ASSESSMENT OF INDOOR AIR POLLUTION, HEALTH IMPLICATIONS AND IMPACTS OF IMPROVED STOVE INTERVENTIONS IN BUNGOMA AND TRANS NZOIA COUNTIES, KENYA

BY:

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DECLARATION

Declaration by the Candidate

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DEDICATION

I dedicate this work to my husband Dr. Nehemiah Kiprutto and my parents Mr. and Mrs. Francis Munyao for their unwavering support and prayers and to my daughter, Joy Chichi and my son, Asher Killy for their encouragement. Let the Almighty God bless you always.

ABSTRACT

The use of biomass fuels poses great threats to environmental degradation and public health 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, efficiency of improved biomass stoves in fuel consumption, indoor air pollution reduction, analyze potential health risks associated with these stoves and assess how kitchen characteristics influence levels of area pollutant concentration in Bungoma and Trans Nzoia Counties, Kenya. The data were collected through kitchen performance testing, continuous real-time monitoring of kitchen pollution concentration for a period of 24 hours using UCB-PATS and CO monitors, questionnaires and time activity budgets. Data analysis was undertaken by first categorizing pollution data and exposure concentrations into three microenvironments then ANOVA done to test for their variations from WHO stipulated safe standards. Multiple regression analysis was undertaken to evaluate the association between pollutant concentration and kitchen characteristics. The study found that households with improved cook stoves that included the Cheprocket and mud rocket stoves consumed 1.5 kg/day (95% CI (Confidence Interval): 1.3, 5.8) and 1.3 kg/day (95% CI: 1.2, 5.9) less fuel than households with three-stone stoves respectively. While households using Chepkube stove consumed 2.7 kg/day (95% CI: 1.2, 3.6) less compared to three-stone stove. Further at 95% CI, mean 24-hr kitchen PM concentrations from all the stoves were significantly higher than the stipulated WHO threshold. Three-stone fire had the highest average 24-hour kitchen PM and CO emissions using firewood at 4272.414 µg/m^3 ($p = 0.000$) and 75.4417 ppm ($p < 0.001$), respectively, while Chepkube stove had the least at 682.646 µg/m^3 ($p < 0.001$) and 8.7224 ppm ($p < 0.001$), respectively. Long-term and short-term exposure concentrations were much lower than kitchen concentration although significantly higher than stipulated safe limits for $PM_{2.5}$. The daily exposure of CO using different stoves were all above the safe limits of 6ppm apart from Chepkube stove which had (5.6 ppm, $p < 0.001$) and (5.7 ppm, $p < 0.001$) using wood and crop residues as fuels respectively. Average peak exposures of CO were within WHO safe 60-minute limits of 30ppm for all stoves. Multiple regression models predicted that well ventilated kitchens (B = 2.556, SE = 1.646, $p = .036$) using Cheprocket stove; (B =1.484, SE = .050, p = .005) using mud rocket stove; (B = .083, SE = 019, p = .000) using Chepkube stove with cemented floors (B = -.091, p = .001) and increased number of windows were negatively associated with $PM_{2.5}$ while smaller kitchen window size, lack of connectivity to main grid, increased duration in warming water were positively associated with kitchen PM concentrations. The study concluded that, improved biomass stoves provided an overall reduction in pollutant concentration and fuel use compared to three-stone fire but the local innovation Chepkube stove that has been classified as ungraded stove had the highest pollutant reduction and fuel use reduction. In addition, indoor air pollution in rural areas is a real health risk. Consequently, it was recommended that programs aiming to reduce the adverse health impacts of indoor air pollution should focus on measures that result in larger reductions of CO and $PM_{2.5}$ emissions especially during burning and peak periods.

