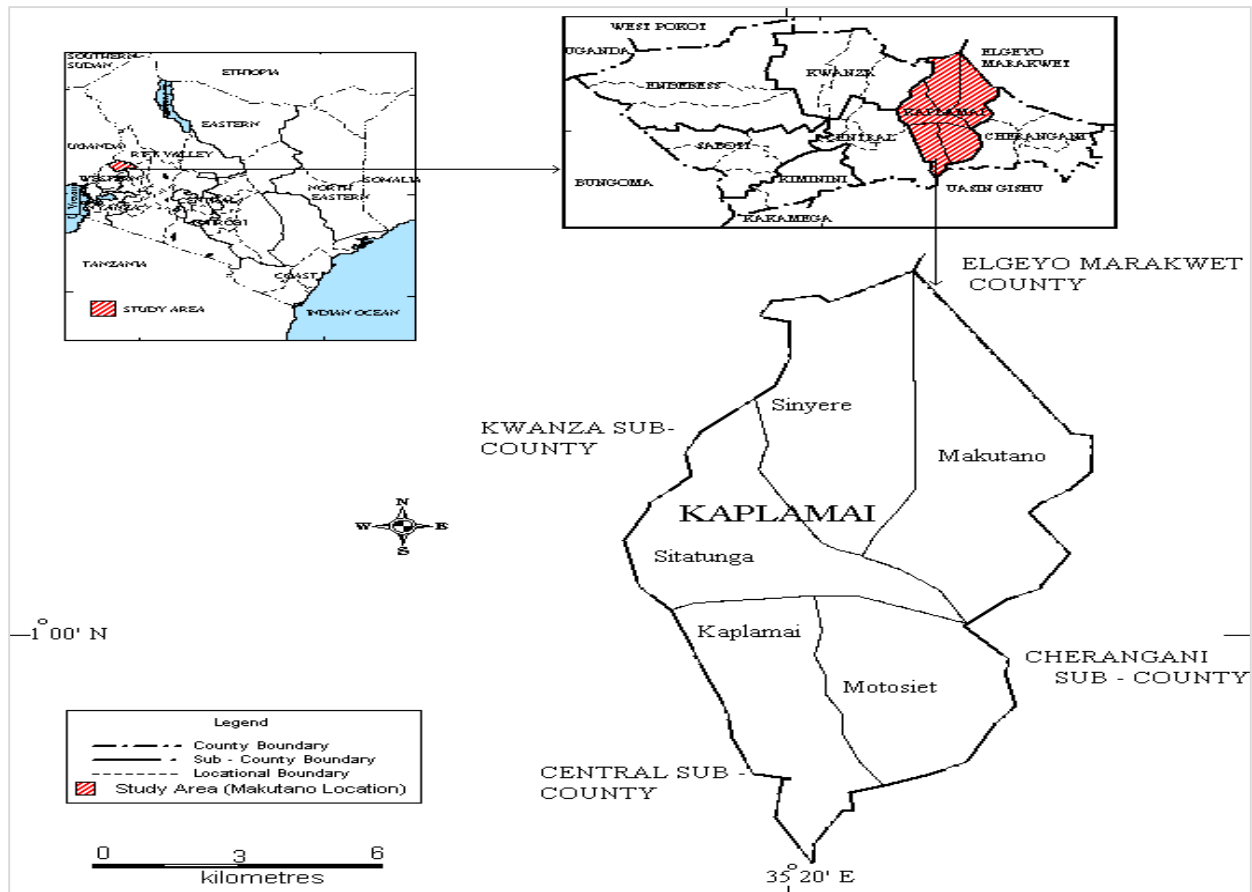

Figure 1: Trans Nzoia County indicating Location of Kaplamai Sub-county

Source: Moi University, 2017

2.1.2 Position and Location of Bungoma County

Bungoma County lies between latitude 0º 28' and latitude 1º 30' North of the Equator, and longitude 34º 20' East and 35º 30' East of the Greenwich Meridian. The County covers an area of 3032.4 km². It boarders the republic of Uganda to the North west, Trans Nzoia County to the North-East, Kakamega County to the East and South East, and Busia County to the West and South West as shown in figure 2.
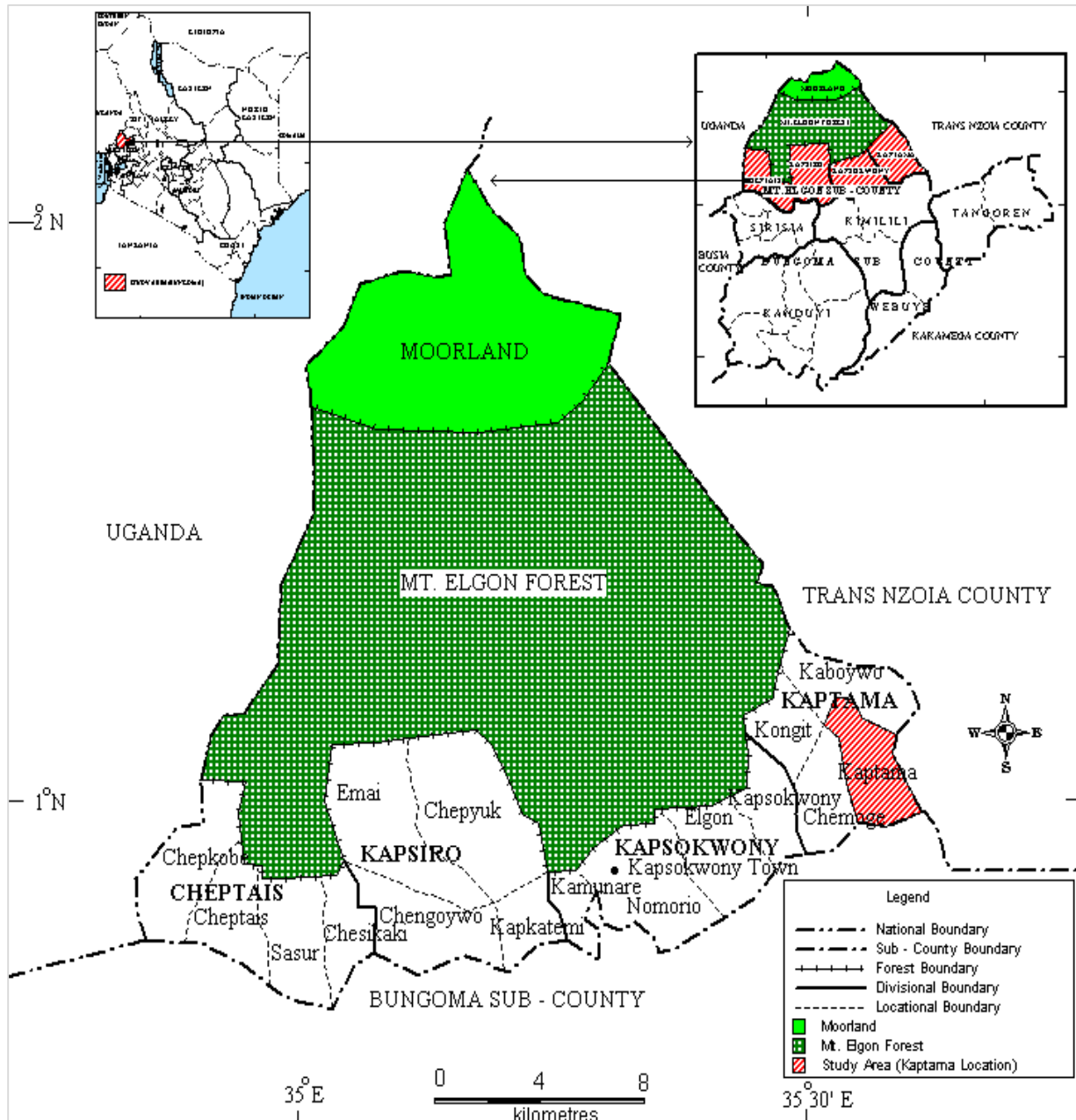

