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Abstract

Purpose: The use of biomass fuels poses great threats to environmental degradation and public health risk accounting for 32% of the total attributable burden of diseases due to indoor air pollution (IAP) in especially Africa. Heavy reliance on biomass fuels for household energy in Kenya makes the country more vulnerable with 90% of the rural population relying on biomass fuels for domestic purposes. The objective of this study was to assess cooking fuel types and efficiency of improved biomass stoves in fuel consumption in Western, Kenya.

Methodology: The data were collected through continuous real-time monitoring of kitchen Particulate Matter and Carbon II Oxide concentration for a period of 24 hours using UCB-PATS and CO monitors, questionnaires and time activity budgets. The total target population was 383 households and 204 households were selected as the sample size for HH 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. Tables and means were used to present results.

Findings: The study found that Hazard quotients (HQ) for both long-term and short-term PM exposure using all stoves were all above 1 implying that health risk is real. During 24-hour cooking duration, three-stone stove using crop residues produced 145.8 times higher $PM_{2.5}$ compared to RfD (Reference Dose) value while Cheprocket produced 26.4 times higher than $PM_{2.5}$ RfD. People using solid biomass fuels are likely to experience headaches and running nose by the end of 24-hour period as a result of CO exposure when mud rocket stove, three stone stove and Cheprocket stoves were used. However cooks who use Chepkube stoves are not likely to experience any adverse health effects from CO exposures since the HQs were less than 1 using both wood and crop residues as fuel. The study concluded that, improved biomass stoves provided an overall reduction in pollutant concentration compared to three-stone fire but the local innovation Chepkube stove that has been classified as ungraded stove had the highest pollutant reduction. There is no health risk associated with exposure to peak CO within the 1-hour duration from all biomass stoves monitored in the study area.

Recommendation: The study recommended that user education is necessary on kitchen practices to reduce overall exposure from improved stove utilization.

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

1.0 INTRODUCTION

Household air pollution (HAP) from cooking with solid fuels has adverse health effects (Abdo et al., 2021). Improved biomass stoves have been long promoted with the aim of addressing energy and environmental issues such as indoor air pollution (Munyao *et al.*, 2017a), fuelwood shortages, deforestation and desertification (Smith *et al.*, 2007). Evaluation of their success has thus been based on energy consumption efficiency (Bruce *et al.*, 2000). Most of the information currently available relates to impacts on fuel consumption rather than on emission and exposure reduction and health impact. Recently however, improved biomass stoves have been seen as having the potential of achieving more benefits by reducing fuelwood consumption and reducing emission of toxic pollutants (Ezzati & Kammen, 2002; Smith *et al.*, 2007; Bruce *et al.*, 2008).

Three key intervention areas have been proposed to reduce indoor air pollution (IAP) in household environments such as changes to the pollution source which include fuel and stove, changes to the living environment including; housing and ventilation and changes in user behaviour such as fuel drying and keeping children away from smoke (Bruce *et al.*, 2000; Smith *et al.*, 2007; Bruce *et al.*, 2008). Of these, improved stoves is seen as the most practical solution in the near term, as other interventions such as fuel choice are not likely to be attained in the near future (WHO, 2006; Wilkinson *et al.*, 2007). Clean fuels do not just have a high cost, but appliances to burn them are also costly, and they require upfront payment that constitutes buying a full gas cylinder which most people cannot afford (Ochieng, 2007). With regard to biomass fuels and stoves use, large variations in pollutant concentrations are observed with key cooking activities and peaks in concentrations recorded when the fire has just been lit, or when fuel is added or moved. Use of averaged room concentrations of $PM_{2.5}$ therefore severely underestimates the exposure of women who are closest to the fire during these intense peaks (Balmes, 2019).

Most emission tests have mainly been carried out in laboratories or experimental houses (Ballard-Tremeer & Jawurek, 1996). An experiment that focuses on emissions in a controlled cooking task will give an inaccurate picture of exposure since improved biomass stoves have longer simmering periods and therefore imply longer exposure periods (Ballard-Tremeer & Mathee, 2000). Most stove experiments have left out crucial factors such as technical complexities of stove design, lack of maintenance and user behaviour patterns, which modify ideal combustion, contributing to highly variable stove performance in everyday use compared with the outcome of stove tests (Bruce *et al.*, 2008). Therefore, improved biomass stoves performance in IAP exposure reduction should be carried out in the real kitchens in order to account for behavioral patterns such as time spent breathing in polluted air, location and distance from pollution source and pollutant concentration in the environment (Munyao *et al.*, 2017b).