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ACRONYMS AND ABBREVIATIONS

AED – Aerodynamic Equivalent Diameter

ANOVA – Analysis of Variance

AQG – Air Quality Guideline

ARI – Acute Respiratory Infections

AT – Averaging Time

BW – Body Weight

CA – Contaminant Concentration

DALYs – Disability Adjusted Life Years

EAA – Energy Alternative Africa

EC – Exposure Concentration

EF – Exposure Frequency

EPA – Environmental Protection Agency

ET – Exposure Time

FDG – Focus Group Discussion

HAP – Household Air pollution

HH – Household

HQ – Hazard Quotient

IAP- Indoor Air Pollution

IARC – International Agency for Research and Cancer

IKWP – Indoor Kitchen With Partition

IKWOP – Indoor Kitchen Without Partition

IQR – Interquartile Range

IR – Inhalation rate

KCJ – Kenya Ceramic Jiko

KShs – Kenya shillings

LED – Light Emitting Diode

LPG – Liquefied Petroleum Gas

MDG – Millennium Development Goals

MDI – Maximum Daily Intake

ME – Microenvironment

MoE – Ministry of Energy

OK – Open Kitchen

PAH – Polycyclic Aromatic Hydrocarbon

PIC – Products of Incomplete Combustion

$PM_{2.5}$ – Particulate Matter with diameter less than 2.5 microns

PM_{10} – Particulate Matter with diameter less than 10 microns

RfC – Reference Concentration

RfD – Reference Dose

SOK – Separate Open Kitchen

SPSS – Statistical Package for Social Sciences

TB – Tuberculosis

TSP – Total Suspended Particles

UCB-PATS – University of California Berkeley-Particle and Temperature Sensors

UNEP – United Nations Environmental Development Programme

WHO – World Health Organization

CHEMICAL SYMBOLS

CO – Carbon monoxide

CO_2 – Carbon (IV) oxide

SO_2 – Sulphur (IV) oxide

NO – Nitrogen oxide

O_2 – Oxygen

NO_2 – Nitrogen (IV) oxide

DEFINITION OF TERMS

Chepkube – is a fixed biomass stove made of clay and fitted with an oven or food warming cavity designed by women of the larger Kalenjin community.

Cheprocket – is a biomass stove made of clay; that uses the rocket principle for combustion and it is fitted with a chick brooder and or a food warming cavity.

Crop Residues – refers to remains of crops after harvesting that were used as fuel. They included maize stalks, maize cobs and dry banana leaves.

Disability Adjusted Life Years (DALYs) – it is a measure combining years of life lost due to disability and death.

Energy ladder – steps showing the improvement of energy use corresponding to an increase in the household income.

Exposure– is any contact between a substance in an environmental medium and the surface of the human body

Household Air Pollution (HAP) – is term used when referring to indoor air pollution in household environments.

An improved biomass stove - is a biomass cookstove which has been especially/specifically designed to use less fuel, cook food more quickly, and produce less smoke.

Indoor Air Pollution (IAP) – is contamination of the indoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the indoor atmosphere.

Mud rocket stove – is a fixed biomass stove made of mud outer lining that uses rocket principle in combustion and modified from the rocket stove developed by Dr. Larry Winiarski in the 1980s.

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Household air pollution (HAP) from biomass cooking fuels has been linked to several respiratory diseases such as acute lower respiratory infections and chronic obstructive pulmonary disease and is therefore a major cause of morbidity and mortality globally especially in developing economies (WHO, 2007; Ezzati & Kammen, 2001; Bruce *et al.*, 2004; Burnett *et al.*, 2014). A large part of this is due to developing countries' overreliance on traditional, unprocessed biomass fuels such as wood, crop residues, and animal wastes. Approximately half the world's population and up to 90% of rural households in developing countries still rely on unprocessed biomass fuels in the form of wood, dung and crop residues (UNEP, 1998). In Kenya, over 90% of the rural population rely on solid biomass fuels (GoK, 2002). In Bungoma and Trans Nzoia Counties, the main source of cooking energy is firewood at 93.4% and 71%, respectively (GoK, 2009).

Biomass fuels used are typically burnt indoors in open fires or poorly functioning stoves. Under these conditions, these fuels do not burn completely and result in complex mixture of products of incomplete combustion (PICs). Some of PICs include pollutants such as particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), formaldehyde and polycyclic aromatic hydrocarbons (PAH), including benzo [*a*] pyrene, dioxin (Ezzati & Kammen, 2002), a carcinogen. According to Naeher *et al.* (2007), it is still not clear which other pollutants are contained in biomass smoke as there could be hundreds of other health damaging chemical pollutants. In addition to direct effects on household air pollution and health, carbon dioxide and black carbon emissions from burning solid fuels are also important contributors to global climate change (Ramanathan & Carmichael, 2008). Household air pollution in developing countries contributes to up to 76% of the global particulate matter an important air pollutant and CO exposure. Consequently, there are high levels of air pollution, to which women, especially those responsible for cooking, and their young children, are most heavily exposed (Bruce *et al.*, 2004; Bruce *et al.*, 2008; Lim *et al.*, 2012).