Figure 2: Location of Mt. Elgon Sub-county in Bungoma County

Source: Moi University, 2017

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2.2 Research Design

This research employed cross-sectional study design where there was quantification of indoor air pollution and personal exposure levels of improved biomass stoves users and traditional biomass stove users. Both quantitative and qualitative research methods were applied. Quantitative research method was used during measurement of concentrations of pollutants while qualitative research method entailed use of key informants and observations in order to get opinions regarding biomass stoves. A systematic approach to the study design entailed sampling, data collection through pre-testing of emission meters and revision of questionnaires, data coding and analysis as illustrated in figure 3.
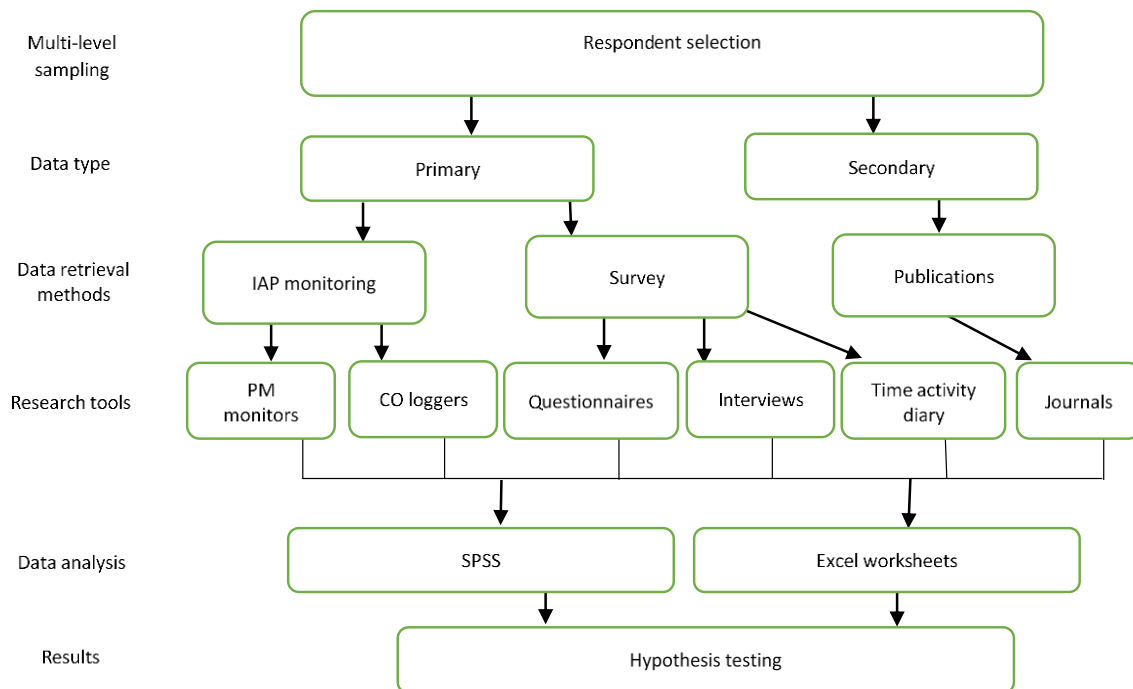

Figure 3: Schematic diagram of the research design

A multi-stage sampling technique was used in this where 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. 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. Stratified cluster sampling was used to select two villages from each sub-location depending on whether training on ecosystem conservation such as on improved biomass stoves, or on tree planting undertaken. Selection of respondents from each village was done using random systematic sampling method where a list of all households in each strata was given; the first household was picked randomly then subsequent respondents picked according to the working function obtained after apportioning the target population. The total target population was 383 households and 204 households were selected as the sample size

for household survey. The sample size was determined using sample size algorithm by Boyd *et al.* (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. A total of 56 HH were selected for indoor air pollution monitoring; 14 rocket stoves, 16 Chepkube stoves, 10 three stone and 16 Cheprocket.

2.3 Data Collection

2.3.1 Questionnaire Surveys

Questionnaires were used to collect information on socio-demographic characterization of households. Questionnaires were administered to the women and family heads in the 204 selected households. They provided information on various household characteristics fuel use, cooking patterns, stoves use and ventilation parameters. Interviews using key informant guide were also used to collect information from opinion and local leaders on stoves adoption matters, area population and government involvement in biomass stoves dissemination. Observation method was used to collect information about stoves design, fuel type used and kitchen characteristics during kitchen emissions monitoring exercise. Focus group discussions using guide questions were held in every village with groups of 8 respondents to validate questionnaire data on cooking activities and kitchen characteristics and use of improved stoves. The discussions concentrated on behavioural practices during cooking, challenges of using improved biomass stoves, cooking behaviours such as warming and chatting after taking supper, durations and number of cooking in a day. This information was useful in discussing fuel use. The FGDs were also helpful in validating related questionnaire responses.

2.3.2 Time-Activity Budget

In each household, the cook was asked to record their activities and location from morning to evening before going to bed as indicated in time activity diary during the day of emissions monitoring. This information was important in establishing other kitchen activities that influenced levels of pollutant concentration and exposure such as food warming, sweeping in kitchens and chatting during or after meals.