Assessment of household air pollution reduction of widely used stoves such as the Mud Rocket Stove (MRS), Chepkube and Cheprocket stoves in North rift and Western regions Kenya has also been limited. According to SCC-Vi Agroforestry (2010), there has been no systematic assessment of performance of Cheprocket and Chepkube stoves in terms of personal exposure and durations of exposure hence difficult to estimate its health risks to the population using it. Monitoring is mainly done on energy consumption and adoption rates (SCC-Vi Agroforestry, 2010). Lack of knowledge on stove performance in terms of emissions reduction can be a serious hindrance to developing programs and interventions to reduce pollution exposure in rural Kenyan communities and beyond. The main objective of this study was to analyze health risks associated with improved biomass stoves use in Western, Kenya.

1.1 Burden of Disease Related to Exposure to PM

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 exposure to elevated particulate matter levels is linked to a variety of negative health outcomes. Some of the negative health outcomes include 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 (EPA, 2018). 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).

1.1.1 Standards on Indoor Particulate Matter Concentrations

World Health Organization's (WHO) air quality guidelines states that $PM_{2.5}$ levels should not exceed an annual mean of 10 μg/m^3, or a 24-hour mean of 25 μg/m^3. The WHO air quality guidelines state that PM_{10} levels should not exceed an annual mean of 20 μg/m^3 and a 24-hour mean of 50 μg/m^3 as indicated in Table 1. These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to $PM_{2.5}$ and hence the set safe limits. The WHO encourages all countries to take steps to attain these guideline values due to the significant reduction that would take place in acute and chronic health morbidities associated with elevated PM exposure (WHO, 2014).

Table 1: WHO guidelines of PM

Pollutant	WHO Indoor air quality Guidelines
$PM_{2.5}$	10 μg/m^3 annual mean 25 μg/m^3 24-hour mean
PM_{10}	20 μg/m^3 annual mean 50 μg/m^3 24-hour mean

Source: WHO, 2014

1.2 Carbon Monoxide

Carbon monoxide (CO) is tasteless, odourless, colourless, and non-corrosive gas making it difficult to detect in the kitchens. It is produced by the incomplete combustion of carbonaceous fuels such as wood, petrol, coal, natural gas and kerosene. Its molecular weight is 28.01 g/mol, melting point –205.1 ^{0}C, boiling point at 760 mmHg, density 1.250 kg/m^3 at 0 ^{0}C and 1 atm and 1.145 kg/m^3 at 25 ^{0}C and 1 atm (Green, 2008). The molecular weight of carbon monoxide is similar to that of air. It mixes freely with air in any proportion and moves with air via bulk transport. It is combustible, may serve as a fuel source and can form explosive mixtures with air. Carbon monoxide is not detectible by humans either by sight, taste or smell. It is only slightly soluble in water, blood serum and plasma. In the human body, it reacts with haemoglobin to form carboxyhaemoglobin (COHb) which is poisonous.

1.2.1 Sources of Carbon Monoxide

Carbon Monoxide (CO) is produced whenever a material burns. Inhalation is the only exogenous exposure route for carbon monoxide. Anthropogenic emissions are responsible for about two thirds of the carbon monoxide in the atmosphere and natural emissions account for the remaining one third. Small amounts are also produced endogenously in the human body (EPA, 2006). Exposure to low levels of carbon monoxide can occur outdoors near roads, as it is also produced by the exhaust of petrol- and diesel-powered motor vehicles. Parking areas can also be a source of carbon monoxide (Kleinman, 2020). Carbon monoxide is produced indoors by combustion sources (cooking and heating) and is also introduced through the infiltration of carbon monoxide from outdoor air into the indoor environment (WHO, 1999).

In developed countries, the most important source of exposure to carbon monoxide in indoor air is emissions from faulty, incorrectly installed, poorly maintained or poorly ventilated cooking or heating appliances that burn fossil fuels. In developing countries, the burning of biomass fuels and tobacco smoke are the most important indoor sources of exposure to carbon monoxide. Clogged chimneys, wood-burning fireplaces, decorative fireplaces, gas burners and supplementary heaters without properly working safety features could vent carbon monoxide into indoor spaces.

Incomplete oxidation during combustion may cause high concentrations of carbon monoxide in indoor air. Tobacco smoke can be a major source of indoor exposure, as can exhaust from motor vehicles operating in attached garages (Kleinman, 2020). Combustion of low-grade solid fuel and biofuels in a small stove or fire place can generate high carbon monoxide emissions, which may become lethal to occupants unless the flue gases are vented outdoors via a chimney throughout the entire combustion process. At the beginning of combustion, the pollutants released are dominated by particulate matter (elemental and organic carbon) but carbon monoxide dominates towards the end. Combustion of high-grade fuels such as natural gas, butane or propane usually produces much less carbon monoxide, provided that sufficient air is supplied to ensure complete combustion. Nevertheless, even devices using such fuels can cause lethal carbon monoxide intoxication if they are not properly maintained or vented or if air: fuel ratios are not properly adjusted.