Previous studies have demonstrated that improved combustion stoves, improved ventilation, and reduced use of solid fuels would help reduce pneumonia morbidity and mortality in children (Ezzati & Kammen, 2001; Bruce *et al.*, 2008; Lim *et al.*, 2012). Published evidence on the relationships between exposure to $PM_{2.5}$ and risk of a range of diseases suggested that reductions in $PM_{2.5}$ exposure are needed to prevent the majority of diseases attributable to its exposure (Lim *et al.*, 2012; Burnett *et al.*, 2014).

1.2 Biomass Stove Fuel Use

In Kenya, biomass fuel accounts for 68% cooking fuel both for rural and urban population (GoK, 2002). 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 & Gathui, 2010). Fuel use efficiency of improved wood stoves is one of critical aspects in evaluation of overall stove performance in household in various settings (Malla *et al.*, 2011). However, performance of wood stoves in fuel use reduction has mainly been done using experimental methods such as Water Boiling Tests and Controlled Cooking Tests (CCTs). These tests have however been shown to be inaccurate to give performance of biomass stoves in daily cooking activities (Ochieng *et al.*, 2013; Berrueta *et al.*, 2008; Johnson *et al.*, 2010; Smith *et al.*, 2007). A more representative method is the kitchen performance test (KPT), a stove performance test that measures fuel use in households under actual use (Smith *et al.*, 2007). To date, very few studies have utilised this method especially in Africa (Ochieng *et al.*, 2013; Bensch & Peters, 2011, 2012; Wallmo & Jacobson, 1998). Therefore, there is little empirical evidence on fuel use performance of improved wood stoves such as mud rocket stove and Cheprocket stove and the traditional innovation; Chepkube stove.

1.3 Health Effects of Exposure to $PM_{2.5}$ and CO

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

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

1.4 Improved Biomass Stoves and Indoor Air Pollution Reduction

Improved biomass stoves have been long promoted with the aim of addressing energy and environmental issues such as 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 (Ezzati & Kammen, 2001).

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.

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 (2011), 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.

1.5 Determinants of Exposure

Exposure is any contact between a substance in an environmental medium and the surface of the human body. 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. Women and young children bear most of this exposure, women because of their cooking role and young children because they are near their mothers as they cook, or are carried on the back. Not only do they experience extended durations of exposure of 3 – 7 hours in a day (Jaakkola & Jaakkola, 2006; Suzzanne *et al.*, 2014), but also intense peaks of pollution. Particulate matter levels of up to 30,000 $\mu g/m^3$ have been recorded (Bruce *et al.*, 2000; Rehfuess *et al.*, 2006). In Kenya, few studies have been done especially comparing exposures at different cooking periods from different solid biomass fuels and none from the traditional Chepkube stove that is widely used in the North rift region and Western part of the country (SCC-Vi Agroforestry, 2010).

1.6 Statement of the Problem

In Kenya there is deficit of fuelwood a scenario that is set to increase by 2030. Although improved biomass stoves can potentially provide numerous benefits for local environments and climate through reduced fuel use compared to traditional stoves, limited in-field evaluations implies that there is little information on effectiveness of improved biomass stoves. Still, there is limited knowledge in Kenya on indoor air pollution and therefore household air pollution remains a major cause of morbidity and mortality due to overreliance of solid biomass fuels for domestic cooking in rural areas. High poverty levels in these areas do not allow the communities to move up the energy ladder to cleaner fuels or adopt improved energy technologies therefore larger population remains exposed. Worse still, cooking is a daily activity implying that household air pollution is a lifetime challenge to women who are the main domestic cooks and young children always accompanying them during cooking remain exposed. Although there have been efforts to reduce household air pollution through introduction and promotion of improved cook stoves by mainly non-governmental organizations in Kenya, systematic evaluations to assess whether these programs have achieved the intended efforts are lacking. There has been no performance testing of emissions reduction potential of Cheprocket stove disseminated in the Elgon sub-county through VI-agro forestry project in 2012 and therefore associated health risks unknown. Further, majority of improved biomass stoves are disseminated through energy saving programs whose main aim is to cut on fuelwood consumption and not necessarily reduce indoor air pollution. It is of concern that Chepkube stove, the highest adopted stove in the North rift region is untested for particulate matter and carbon monoxide emission levels. Absence of this information hinders proper planning by the county governments on public health issues.