2.3.3 Kitchen Air Pollution Monitoring and Performance Test

University of California Berkeley-Particle and Temperature Sensors (UCB-PATS) instruments were used to monitor the levels of $PM_{2.5}$ in the kitchens. The UCB-PATS use smoke detector technology, which combines chambers of photoelectric sensors (of light dispersion) and ionization (loss of ions by particles in suspension). This combination guaranteed precise measurements of fine particles. The light dispersion chamber uses a light emitting diode (LED), with a wavelength of 880 nm, and a photodiode that measures the light intensity scattered in an angle of 45°. Even though the UCB does not select particles, using a device of traditional cut-off size as the cyclones, the photoelectric sensor is more sensitive to particles smaller than 2.5μm aerodynamic diameter (University of California, 2016).

Measurements of kitchen and personal CO concentrations were done using portable EL-USB-CO loggers (Lascar Electronics Ltd, Whiteparish, UK) that measures CO concentrations in real time. The instrument uses an electrochemical sensor, NAP-505 manufactured by Nemoto (2009). It is a battery-operated universal serial bus (USB) data logger that measures and measures mass

concentrations between 1 to 400 mg/m^3 for particles with aerodynamic diameters between 0.1 μm and 2.5 μm. The monitors have an accuracy of ±5% of the reading (University of California, 2003). Real-time signals were measured every second and the average concentration logged every minute, which was subsequently downloaded onto a computer. Both UCB-PATS instrument and CO loggers were launched in kitchens for 24 hours. All the kitchen monitors were placed in a mesh wire basket hanged from the kitchen roof to a height standard of 1.5 m above the ground, which is the average breathing height of a standing woman and young children carried on her back and 2 m from the stove (Moradi, 2006).

The Kitchen Performance Test (KPT) is the principal field–based procedure to demonstrate the effectiveness of stove interventions on household fuel consumption. KPT was conducted to assess variation in fuel use among the two stove groups; improved stoves and traditional stoves. This was done through quantitative surveys of fuel consumption, aimed at demonstrating the differences in consumption of cooking fuels between households using traditional biomass stoves; three-stone stove and Chepkube stove and those using the improved biomass stoves which included mud rocket stoves and Cheprocket stoves. The kitchen performance test was done during the questionnaire survey for one day and further during IAP monitoring for another day. Respondents were asked to set aside fuel enough for the day, then sample of the fuel selected and their moisture taken, which was then averaged and the whole batch weighed. A weighing scale was used to measure the amount of fuelwood used per day then recorded in the questionnaires.

During IAP monitoring, respondents were asked to put aside fuel enough for a day; may be more, then the fuel was weighed before beginning of cooking activities and the weights were recorded on the fuel monitoring sheet. Respondents were asked to keep aside the remaining fuel and not use it. The following day when removing the emission meters, the remaining fuel was weighed, and the difference in fuel before use and remaining fuel computed to provide actual fuel use. Fuel moisture content was also taken during this phase using a moisture meter. A few random batches of the fuels were measured for moisture content, which was then averaged. It is necessary to acknowledge that this test can be subjective because there is mixture of different species of wood with different moisture contents in a fuel batch. It was not practical to measure moisture content for each piece of wood within a batch.

2.4 Data Analysis

Data was analyzed using Statistical Packages for the Social Sciences (SPSS). Kitchen and personal CO measures were computed in to short-term time scales including; 1 hour, 24 hour and long-term time scales. Units of analysis included means, standard deviations, minimum values, median values and maximum values and IQR. Multiple regression analysis was undertaken using SPSS to evaluate the association between pollutant concentration and kitchen characteristics and to determine a set of variables that best predict the pollutants. Determinants included the number of meals cooked and cooking durations, kitchen volume, kitchen floor material, kitchen wall material, size of windows and eave spaces, kitchen connection to main electricity grid. The significance of selected kitchen characteristics' influence on kitchen CO and PM$_{2.5}$ concentrations was indicated using *p* value. F-test was used to show significance of prediction models. Tables were used to present results. Spearman's rank correlation coefficients (*r*) were used to assess the relationship between mean daily kitchen CO concentrations and kitchen PM$_{2.5}$ concentrations in order to determine whether all kitchen PM$_{2.5}$ concentrations were as a result of biomass combustion or

there were other microenvironment PM$_{2.5}$ sources. One-way ANOVA was further used to compare the quantified fuel use from different stoves and further multiple tests of mean separation were done according to Tukey's test of significance at $p < 0.05$. Tables and means were used to present results.

2.5 Ethical Considerations

Informed consent was obtained from all study participants, and participation in the study was voluntary. All the data was made anonymous using unique letter identifiers. Individual informed consent from respondents in households participating in the study was sought. In addition, permission to place our monitors within sampled houses was obtained from the respondent or an adult member of the household.

3.0 RESULTS

3.1 Cooking Fuel Use

Firewood and crop residues are the main cooking fuel types used in the study area at 97.1% and 83.3% respectively, as indicated in table 2. Crop residues are seasonal and mainly used during the dry season after harvesting crops or when available.

Table 2: Cooking fuel types

Fuel Type	N = 204	%	*p* value
LPG	12	5.9	0.001
Biogas	8	3.9	
Charcoal	46	22.5	
Firewood	198	97.1	
Crop residues	170	83.3	
Electricity	0	0	

Source: Author

The main source of firewood was nearby protected forests accounting for 62.6%, then owned farm forests accounting for 31.3% and other privately owned forests were the least sources of fuelwood at 6.1% for those who did not own farms or had minimal land size. A majority 57.6% of people covered a distance of one to three kilometers to acquire their fuelwood. All crop residues were obtained from own farms. Chepkube stove was significantly associated with lower fuel use than mud rocket and Cheprocket stoves. The distribution of fuelwood use by stove type is shown in table 3.

Table 3: Average daily firewood use (kgs) in different biomass stoves

Stove type	Mean	Std. deviation	Minimum	Maximum
Three-stone	10.1 a	4.6	4.3 a	25.8 a
Chepkube	7.3 b	3.4	3.2 b	22.2 b
Cheprocket	8.6 c	3.2	3.0 b	20.0 c
Mud rocket	8.8 c	3.1	3.1 b	19.9 c

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

Households with improved cookstoves that included the Cheprocket and mud rocket stoves consumed 1.5 kg/day (95% CI: 1.3, 5.8) and 1.3 kg/day (95% CI: 1.2, 5.9) less fuel than households with three-stone stoves respectively. Households using Chepkube stove consumed 2.8 kg/day (95% CI: 1.1, 3.6) less compared to three-stone stove. The reported fuel consumption amounts were within the national daily fuelwood consumption of 8.3 kg/day to 10.5 kg/day. Fuel saving from mud rocket stove, Cheprocket stove and Chepkube stove compared to three-stone stove are significant and can make an impact in environmental conservation. Chepkube stoves have the potential of saving 243 000 tonnes of fuelwood in the region within one year. Mud rocket stoves has the potential of saving approximately15,000 tonnes of fuelwood per year from the forests while Cheprocket stove can save approximately 23,000 tonnes of fuelwood per year in the region. Fuelwood consumption per day per person using Chepkube stove was 1.55kg, using mud rocket stove it was 1.88kg, while using Cheprocket stove it was 1.87kg and using three-stone stove had the highest fuel consumption at 1.98kg/person/day. The amount of crop residues consumed for all stoves was significantly higher than fuelwood due to the low calorific values of crop residues especially maize stalks. Crop residues consumption for all stoves was as indicated in table 4.