1.2.2 Toxicity of Carbon Monoxide

The toxicity of CO is through two mechanisms. Carbon monoxide reduces the oxygen-binding capacity of blood and it interferes with oxygen release at the tissue level. The CO affinity for haemoglobin is about 240 - 250 times greater than of oxygen. At equal concentrations of the two gases, the blood contains 245 times more COHb compared to oxyhaemoglobin. The relationship between the affinity constant (M), PO_2 and PCO_2 was first expressed by Haldane (1898). In humans, affinity constant (M) is reported to range from 210 to 245. $COHb / O_2Hb = M (PCO_2/PO_2)$ COHb will decrease the oxygen carrying capacity of blood. This is the principle mechanism of action underlying the toxicity effects at low-level carbon monoxide exposures. At this level, there is an induction of hypoxic state in tissues of many organ systems (WHO, 2010).

1.2.3 Health Effects of Carbon Monoxide

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 2 shows symptoms of acute poisoning based on COHb levels.

Table 2: 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.

1.2.4 WHO Guidelines of Carbon Monoxide

Previous WHO guidelines were established for 15 minutes to protect against short-term peak exposures that might occur from, for example biomass stoves using agricultural residues; for 1 hour to protect against excess exposure from, for example, faulty appliances; and for 8 hours which is relevant to occupational exposures and has been used as an averaging time for ambient exposures. However, chronic carbon monoxide exposure appears different from acute exposure in several important respects. Thus, a separate guideline is used to address 24-hour exposures. This is also relevant because the epidemiological studies based on 24-hour exposures using very large databases and thus producing extremely high-resolution findings are now available and indicate important population-level effects at levels that might be lower than the current 8-hour limit. World Health Organization (WHO, 2014) recommends a series of guidelines relevant to typical indoor exposures, as shown in table 3.

Table 3: WHO guidelines of CO

Pollutant	Guidelines	Comments
CO	15 minutes – 100 mg/m^3 (87 ppm)	Excursions at this levels should not occur more than once a day
	1 hour – 35 mg/m^3 (30 ppm)	Excursions at this levels should not occur more than once a day
	8 hours – 10 mg/m^3 (9 ppm)	Arithmetic mean concentrations
	24 hours – 7 mg/m^3 (6 ppm)	Arithmetic mean concentrations

Source: WHO, 2014

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).