1.7 Objectives

1.7.1 General Objective

The main objective of this study was to evaluate efficiency of improved biomass stoves in fuel consumption, indoor air pollution reduction, analyze health risks associated with the stoves and assess how kitchen characteristics influence levels of area pollutant concentration in Bungoma and Trans Nzoia Counties, Kenya.

1.7.2 Specific Objectives of the Study

1. To evaluate cooking fuel types and quantify fuel use in improved biomass stoves and traditional biomass stoves in Kaptama Sub-location, Bungoma County and Kapsara Sub-location, Trans Nzoia County.
2. To determine kitchen concentrations of particulate matter and carbon monoxide from biomass fuels use in Kaptama Sub-location, Bungoma County and Kapsara Sub-location, Trans Nzoia County.
3. To measure personal exposure of particulate matter and carbon monoxide from biomass fuels use in Kaptama Sub-location, Bungoma County and Kapsara Sub-location, Trans Nzoia County.
4. To determine potential health risks associated with particulate matter and carbon monoxide emissions from biomass fuels utilization in Kaptama Sub-location, Bungoma County and Kapsara Sub-location, Trans Nzoia County.

5. To assess effect of kitchen characteristics on the levels of particulate matter and carbon monoxide concentrations in Kaptama Sub-location, Bungoma County and Kapsara Sub-location, Trans Nzoia County.

1.8 Hypotheses of the Study

H_{01}: There is no significant difference in fuel use between the improved biomass stoves and traditional biomass stoves in the study area.

H_{02}: Kitchen concentrations of particulate matter and carbon monoxide from biomass fuels use in the study area do not significantly vary with WHO threshold.

H_{03}: Personal exposures of particulate matter and carbon monoxide from biomass fuels use in the study area do not significantly vary with WHO threshold.

H_{04}: There are no significant health risks associated with particulate matter and carbon monoxide emissions from biomass fuels utilization in the study area.

H_{05}: Kitchen characteristics do not significantly influence particulate matter and carbon monoxide exposure in the study area.

1.9 Justification of the Study

Increasing number of interventions such as dissemination of improved biomass stoves, installation of chimneys and hoods, and behavioural measures such as health education have been carried out in the last two decades to reduce fuel use and IAP from biomass solid fuels in Kenya. However, there has been no attempt to systematically synthesize the evidence that improved biomass stoves can mitigate fuelwood shortage in the country and that IAP interventions in homes using solid biomass fuels improve indoor air quality and health. It is therefore timely and important to understand more about the effectiveness of these interventions. Most studies carried out in Kenya on stoves testing of PM and CO emission have largely been in controlled environments and very few have been done in the country especially the Western Kenya region.

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

1.10 Scope of the Study

This study was confined to assessing fuel use and two indoor air pollutants: fine particulate matter ($PM_{2.5}$) and carbon monoxide in four different biomass stoves that included; Mud Rocket Stove (MRS), Cheprocket stove, Chepkube stove and finally the three-stone stove. Monitoring of emissions was done for a period of 24-hours in the kitchen environment alone. Monitoring of personal emissions focused on cohort of people who do cooking aged between 30 years and 40 years in rural areas. The study was done during the dry season.

1.11 Limitations of the Study

1. PM monitoring gadget was bulky and therefore could not be hanged around cook necks for personal monitoring.
2. The study was only limited to cooks and children below five years.
3. The study was only conducted during the dry season therefore wet season scenario was not given

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Indoor air pollution (IAP) is contamination of the indoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the indoor atmosphere. The term Household air pollution (HAP) is mainly used when referring to IAP in household environments. Household combustion devices are common sources of household air pollution. Pollutants of major public health concern include particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulfur dioxide. Indoor air pollution cause respiratory and other diseases, which can be fatal. Biomass fuels refer to burned plant or animal material; wood, charcoal, dung and crop residues. They account for more than one-half of domestic energy in most developing countries and for as much as 95% in lower income countries (Smith *et al.*, 2004).