Table 4: Average daily crop residues use (kgs) in different biomass stoves

Stove Type	Mean	Std. deviation	Minimum	Maximum
Three-stone	12.3 a	6.4	6.5 a	28.2 a
Chepkube	9.4 b	5.4	5.1 b	24.5 b
Cheprocket	10.6 c	5.6	5.6 b	22.1 c
Mud rocket	11.8 c	5.1	5.2 b	22.3 c

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

Variations in fuel use was influenced by moisture content, cooking duration, and number of adult equivalent in the households. After accounting for fuel moisture content, age of the household members, number of people cooked for and cooking duration, strongly influenced the amount of fuel used daily. Households with children below five years used 1.6 kg/day more fuelwood compared to HH whose majority aged between 18 and 35 years among all the stoves. The average number of meals cooked in the region were not significantly different. However, Chepkube and Cheprocket stoves had the least cooking duration compared to three stone-stove and MRS. As indicated in table 5. Fuelwood used in MRS had the least moisture content because during installation trainings, most household members were trained on drying of wood in order to improve the performance of the stove.

Table 5: Determinants of fuel use

| Determinant | Stoves | | | |
	Three-stone	Chepkube	Cheprocket	Mud rocket
No. of adult equivalents per meal	4.7 ± 1.7 a	4.2 ± 1.9 b	4.2 ± 1.7 b	4.2 ± 1.7 b
Number of meals cooked per day	3.1 ± 1.2 a	2.8 ± 0.7 a	2.7 ± 0.9 a	2.8 ± 0.8 a
Moisture content, wet basis (%)	18.5 ± 6.8 a	17.7 ± 4.3 b	19.5 ± 5.5 c	16.9 ± 8.1 d
Average cooking duration in minutes	198 ± 114 a	185 ± 103 b	187 ± 96 b	216 ± 98 c

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

High moisture content, prolonged cooking duration and increased number of household members were associated with higher fuel use in all the stoves. The number of meals cooked were not significantly varied for all stove types.

3.2 Relationship between Kitchen Characteristics and Indoor air Pollution

3.2.1 Correlation between 24-hour PM$_{2.5}$ and CO Concentrations

It was necessary to undertake correlation between kitchen PM$_{2.5}$ and CO concentrations in order to ascertain whether the kitchen PM$_{2.5}$ recorded was as a result of biomass fuels use and combustion or there were other indoor sources. A 24-hour average CO and PM$_{2.5}$ concentrations using firewood as fuel were moderately correlated for all stoves using firewood; mud rocket stove ($r = 0.514$; $p < 0.001$), Cheprocket stove ($r = 0.471$; $p < 0.001$) but weakly correlated using crop residue as fuel in all stoves; mud rocket stove($r = 0.070$; $p < 0.001$) as indicated in table 6.

Table 6: Correlation of PM$_{2.5}$ and CO concentrations

Stoves	Firewood		Crop residues	
	R	p value (two-tailed)	r	p value (two-tailed)
Rocket	0.514	0.001*	0.070	0.001*
Cheprocket	0.471	0.001*	0.381	0.001*
Chepkube	0.415	0.001*	0.294	0.001*
Three stone	0.362	0.001*	0.398	0.001*

*correlation was significant at the 0.01 level.

Weak correlation between PM$_{2.5}$ and CO was a clear indication that the extremely high PM$_{2.5}$ concentrations were also contributed by other external factors other than biomass fuel combustion alone in the kitchen environments. Some of the possible kitchen characteristics leading to increased PM$_{2.5}$ kitchen concentrations are discussed in kitchen characteristics section below.

3.2.2 Kitchen Characteristics

The most popular biomass stove type was the traditional three-stone at 52.1%, followed by Chepkube stove illustrated in figure 4 at 30.8%, then Cheprocket stove (Plate 1) at 8.9% and mud rocket stove (Plate 2) was least used at 8.2%. Chepkube stove had increased air inlet compared to MRS and Cheprocket stoves as indicated in figure 4.
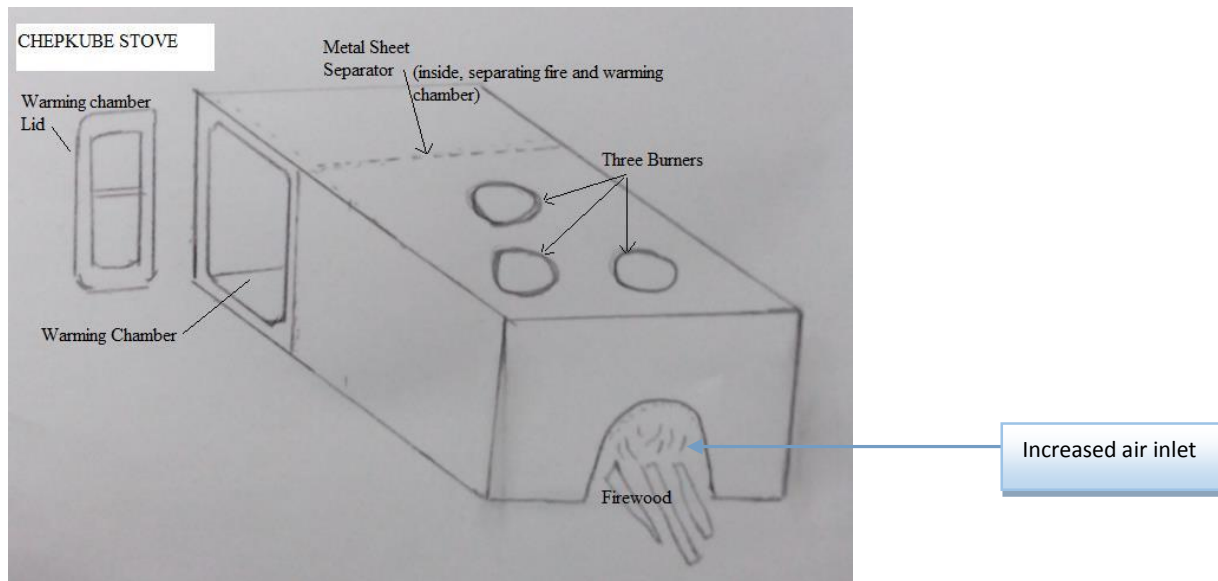
Figure 4: Schematic diagram of Chepkube Stove