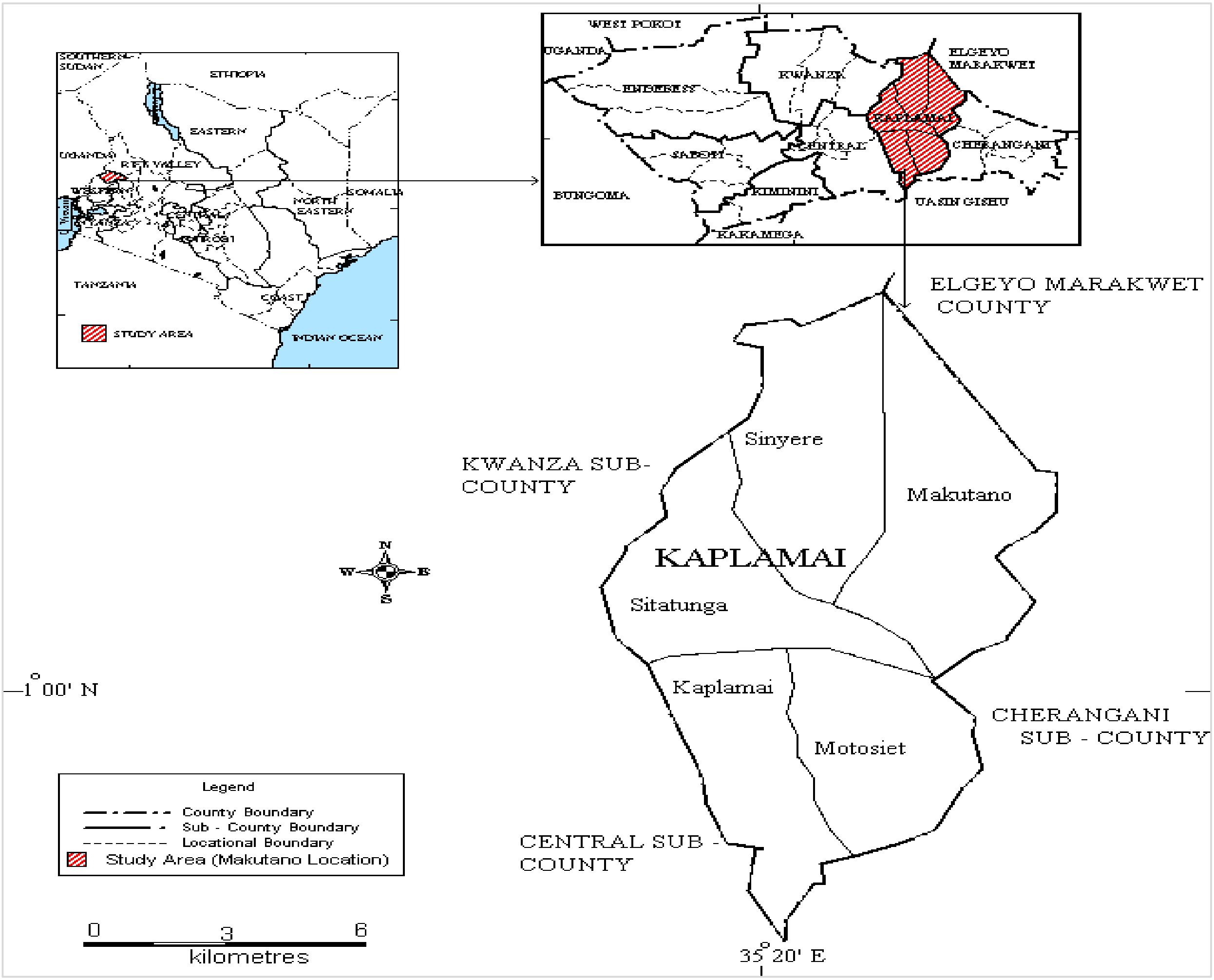

Figure 1: Trans Nzoia County indicating Location of Kaplamai Sub-county

Source: Moi University, 2017

2.1.2 Physical and Topographic Features in Trans Nzoia County

Trans Nzoia County is generally flat with gentle undulations rising steadily towards Mt. Elgon in the northwest with an altitude of 4,313 m above the sea level. Mt. Elgon is the second highest mountain in Kenya. It is an important ecosystem shared between Trans Nzoia and Bungoma Counties in Kenya and the Republic of Uganda hence it is a unique resource for forestry and wildlife conservation (GoK, 2013a).

On average the County has an altitude of 1,800 m above sea level. The altitude varies from 4,313 m above sea level in Mt. Elgon and gradually drops to 1,400 m above sea level towards the North. Because of the hilly nature, especially the Northwest and the Eastern parts of the County, there are difficulties in communication especially during the rainy season when roads sometimes become impassable. The County has two major rivers namely Nzoia and Suam. River Nzoia and its tributaries Sabwani, Ewaso, Rongai, Koitobos and Noigamet just to name a few flow into Lake Victoria while Suam River drains into Lake Turkana, through River Turkwel (GoK, 2013a). The water from the rivers could be utilized for the generation of hydroelectric power for use to support rural electrification, irrigation, fisheries and domestic consumption. These activities could also contribute towards flood mitigation. River Nzoia catchments and its tributaries are, however, threatened by encroachment, agriculture and other human activities along the riverbanks. Most of the natural forest cover is found in Mt. Elgon and the Cherangany Hills. However, continued pressure from fuelwood and charcoal production has had a significant negative effect on the forest cover. The forests in the County are critical to the climatic conditions of the territorial boundaries of the County and beyond as they form part of the water catchments for Lakes Turkana and Victoria.

2.1.3 Climatic Conditions of Trans Nzoia County

The County has a highland equatorial type of climate. The rainfall is well distributed throughout the year. The annual rainfall ranges between 900 mm and 1400 mm. The slopes of Mt. Elgon to the west receive the highest amount of rainfall while the region bordering West Pokot County receives the least. The County experiences bi-modal rainfall pattern. The long rains occur from April to June, while the short rains fall from July to October. The mean temperature in the County is 18.6 °C. However, temperatures range from a low value of 10 °C to a high value of 30 °C. The County has favourable climate for both livestock and crop production and vegetation growth (GoK, 2013a).

The study was undertaken in Lower Highland Zone that covers the slopes of Mt Elgon and Cherangany Hills with an altitude ranging from 1,800 m to 2,400 m above sea level. This zone covers 848.64 km^2 and it constitutes 34% of the total area of the County. The soils found in this zone are red and brown clays derived from volcanic ash. These soils are fertile with a high content of clay mineral which gives a continuous supply of plant nutrients (GoK, 2013a).