2.2 Household Energy Use in Developing Countries

Energy and fuel use are important for the welfare of households in developing countries. For most people in developing countries, energy comes from wood, waste, dung, candles, and occasionally kerosene. In Ghana, solid biomass fuels account for 80% of energy consumption in rural areas (UNDP, 2003). The provision of adequate and secure sources of energy in its various forms is essential for a nation’s growth and economic development. In Kenya, energy sources can be broadly classified into two categories: traditional, which include wood, charcoal and other biomass, and conventional, such as petroleum products and electricity. Bio-energy is the energy derived from various sources of solids, liquids and gaseous biomass, including fuel wood, charcoal, ethanol, bio-diesel and biogas. Biomass contribution to Kenya’s final energy demand is 70% and provides for more than 90 per cent of rural household energy needs (GoK, 2002). The main sources of biomass for Kenya include charcoal, wood-fuel and agricultural waste. Traditional energy types are used in traditional ways, such as three-stone stoves and open fireplaces. These energy forms often do not enter the formal market but nevertheless are critical and most appropriate for particularly the low-income families.

Rural households often consume a mix of both traditional and conventional energy types depending on household income. Poorer households use greater quantities of traditional fuels while higher income families tend to rely more on modern energy resources. Approximately 90% of rural and 7% of urban households have regular use of firewood, giving a national average of 70% of all households in Kenya. The projected average annual per capita consumption by 2017 is approximately 998 kg for rural households. Firewood comes from agroforestry or on-farm sources (84%), from trust lands (8%) and from gazetted forests (8%) (GoK, 2002; UNDP, 2003). Approximately 76% of households obtain all their firewood free, 17% of households regularly purchase it while 7% supplement their free collection by purchasing some firewood (UNDP, 2003). However, at the national level, there is an annual deficit of 20 million tonnes which translates to 57% shortfall in supply, putting the entire country into an acute scarcity category (GoK, 2002; Mugo & Gathui, 2010).

Overall, about 21% of households use farm residues, but their use is mainly in rural areas with 29% households as compared to 0.5% in urban households. However, during the dry season, farm residues account up to 80% of cooking energy used.

Use of charcoal is about 47% at the national level representing 82% and 34% of urban and rural households, respectively (GoK, 2002; UNDP, 2003). Kerosene is often regarded as a "poor man's" fuel and is used by approximately 92% of all households accounting for 94% in rural areas and 89% in urban areas, mainly for lighting. Liquified petroleum gas (LPG) is not widely used with only 7.8% (23% urban and 1.8% rural) households using it due to various constraints (UNDP, 2003). LPG is used along with firewood in rural areas while in urban areas, it is used as a supplement for electricity. Electricity is the most modern and convenient fuel and ranks highest on the energy ladder. However, electricity is expensive for the majority of the households, and currently 55% of urban and 10.8% of rural households have access to electricity. Nationally, this translates to only 30% households with access to electricity (GoK, 2015). According to the Intermediate Technology Development Group (ITDG), approximately 1,100 biogas units are operational in Kenya (UNDP, 2003). Maintenance technology and the fact that most households do not have piped water are among the constraints to wider adoption of biogas.

2.3 Indoor Air pollution in Developing Countries

Globally, 6 million deaths annually are attributed to exposure to IAP in developing countries due to pneumonia, chronic respiratory diseases and lung cancer, with the overall disease burden in DALYs exceeding the burden from outdoor air pollution by five-fold (WHO, 2013). Indoor air pollution associated with combustion of solid fuels in households in developing countries is now recognized as a major source of health risks. Use of open fires with simple solid fuels, biomass, or coal for cooking and heating exposes an estimated 2 billion people worldwide to concentrations of particulate matter and gases that are 10 to 20 times higher than health guidelines for typical urban outdoor concentrations. Although biomass makes up 10 to 15 percent of total human fuel use, since nearly half the world's population cooks and heats their homes with biomass fuels on a daily basis, indoor exposures are likely to exceed outdoor exposures on a global scale (Bruce *et al.*, 2000; Rehfuess *et al.*, 2006).

In rural Kenya, it was found that the amount of indoor air pollution a child is exposed to directly correlate with the risk of developing pneumonia (Ezaati & Kammen, 2001). Nationally in Kenya, respiratory infections account for 12% of annual deaths (WHO, 2007). Use of traditional biomass fuels such as wood, dung, and crop residues is widespread in rural Kenya. According to GoK (2002), 90% of rural households and 70% of urban households rely on biomass as their primary cooking fuel. Since much of the cooking is carried out indoors in environments that lack proper ventilation, millions of people in the country, primarily poor women and children face serious health risks. In Kenya, efforts to address the overall health risks associated with solid biomass fuels use among rural women and children are currently done through promotion of improved biomass stoves.