Source: Munyao et. al., 2017a

Cheprocket stove had an increased height due to installation of a chick brooder below the combustion chamber as illustrated in plate 1.
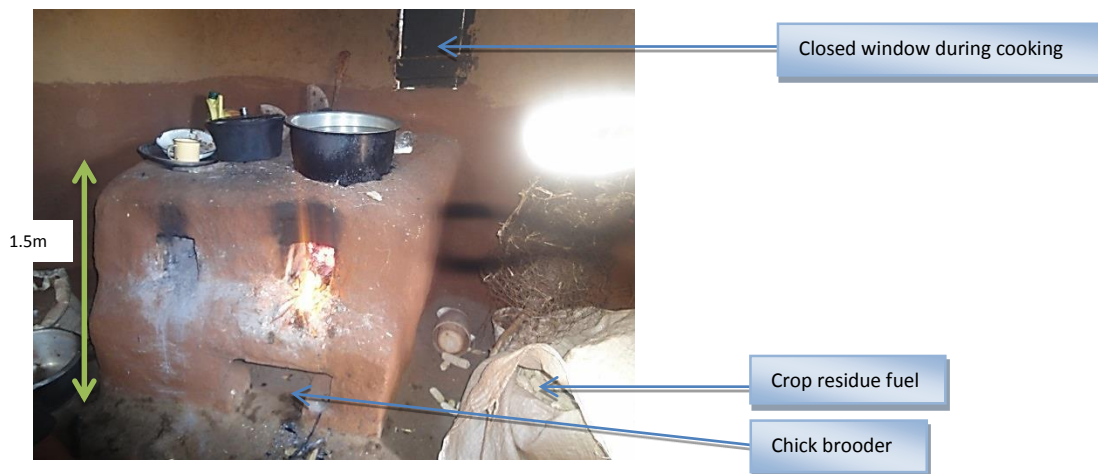

Plate 1: Typical Cheprocket stove

Source: Munyao et al., 2017a

The height of MRS was lower compared to the Cheprocket stove and therefore necessitated bending during cooking as illustrated in plate 2.
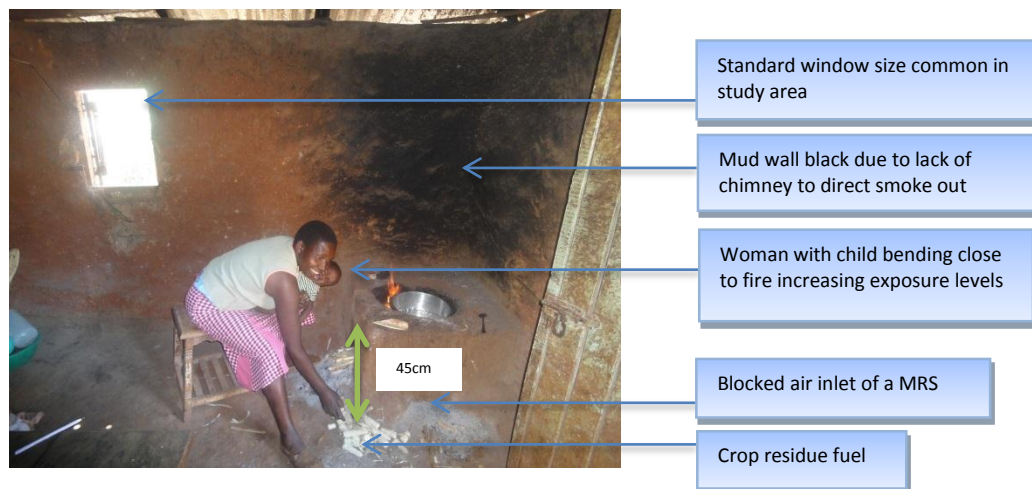
Plate 2: Mud Rocket stove in a typical Kitchen

Source: Munyao et al., 2017a

The highest used fuels were wood and crop residues at 97.1% and 88.7% respectively. Multiple stove usage was common in the households. The majority of households had separate outdoor kitchens at 91.5% for households with rocket stove, 84.6% for households with Cheprocket stove, 88.9% for households with Chepkube stove and 84.1% for households with three-stone stove as indicated in table 7. The main kitchen size was 16.0 m^2 (n = 51, 46.8%); with a dung floor material (n = 170, 83.3%), fitted with two windows (n = 83, 40.6%) whose size was 4ft^2 (n = 120, 59%) as indicated in Table 3.6. At least one of the windows and doors were generally open most of the day especially during cooking. None of the kitchens or stoves had chimneys. The placement of outdoor kitchens varied, with some located next to a wall, in a partially enclosed area or as a free standing structure in the courtyard. The mean number of meals cooked on the day of $PM_{2.5}$ and CO monitoring was 3.4 (95 % CI, 2.8 – 4.7) and the mean time spent in the kitchen on the day of monitoring was 6.2 hours (95% CI, 4.5 – 7.9). Cooking generally occurred in the mornings and at midday and in the evenings.

Table 7: Kitchen characteristics

Kitchen Characteristics		Rocket stove N = 17 n (%)	Cheprocket N = 18 n (%)	Chepkube N = 63 n (%)	Three stone N = 106 n (%)	Average N = 204 n (%)
Location of the kitchen	Open kitchen (OK)	(0) 0.0	(0) 0.0	(0) 0.0	(6) 5.3	(3) 1.3
	Separate Outdoor Kitchen (SOK)	(16) 91.7	(15) 84.6	(56) 88.9	(88) 84.1	(178) 87.3
	Indoor Kitchen with Partition from the rest of the living area (IKWP)	(1) 8.3	(3) 15.4	(1) 2.2	(6) 5.3	(16) 7.9
	Indoor Kitchen without Partition from the rest of the living area (IKWOP)	(0) 0.0	(0) 0.0	(6) 8.9	(6) 5.3	(7) 3.5
	6M by 6M	(1) 8.3	(6) 30.8	(21) 33.3	(29) 27.0	(51) 24.9