2.1.4 Population Size and Composition of Trans Nzoia County

The 2009 Population and Housing Census enumerated a total of 818,757 persons in Trans Nzoia County. Of these 407,172 were male and 411,585 were female. The inter-censal growth rate was 3.7% between 1999 and 2009 which is above the national average of 3%. Assuming the growth rate is maintained, the population in the County was projected to increase to 1,100,794 by 2017**.**

Table 4 shows the population projections for the years 2015 and 2017 both at county level and for Kaplamai sub-county (GoK, 2013a).

Table 4: Trans Nzoia County and Kaplamai Sub-county population

	2015			**2017**		
Region	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
County	508,383	513,893	1,022,277	547,431	553,364	1,100,794
Sub-county	120,607	123,080	243,687	129,870	132,534	262,404

Source: GOK, 2013(a)

The high population growth rate in the county has seen the population density rise from 328 persons per square kilometre in 2009, to 441 people per square kilometre in 2017 (GoK, 2013a). The high population growth rate in the county puts more pressure on existing forest cover for energy resources hence need for improved biomass stoves.

2.2 Position and Location of Bungoma County

Bungoma County lies between latitude 0^o 28’ and latitude 1^o 30’ North of the Equator, and longitude 34^o 20’ East and 35^o 30’ East of the Greenwich Meridian. The County covers an area of 3032.4 km^2. 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.