2.4 Characteristics of Wood Smoke

Wood is primarily composed of two polymers including cellulose that is about 50 - 70% by weight and lignin that is approximately 30% by weight (Naeher *et al.*, 2007). These two polymers are the primary components in many biomass fuels, although the ratios of composition may vary depending on the source of biomass such as wheat and grasses among others. Wood also contains small amounts of low-molecular-weight organic compounds and various trace metals, which often vary based on the soil composition and the climate where the wood grew. During combustion, carbon dioxide, nitrogen, and water are released from complete combustion while incomplete combustion produces various inorganic gases such as carbon monoxide, ozone, nitrogen oxides, polycyclic aromatic hydrocarbons (PAHs), benzene, aldehydes, free radicals and inhalable particulate matter, all of which negatively impact health (Schauer *et al.*, 2001; Naeher *et al.*, 2007).

In addition to these pollutants, a number of compounds present in biomass smoke have been shown to be toxic and/or carcinogenic to humans, including free radicals, aldehydes, and phenols, hydrocarbons such as PAHs, dioxins, benzene, and styrene (Schauer *et al.*, 2001). These compounds begin to affect health when they enter the lungs and bloodstream by adhering to particulate matter, and as such, previous studies have found wood smoke PM to be more potent, or comparable, to cigarette smoke (Danielsen *et al.*, 2011).

2.5 Particulate Matter

Particulate matter (PM) is a mixture of solid particles and liquid droplets that are suspended in air. PM can be generated from either natural or manmade sources, and can be composed of acid, organic, metal, soil, or dust particles (EPA, 2013). Particulate matters are classified by their aerodynamic equivalent diameter (AED), and are generally placed in one of three categories: AED <10 microns = PM_{10}, < 2.5 microns = $PM_{2.5}$, and < 0.1 microns = $PM_{0.1}$. Particulate matter is considered coarse when between 2.5 - 10 microns, fine when less than 2.5 microns, and ultrafine (or nanoparticles) when less than 0.1 microns in diameter. Using these definitions PM_{10} includes all course, fine, and ultrafine particulate matter. Because PM larger than 10 microns is filtered out through the nose, cilia, and mucus of the respiratory tract, they are of lesser public health concern. Particulate matter begins to affect health when particles are present that are smaller than 10 microns, PM_{10}, and as such, these are the particles and exposures that are most often studied.

Particulate matter that is released during biomass fuel combustion peaks are at 0.1 µm - 0.2 µm in diameter, with a majority of all particulate matter less than 1 µm in diameter (Kleeman *et al.*, 1999). Due to size, these particles are not easily extracted from air via gravitational settling and can therefore travel hundreds of kilometers (Zuk *et al.*, 2007). PM emissions are highly dependent on fuel type, moisture content of the fuel, and the burn conditions (Khalil & Rasmussen, 2003).

2.5.1 Sources of Indoor Particulate Matter

Previous studies have found that there is a high correlation between outdoor, indoor, and personal PM exposures, with changes in outdoor PM levels often reflected in indoor/personal exposures (Janssen *et al.*, 2000). As one might expect, the correlation between indoor, outdoor, and personal PM levels becomes stronger as particulate size decreases (Monn, 2000). Due to this, outdoor ambient $PM_{2.5}$ levels are often used as a surrogate for indoor and personal PM exposure. Outdoor PM is second only to smoking in contaminating indoor air. In the absence of this or other human activity, about 70% of indoor PM comes from outside sources (Monn *et al.*, 1997). Personal PM exposures often exceed indoor and outdoor values due to various indoor sources or human activity, including: cooking, the use of gas appliances, dusting, vacuum cleaning, smoking, time spent in a vehicle, and human activity as this re-suspends settled PM (Weisel *et al.*, 2005). In the presence of these indoor sources, the percentage of PM attributed to outdoor sources drops to about 50% (Weisel *et al.*, 2005).

Cooking, along with cleaning, smoking, and human activity are the dominant indoor sources of PM_{10} (Jones *et al.*, 2000). Cooking and smoking are the major sources of indoor $PM_{2.5}$. It is important to note that these studies were not done in homes heated with indoor or outdoor biomass combustion products. Few studies have been conducted in developed countries to monitor the impact of these units on indoor and personal PM exposure levels.