Size of the kitchen	4M by 4M	(9) 50.0	(6) 30.8	(32) 51.1	(59) 55.4	(95) 46.8
	3M by 3M	(7) 41.7	(7) 38.4	(10) 15.6	(18) 17.6	(58) 28.3
Kitchen floor Material	Dung	(15) 83.3	(11) 61.5	(57) 91.1	(103) 97.3	(170) 83.3
	Cement	(2) 16.7	(7) 38.5	(6) 8.9	(3) 2.7	(34) 16.7
Number of kitchen windows	One	(6) 33.3	(6) 30.8	(11) 17.8	(26) 24.3	(54) 26.6
	Two	(4) 25.0	(10) 53.8	(24) 37.8	(49) 46.0	(83) 40.6
	Three	(7) 41.7	(2) 15.4	(28) 44.4	(31) 29.7	(67) 32.8
Size of kitchen window size	1ft by 1ft	(2) 16.7	(0) 0.0	(4) 6.7	(11) 10.8	(17) 8.5
	2ft by 2ft	(6) 33.3	(11) 61.5	(44) 69.8	(76) 71.6	(120) 59.0
	3ft by 3ft	(9) 50.0	(7) 38.5	(15) 24.5	(19) 17.6	(67) 32.5
Duration taken in cooking breakfast	Less than 15 minutes	(11) 66.7	(11) 61.5	(7) 11.1	(24) 22.4	(83) 40.5
	Between 16 and 30 minutes	(6) 33.3	(7) 38.5	(53) 84.5	(80) 75.0	(118) 57.8
	Between 31 and 45 minutes	(0) 0.0	(0) 0.0	(3) 4.4	(2) 2.6	(3) 1.7
Duration taken in cooking lunch	Between 16 and 30 minutes	(4) 25.0	(8) 46.2	(0) 0.0	(4) 3.9	(38) 18.8
	Between 31 and 45 minutes	(7) 41.7	(6) 30.8	(26) 42.2	(42) 39.5	(79) 38.6
	Between 46 and 60 minutes	(2) 8.3	(0) 0.0	(35) 55.6	(43) 40.8	(53) 26.1
	Above 60 minutes	(4) 25.0	(4) 23.0	(2) 2.2	(17) 15.8	(34) 16.5
Duration taken in cooking supper	Less than 15 minutes	(0) 0.0	(1) 7.7	(0) 0.0	(0) 0.0	(4) 1.9
	Between 16 and 30 minutes	(4) 25.0	(7) 38.5	(0) 0.0	(4) 3.9	(34) 16.8
	Between 31 and 45 minutes	(6) 33.3	(6) 30.8	(24) 37.8	(39) 36.8	(71) 34.6
	Between 46 and 60 minutes	(4) 25.0	(0) 0.0	(35) 55.6	(46) 43.4	(63) 31.0
	Above 60 minutes	(3) 16.7	(4) 23.1	(4) 6.7	(17) 15.8	(32) 15.5

3.2.3 Multiple Regression Analysis of Kitchen Characteristics and PM$_{2.5}$ Concentration

Several variables were found to be associated with kitchen PM$_{2.5}$ using different stoves using multiple regressions and a significance level of 0.05 as indicated in table 8.

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Table 8: Association of kitchen characteristics with PM$_{2.5}$ concentration

	Cheprocket stove			Three stone stove			Chepkube stove			Mud rocket stove		
	Unstandardized Coefficients			Unstandardized Coefficients			Unstandardized Coefficients			Unstandardized Coefficients		
	β	Std. Error	p value	β	Std. Error	p value	β	Std. Error	p value	β	Std. Error	p value
(Constant)	67.394	25.320	.006	93.245	18.940	.006	15.268	.115	.023	61.962	.231	.000
Location of the kitchen	8.823	3.835	.032	2.993	1.738	.087	.052	.012	.000	3.173	.099	.056
Status of kitchen ventilation	2.556	1.646	.036	5.090	2.261	.026	.083	.019	.000	1.484	.050	.005
Size of the kitchen	-3.421	1.818	.055	-1.641	1.484	.071	-.044	.009	.078	-.004	.072	.256
Material of kitchen floor	-	-	-	-12.898	4.525	.005	-.091	.026	.001	-	-	-
Number of kitchen windows	-4.475	2.841	.031	-6.705	1.445	.000	-.045	.010	.000	-.446	.042	.030
Size of kitchen window	-18.845	6.412	.581	-2.660	1.575	.004	-.019	.009	.330	-.228	.048	.993
Frequency of cooking	7.318	4.042	.015	1.182	.995	.007	.051	.012	.000	.089	.023	.021
Duration taken in cooking breakfast	9.310	5.539	.008	4.154	1.934	.004	.032	.014	.027	1.333	.055	.007
Duration taken in cooking lunch	3.096	3.379	.000	4.434	3.090	.054	.108	.029	.000	2.341	.071	.400
Duration taken in cooking supper	2.338	3.402	.000	3.849	2.956	.095	.062	.025	.014	1.775	.070	.102
Duration taken in warming food	-	-	-	10.690	4.681	.024	.111	.041	.009	-	-	-
Duration taken in warming water	6.861	2.833	.005	8.009	3.231	.015	.010	.017	.573	2.913	.081	.958

Connectivity to main grid	6.060	2.661	.004	22.161	7.868	.006	.069	.033	.038	2.169	.051	.048

The multiple regression models produced using various stoves were significant; mud rocket stoves was (R^2 = .857, F (11, 16) = 3.111, p = .003), Cheprocket stoves was R^2 = .714, F (11, 17) = 4.538, p = .002, three stone stove was R^2 = .275, F (13, 105) = 3.711, p = .000 and Chepkube stove was R^2 = .672, F (13, 62) = 10.550, p = .000. From Table 4.9, results indicated that well ventilated kitchens (β = 2.556, SE = 1.646, p = .036) using Cheprocket stove; (β = 5.090, SE = 2.261, p = .026) using three stone; (β =1.484, SE = .050, p = .005) using mud rocket stove; (β = .083, SE = 019, p = .000) using Chepkube stove, with cemented floors (β = -12.898, SE = 4.525, p = .005) using three stone stove; (β = -.091, SE = .026, p = .001) using Chepkube stove and higher number of windows (β = -4.475, SE = 2.841, p = .031) using Cheprocket stove; (β = -6.705, SE = 1.445, p = .000) using three stone; (β = -.446, SE = .042, p = .030) using rocket stove; (β = -.045, SE = .010, p = .000) using Chepkube stove were associated with lower kitchen $PM_{2.5}$ concentrations as indicate in Table 3.7. In addition, separate outdoor kitchens were associated with lower $PM_{2.5}$ levels compared to indoor kitchens with partitions from the rest of the living area and outdoor kitchen for all the kitchens using different stoves.