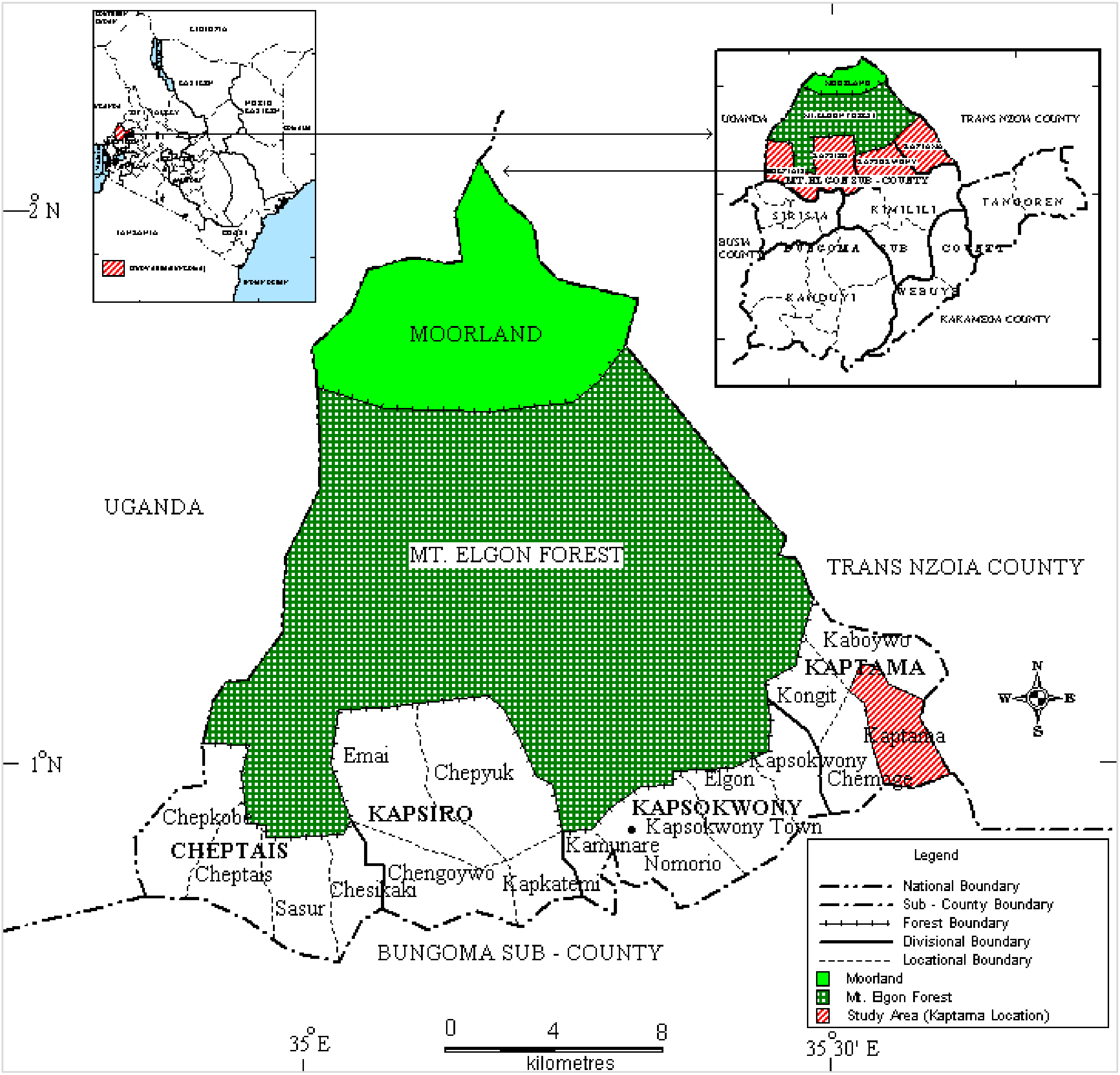

Figure 2: Location of Mt. Elgon Sub-county in Bungoma County

Source: Moi university, 2017

2.2.1 Climatic Conditions of Bungoma County

The County experiences two rainy seasons; the long rains which run from March to July and short rains which run from August to October. The annual rainfall in the County ranges from 400 mm (lowest) to 1,800 mm (highest). The annual temperature in the County varies between 0 °C and 32 °C due to different levels of altitude, with the highest peak of Mt. Elgon recording slightly less than 0 °C (GoK, 2013b). The altitude of the County ranges from over 4,321 m at the mountain side to 1200 m above sea level in the lower areas. The study was undertaken at the lower areas with altitude ranging between 1800 m to 2100 m above sea level. These regions are highly settled since they have fertile alluvial soils that are well drained for agricultural purposes. The high population pressure in the County has led to encroachment on protected forests for farming purposes and energy resources.

2.2.2 Population Size and Composition of Bungoma County

The 2017 projected population for Bungoma County based on the growth rate of 3.1% is 1,759,499 (Male 859,350 and Female 900,149). The male to female ratio is 1: 1.2. The county has a growing population with varying demographics, which include fertility, mortality, birth rates, migrations, immigrations among others. Table 3.3 presents the predicted population in the Bungoma County and Elgon sub-county for the years 2015 and 2017 (GoK, 2013b).

Table 5: Bungoma County and Elgon Sub-county population

	2015			2017		
Region	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
County	808,449	846,832	1,655,281	856,350	900,149	1,759,499
Sub-county	94,104	112,925	207, 029	100,029	120,035	220,064

Source: GOK, 2013b

The population of Bungoma County is of mixed demographic characteristics. Mt Elgon has the least population in the County. This is due to lack of socio-economic opportunities, poorly developed infrastructure and lack of government institutions which makes unemployment levels high in the sub-county and hence income levels equally low. The low income levels have denied the population a chance to access to modern forms of energy and therefore mainly use traditional biomass fuels such as firewood and crop residues. In Bungoma County, the main sources of energy include: firewood (93.4%), charcoal (4.7%) and crop residue (3.5%). the main sources of lighting fuel include: paraffin (96.65%), firewood (3.8%), and dry cells (2.3%). Electricity connectivity stands at a mere 1.5% (GoK, 2002).

2.3 Research Design

This research employed cross-sectional study design where there was quantification of indoor air pollution from 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.

2.4 Sampling Method

A multi-stage sampling technique was used in this study. 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 County were selected using cluster sampling method because in these sub-counties, divisions where stove promotion was undertaken are found. Kaptama 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. 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. 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 strata was given; the first households was picked randomly then subsequent respondents picked according to the working function obtained after apportioning the target population. The total target 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 *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. 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.

2.5 Data Collection

2.5.1 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, stove 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.

2.5.2 Exposure Concentration 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.

2.5.3 Health Risk Assessment

For substances associated with a presumed threshold of effect, the typical risk calculation process is more straightforward. The process has been used for many years, for example in setting safe workplace exposure levels. Health risks were estimated by acquiring the Hazard Quotient (HQ). The hazard quotient for PM and CO effects was estimated by dividing the intake of the pollutant by an appropriate risk Reference Dose (RfD). After characterizing the exposure scenarios and estimating Exposure Concentrations (ECs) for each pollutant, an appropriate RfD values for each inhaled contaminant was selected using WHO values given in Table 6.

Table 6: Long-term and short-term RfD of PM and CO

	RfD	
Pollutant	**Short term**	**Long term**
CO	30 ppm (1 hr)	-
CO	6 ppm (24hrs)	-
$PM_{2.5}$	(25 $\mu g/m^3$)	10 $\mu g/m^3$

Source: WHO, 2010

Hazard quotients were estimated by use of the Equation 1 to indicate whether there was any health risk.

$$HQ = EC/RfD \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

A hazard quotient less than or equal to one indicated that adverse effects are not likely to occur, and thus can be considered to have negligible hazard. HQs greater than 1 are a simple statement of whether and by how much an exposure concentration exceeds the reference concentration (RfC) and therefore there is a real health risk.