On the other hand, increased number of cooking (β = 7.318, SE = 4.042, p = .015) using Cheprocket stove; (β = 1.118, SE = .995, p = .007) using three stone; (β =0.089, SE = .023, p = .021) using rocket stove; (β = .051, SE = .012, p = .000) using Chepkube stove, and poor ventilation in kitchens were associated with increased kitchen PM concentrations. Other kitchen and household characteristics such as kitchen window size (β = -18.845, SE = 6.412, p = .581) using Cheprocket stove; (β = -.019, SE = .009, p = .330) using Chepkube stove; (β = -.228, SE = .048, p = .993) using mud rocket stove, duration taken in warming water (β = 2.913, SE = .081, p = .958) using mud rocket stove; (β = .010, SE = .017, p = .573) using Chepkube stove and kitchen size, were not significantly associated with kitchen $PM_{2.5}$ concentrations as indicated in table 8.

3.2.4 Multiple Regression Analysis of Kitchen Characteristics and CO Concentration

The multiple regression models produced using various stoves were not significant; for mud rocket stoves, it was (R^2 = .232, F (10, 16) = .513, p = .858), for Cheprocket stoves, it was (R^2 = .261, F (10, 17) = .642, p = .774), for three-stone stove, it was (R^2 = .084, F (10, 105) = 1.224, p = .281) and for Chepkube stoves, it was (R^2 = .086, F (10, 62) = .702, p = .719). There was no kitchen variable found to be associated with kitchen CO concentrations for different stoves using multiple regressions at a significance level of 0.05 as indicated in table 9.

Table 9: Association of kitchen characteristics with CO concentration

	Three- stone stove			Chepkube stove			MRS			Cheprocket stove		
	Unstandardized coefficients			Unstandardized coefficients			Unstandardized coefficients			Unstandardized coefficients		
	β	Std. Error	p value	β	Std. Error	p value	β	Std. Error	p value	β	Std. Error	p value
(Constant)	18.817	4.964	.028	8.885	6.003	.490	6.671	1.631	.927	9.685	2.194	.711
Cooking in a day	2.339	3.597	.517	10.683	7.260	.145	1.515	3.395	.661	4.413	39.782	.913
Duration of cooking breakfast	.689	7.080	.923	12.175	9.303	.195	3.689	8.369	.665	7.065	54.513	.898
Duration of cooking lunch	21.192	10.049	.337	10.021	14.926	.504	5.224	10.900	.638	9.788	33.253	.772
Duration of cooking supper	12.920	10.125	.204	9.096	14.250	.525	5.293	12.373	.674	10.726	33.478	.752
Duration of warming water	-4.161	5.799	.474	-16.178	7.424	.032	-1.989	20.088	.922	-6.542	27.879	.817
Location of kitchen	7.067	6.017	.242	12.877	8.034	.113	7.016	16.928	.684	10.203	37.746	.790
Size of kitchen	-.138	5.047	.978	-5.476	6.666	.414	-1.077	9.205	.908	-.807	17.892	.964
Number of kitchen windows	-2.925	3.912	.456	-6.946	5.178	.184	-.697	6.282	.913	-.207	27.963	.994
Size of kitchen window size	-.331	5.172	.949	-4.406	6.206	.480	-3.292	4.693	.493	-21.046	63.108	.742
Connectivity to main grid	-28.029	19.572	.154	-2.381	16.250	.884	-.590	8.617	.946	-10.121	26.189	.703

At 95% confidence level, results indicated that none of the predictor variables were found to be significant. Increased number of cooking, durations taken in warming food and water, cooking durations, size and location of kitchens using the different stoves were not significant variables to predict concentrations of kitchen CO as p values of all coefficients were above 0.05 as indicated in table 9.

4.0 DISCUSSION

4.1 Fuel Use Efficiency

This study found that variation in fuel use was related to the type of stove used, with Chepkube stove consuming substantially less fuel than mud rocket stoves and Cheprocket stoves and the traditional three-stone stoves. This could be as a result of food warming compartment among the Chepkube stoves which enabled some foods such as ugali (solid mixture of boiling water and maize flour) to be half cooked then put in the warming compartment to continue cooking as the fire simmered. Although Cheprocket stoves were also fitted with food warming compartments, poor air circulation in to the firing chamber reduced the stoves performance hence the increased fuel use in the stove. Most cooks using Cheprocket stoves used firewood with higher moisture content leading to reduced combustion of the fuel therefore higher fuel usage. This implies that Cheprocket stove users were not equipped with stove-user education which builds capacity on type of fuel, fuel selection and processing and stove maintenance for optimal performance of the stove.

Mud rocket stove; although a stove with improved combustion principles consumed more fuel because of user behavior. Users were not removing ash from previous cooking at the air inlet leading to blockage and poor air supply in to the firing chamber. Improved biomass stoves and the Chepkube stove were found to use significantly less fuel compared to three-stone stove; a finding that is of similar opinion as McCracken and Smith (1998), Granderson *et al*. (2009) and Ochieng *et al.* (2013). The less fuel consumed by mud rocket stoves were comparable to findings reported by other studies (McCracken & Smith, 1998; Jetter & Kariher, 2009; Edwin *et al.,* 2010; Ochieng *et al.,* 2013). Findings in this study were also in agreement with Mugo *et al.* (2010) that fuelwood in areas adjacent to protected forests are sourced mainly from indigenous vegetation such as bush lands in the forests, followed by farmlands and plantations around.

Fuel from indigenous vegetation is lower in quantity compared to cutting of trees in farms and plantations. This implies that the frequency of travelling to and from the forest is increased especially where the amount of fuelwood consumed per day is more. Increased time for collecting firewood affects negatively the development of children by consuming most of their time which would otherwise be for playing. For people farther away from the forest, more money is spent buying the fuelwood since they are unable to collect the fuel personally. Therefore it is necessary to build capacity in the region the importance of establishing farm forest which would help in reducing time and money spent in acquiring fuelwood. Cooking duration emerged as a strong predictor of fuel use in this study contrary to Ochieng *et al.* (2013) probably because of the designs of Chepkube and Cheprocket stoves that included the food warmers hence reduced cooking durations.

Fuel moisture content was a strong determinant that influenced amount of daily fuelwood used; a finding that was similar to Ochieng *et al.* (2013). High moisture content in wood was associated with high fuel use as most of the energy in the wood was used to dry the wood instead of heating food. Very few studies have been undertaken to assess household fuel use by conducting KPTs in Kenya (Ochieng *et al.*, 2013; Ezaati, 2000) since most studies have assessed fuel use in controlled cooking environments. However results from controlled environments are not comparable to KPTs, because fuel saving estimates based on these tests are not fully representative of daily cooking activities under real kitchen scenarios that KPTs aim to assess (Johnson *et al*., 2010). It

was difficult to compare fuel use with other regions because of variations in stove designs, user behavoir of the cooks, meal types, fuel types and other cultural characteristics.

The main study finding was that the Chepkube stove used less fuel than the improved biomass stoves that were disseminated by NGO and other agencies in the region. This finding has an important implications for policy and programmes that aim to relieve the burden of fuelwood collection and costs associated with it and in local environmental impacts of fuelwood collection. The significant reduction in fuel use observed in this study could also lead to reduced vegetation loss at local level. Chepkube stoves has the potential of saving 243 000 tonnes of fuelwood in the region within one year. Rocket stoves has the potential of saving approximately15,000 tonnes of fuelwood per year from the forests while Cheprocket stoves can save approximately 23,000 tonnes of fuelwood per year in the region. In rural settings where biomass fuel use leads to deforestation, our estimates of fuel use reduction from Chepkube stove, mud rocket stove and Cheprocket stove use could contribute towards curbing deforestation. Other benefits such as climate change mitigation and improved health; discussed more in later sections could also accrue from reduced fuel use.

4.2 Indoor Air Pollution and Kitchen Characteristics

It was found that well ventilated kitchens with cemented floors and increased number of windows were negatively associated with $PM_{2.5}$ concentrations. This is because particulate matter could be easily diluted by air circulating through the windows, while cemented floors reduce the amount of dust rising from earthen floors. The study observed higher average pollutant concentrations associated with mud wall composition, suggesting a role of micro-environmental factors on overall average kitchen $PM_{2.5}$ concentrations. Contrary to Yamamoto *et al.* (2014), who reported that households with larger kitchens appeared to have higher mean $PM_{2.5}$ and CO concentrations than those with a smaller floor surface, this study found that kitchens size was not significantly associated with $PM_{2.5}$ and CO concentrations in all kitchens using both improved and traditional biomass stoves. Other kitchen and household characteristics such as smaller kitchen window size, lack of connectivity to main grid, increased duration taken in warming water, were positively associated with kitchen $PM_{2.5}$ concentrations, similar to findings reported by Bruce *et al.* (2004) and Munyao *et al.* (2017b). Failure to connect to the main electricity grid means that households would use alternative lighting methods at night such as use of lamps or fires that are more sources of $PM_{2.5}$. Similarly, Dasgupta *et al.* (2006) found that ventilation, as influenced by household construction, was a significant factor that affected PM_{10} concentrations.

Similar to what was reported in this study, Suzzanne *et al.* (2013) found that the number of cooking hours on a typical day ranging from 1 to 6 hours were positively associated with increased 24-hour PM concentrations. In addition, Baumgartner *et al.* (2011) found a significant association between $PM_{2.5}$ exposure and ventilation in households in rural China. Consistent with findings in this study, Akunne *et al.* (2006) suggested that shifting cooking activities outdoors and thereby increasing ventilation could reduce the fraction of acute respiratory infections in children attributable to biomass smoke exposure in Nouna. An important finding of this study, however, was that even though outdoor kitchens were associated with much lower $PM_{2.5}$ levels, concentrations were still unacceptably high, which suggests that the promotion of improved stove alone did not achieve the objective of emissions reduction therefore improved fuel and improved kitchens with less sources of $PM_{2.5}$ may be necessary to tackle IAP.

The low correlation between kitchen CO and $PM_{2.5}$ concentrations reported during cooking sessions were comparable to correlations reported by Barington (2017) in Dhanusha region of Nepal but contrary to Lin *et al.* (2012) who reported a correlation coefficient of 0.92 between CO and $PM_{2.5}$ concentrations using wood fuel in Guatemala. The low correlation between hourly kitchen CO and PM concentrations reported in this study were similar to findings reported by others (Naeher *et al.,* 2001; Zuk *et al.,* 2007; Cynthia *et al.,* 2008; Smith *et al.,* 2010; Dionisio *et al.,* 2012). The moderate correlation confirmed that there were other sources of $PM_{2.5}$ present in rural kitchen contributing to the extremely high levels of concentrations. Similarly, investigators in Burkina Faso reported a weak correlation (Spearman $r = 0.22$) between PM_{10} and CO (Yamamoto *et al.,* 2014).

Findings in this study were, however, contrary to Naeher *et al.* (2001) and Bruce *et al.* (2004) who both suggested that CO concentrations correlate well with PM concentrations and since they are generally easier and more cost-effective to measure than PM, they both suggested that CO measurements alone could be used to reduce costs during exposure assessments and make it possible to study increasingly larger sample sizes. More recently, Smith *et al.* (2010) also supported their findings. This study suggests that carbon monoxide has limited utility as a proxy measure for accurate $PM_{2.5}$ exposure assessment in similar traditional domestic settings due to possible external sources of $PM_{2.5}$ in rural kitchens other than from biomass combustion.

The variations in CO and PM correlation may be explained by the local cooking characteristics, including fuel type and cooking style or influences of the local microenvironment. According to Klasen *et al.* (2015), there is greater discordance at low pollutant concentrations and high PM variability for a single CO concentration suggesting a complex relationship between the two pollutants that is determined by a range of local factors such as kitchen characteristics and cultural practices. Naeher *et al.* (2001) also observed that the PM-CO relationship may be determined by housing characteristics and stove conditions that differentially influence the emission and dispersal of particle and gaseous pollutants. Although according to Northcross *et al.* (2015) CO has been applied as a surrogate measure of PM. Findings from this study suggest limited utility as a proxy measure concentration in rural kitchen settings. Furthermore, individual pollutant measurements are more informative for assessing different health risks, with $PM_{2.5}$ widely associated with respiratory conditions and increasing evidence regarding an association between high CO exposure and adverse cardiovascular, neuro-developmental and feotal outcomes (Mustafic *et al.,* 2012).

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study concluded that improved cookstoves led to substantial reduction in fuel consumption compared to traditional three-stone stoves in rural Kenya and thus contribute to environmental conservation. High reliance on traditional biomass fuels with low combustion efficiency contributed to high levels of kitchen $PM_{2.5}$ concentrations, which are more damaging to health.

Traditional Chepkube stove; a local innovation among the Kalenjin community is an improved biomass technology capable of saving more fuel and emitting lesser $PM_{2.5}$ and CO emissions from biomass combustion compared to mud rocket stove and Cheprocket stoves; long perceived improved biomass stoves.

Poor kitchen practices such as lack of 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, Improved housing materials such as cemented floor, concrete walls, proper kitchen ventilation, and behavioral changes such as cooking with open windows, wetting the earthen floor before sweeping are necessary and may reduce if not eliminate other kitchen PM sources.

5.2 Recommendation

1. User education by county governments and non-governmental organisations is necessary for improved stoves users for behavioural change to reduce PM and CO kitchen concentrations and exposure.

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