2.6 Data analysis

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.

2.7 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 Socio-demographic Characteristics of Households

Majority (89.2%, $p = 0.000$) of the household heads in the study were men; farmers (65.7%, $p = 0.001$), aged between 35 years and 59 years (77%, $p = 0.001$), with high school education level (45.1%, $p = 0.005$) and monthly income ranging between 5,000 KShs to 30,000 KShs per month (58.3%, $p = 0.025$). The highest percentage of the households in the study area own land (90.2%, $p < 0.001$) and the average land holding size ranged between 1 acre and 5 acres (52.2%, $p < 0.001$) and only 2.2% ($p < 0.001$) of the households owned land acreage above 10 acres as shown in Table 7. The community largely (74.5%, $p = 0.002$) used three-stone stove for mainly cooking and heating purposes which led to indoor air pollution.

Table 7: Socio-demographic characteristics of the study population

Characteristic	Category	N = 204	%	*p* value
Age (HH Head)	18 - 34 years	20	9.8	0.001
	Between 35 to 59 years	157	77.0	
	60 years and above	27	13.2	
HH head	Woman	22	10.8	0.000
	Man	182	89.2	
Education level	Primary school and less	60	29.8	
	Secondary	92	45.1	
	Tertiary	52	25.5	
HH size	1 - 3	25	12.3	0.005
	4 – 6	86	40.7	
	7 and above	96	47.1	
HH occupation	Farming (crops and livestock)	134	65.7	0.001
	Formal employment	40	19.6	
	Business	30	14.7	
Monthly income (KShs)	Less than 5000	21	10.3	0.025
	Between 5001 - 30000	119	58.3	
	Between 30,001 – 60,000	55	27.0	
	Between 60,001 – 150,000	5	2.5	
	Above 150,000	4	2.0	
Land ownership	Yes	184	90.2	0.000
	No	20	9.8	
Size of land owned (Acres)	< 1	34	16.7	0.000
	1 – 5	96	52.2	
	6 – 10	50	27.2	
	> 10	4	2.2	
Fuelwood stoves	Maendeleo	8	3.9	0.002
	Envirofit	12	5.7	
	Mud Rocket	24	11.8	
	Cheprocket	26	13	
	Chepkube	90	44.1	
	Three stone	152	74.5	

Source: Author

3.2 Personal Exposure

3.2.1 Short-term $PM_{2.5}$ Personal Exposure

At 95% CI, Maximum Daily Intake (MDI) of $PM_{2.5}$ was higher than the recommended WHO threshold of 25 µg/m^3 using crop residues and wood fuel. Maximum daily intake using MRS was 889.889 µg/m^3 ($p < 0.001$) and (311.725 µg/m^3 ($p < 0.001$) using wood and crop residue fuels, respectively. Daily exposureof $PM_{2.5}$ using Chepkube stove was 442.354 µg/m^3 ($p < 0.001$) and 3518.6 µg/m^3 ($p < 0.001$) using firewood and crop residues fuels, respectively. Three-stone stove produced the highest daily exposure of PM and CO using crop residues and firewood fuels. While Chepkube stove produced the least CO exposure at 5.7 ppm as indicated in table 8.

Table 8: Maximum daily intake of CO and $PM_{2.5}$

Stove	**Fuel type**	**PM (mg/m^3)**	**CO (ppm)**	***p*-value**
Mud Rocket	Wood	889.889	11.264	0
	Crop residue	3311.725	21.355	0
Cheprocket	Wood	661.799	15.705	0
	Crop residue	1291.808	14.98	0
Chepkube	Wood	442.354	5.652	0
	Crop residue	3518.591	5.713	0
Three Stone	Wood	2768.524	17.787	0
	Crop residue	3646.545	48.886	0

Source: Munini et al., 2017

3.2.2 Health Risk Assessment

Hazard quotients (HQ) for both long-term and short-term PM exposure using all stoves were all above 1 implying that health risk is real. During 24-hour cooking duration, three-stone stove using crop residues produced 145.8 times higher $PM_{2.5}$ compared to RfD value while Cheprocket produced 26.4 times higher than $PM_{2.5}$ RfD as indicated in table 9. Although HQs for $PM_{2.5}$ in the short-term and long-term periods were higher than one, this study noted that long-term hazard quotients were higher than short-term HQs for $PM_{2.5}$ exposures. As indicate in Table 9, using firewood as fuel, long-term HQ using MRS was 43.1 compared to 25.5 for short-term duration while for Chepkube stove it was 23.5 long-term compared to 17.6 short-term respectively.

Table 9: Short-term and long-term $PM_{2.5}$ and CO hazard quotient

		24 hours		**1 hour**	**70 years**
Stove name	**Fuel type**	**$PM_{2.5}$ RfD = 25µg/m^3**	**CO RfD = 6ppm**	**CO RfD = 30ppm**	**$PM_{2.5}$ RfD = 10 µg/m^3**
Mud Rocket	Wood	35.5	1.8	0.09	43.1
	Crop residues	132.4	3.5	0.08	155.5
Cheprocket	Wood	26.4	2.6	0.1	33.4
	Crop residues	51.6	2.4	0.1	70.8
	Wood	17.6	0.9	0.0	23.5
Chepkube	Crop residues	120.1	0.9	0.0	140.7
Three-stone	Wood	110.7	2.9	0.1	157.6
	Crop residues	145.8	8.1	0.2	194.1

All the HQs of the 1-hour peak CO period from the four biomass stoves were less than 1 and therefore no adverse effects are likely to occur during that cooking duration. During 24-hour period, Chepkube stove had the least HQ of 0.9 crop residues as fuel while three-stone stove had the highest HQ at 8.1 as indicated in Table 9. Similarly, when wood was used as fuel, Chepkube had the least HQ of 0.9 while three-stone stove had the highest at 2.9.

4.0 DISCUSSION

4.1 Health Risk Analysis

Hazard quotients for both long-term and short-term PM exposures were high, indicating that chronic obstructive pulmonary infections and other respiratory infections are likely to occur. This is in agreement with Abdo et al., 2021 who concluded that overall, the REACCTING (Research on Emissions, Air Quality, Climate and Cooking Technologies) intervention did not substantially improve the health outcomes due to HAP. A hazard quotient less than or equal to one indicates that no adverse effects are likely to occur, and thus can be considered to have negligible hazard. HQs greater than one are a simple statement of whether (and by how much) an exposure concentration exceeds the reference concentration (RfC). Adverse health effects due to $PM_{2.5}$ exposures are likely to be severe in the long term compared to short-term period. This is because HQs increased as age increased implying that at old age exposed individuals have increased upper and lower respiratory infects such as asthma, bronchitis, due to $PM_{2.5}$ exposure compared to younger age.

People using solid biomass fuels are likely to experience headaches and running nose by the end of 24-hour period as a result of CO exposure when mud rocket stove, three stone stove and Cheprocket stoves were used. However cooks who use Chepkube stoves are not likely to experience any adverse health effects from CO exposures since the HQs were less than 1 using both wood and crop residues as fuel. Findings from this study indicated that domestic CO and $PM_{2.5}$ levels in biomass fuel households in this region of Kenya frequently exceed WHO Air Quality Standards are likely to contribute to increased morbidity, mortality and adverse birth outcomes. This finding is in line with Ezzati et al. (2001) who reported that long-term exposure to higher particulate levels, even periodically, can potentially lead to a number of important health issues, including acute respiratory infections and chronic obstructive pulmonary disease. The finding also agrees with Munyao *et al.* (2017a) who concluded that household indoor PM and kitchen concentrations associated with biomass fuel combustion in Western Kenya exceed WHO indoor safe limits and are in the hazardous range for human health. The author further indicated that extremely high kitchen $PM_{2.5}$ concentrations suggest that MRS and Cheprocket stoves cannot be an intervention for health effects of $PM_{2.5}$ which are of most interest in household air pollution. However, exposure to peak CO within the 1-hour duration is not likely to cause any adverse health effects from all biomass stoves monitored since hazard quotient was less than 1. This finding is in agreement with Bartington *et al.* (2017) who found that peak1-hour CO exposure was not likely to produce any adverse health effects since the exposure concentration was within stipulate WHO safe limits. This could be due to incoming outdoor air circulation as most kitchens have their windows open throughout the day hence outdoor air quickly dilutes the indoor CO concentration.

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Indoor air pollution in rural kitchens in western Kenya is a real risk capable of contributing to increased morbidity, mortality and adverse birth outcomes due to high CO exposure and acute respiratory infections and chronic obstructive pulmonary diseases due to long-term PM exposures and neurological problems due to chronic episodic CO exposures.

5.2 Recommendation

An epidemiological study should be carried out by county governments and non-governmental organisations to assess the linkage between PM exposures from the different stoves and respiratory infections in the region

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