2.5.2 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 (American Lung Association, 2008).

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

2.5.3 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 2.1. 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 2.1: 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

2.6 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.

2.6.1 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, 2009). 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, 2009). 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.

2.6.2 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).

2.6.3 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 2.2 shows symptoms of acute poisoning based on COHb levels.

Table 2.2: 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.

2.6.4 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 2.3.

Table 2.3: 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

2.7 Biomass Fuels and Improved Stoves Use in Kenya

Biomass fuels are the predominant form of energy in Kenya, used by 90% of households (UNEP, 2003). Fuelwood is mainly used in rural areas while charcoal, a cleaner form of biomass, used in urban areas. According to the Ministry of Energy survey of 2002, 89% of rural population reported fuelwood as the main fuel type while in urban areas it was only 7%. On the other hand, charcoal was used by 82% of urban households, and for rural households it was 34% (GoK, 2002). 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.

In Trans Nzoia County, 90.4% of the households use firewood for cooking, 18.4% use charcoal, 4.9% use paraffin, 3.7% use crop residue (although usage goes up to 90% during dry season), 0.8% use gas and 0.9% of the households use electricity. Another 1.0% uses other sources of energy for cooking (GoK, 2002). In Bungoma County, the main sources of energy include: firewood at 93.4%, charcoal at 4.7% and crop residue at 3.5% (although usage goes up to 90% during dry season). 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%.

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 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 2.4.

Table 2.4: 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

The improved wood stoves have, however, not been as successful on a national scale, with the Maendeleo stove being used by only 4% households despite its promotion since 1987. This is partly because there is no monetary value attached to the firewood in rural areas as it is gathered for free from dead wood material. Therefore the energy efficiency driver of improved stoves in urban areas does not work for rural areas. Secondly, the three stone open fire comes at no cost while the improved stove has to be bought. Some of the wood stoves also require specialized skills for installation in the kitchen such as MRS and Cheprocket stove. Stove production is also limited to clay deposits areas, and once produced and transported to other areas, its price increases, making it potentially unaffordable to many rural households. Some stoves are however local innovations among rural communities for example the Chepkube stove.

2.7.1 Chepkube Stove

The Chepkube stove is a model that has been designed by women of the larger Kalenjin community. Its key component is an oven or food warming cavity which is built into the clay that the main structure of the stove is made out of. The idea behind it is that since the clay of the stove holds heat and radiates it slowly after use, that heat is able to be captured in some way. It is very efficient in terms of firewood usage, especially if more than one pot is cooked at once, and if food is kept in the oven/ warmer, thus avoiding reheating (SCC-Vi Agroforestry, 2010).

Simple models have one opening for fuel and two to four burners as indicated in Plate 2.1. The women smear clay around a metal can or small drum which is right next to the wall of the fire cavity to form the food warmer. The warmer should have a firm door usually the lid of the can or a piece of metal in order to keep food or water warm all day.

Plate 2.1: Typical Chepkube stove
(Source: Allison, 2008)

There are more complex Chepkube models that look similar to the first, but they are raised about 50 cm so that a small compartment for chicks is created under the clay. Chicks may be raised in here from one day old up to two months old, then grown somewhere else, or sold for market. The bottom part must have two doors; one that allows the user to insert food, water, and medicine and one that allows chicken easy passage to an enclosed chicken run used when the heat from the fire is too intense. With regular (daily) use, the chicks get enough heat so that the mother hen can be free to lay more eggs. The most complex model also includes a covered cavity with a soft bottom to act as an incubator for eggs. In this case, fertilized eggs can be kept there for the whole incubation period of 21 days and hatch with an 80% success rate, if the user is vigilant in turning the eggs twice a day at regular times (SCC-Vi Agroforestry, 2010).

Some Chepkube models are fitted with one burner that utilizes sawdust purely or charcoal. The sawdust compartment is constructed right into the main body of the Chepkube. This makes lighting of the sawdust automatic and once well-lit the food is transferred in to the compartment saving on firewood consumption (SCC-Vi Agroforestry, 2010).

All models are constructed from locally available materials; mud, bricks, metal rods, for the stove, and an iron sheet or preferably and old metal can for the oven. The materials are then smeared with clay or dung mixture that is usually smeared on the kitchen walls. Different households have different models and stove finishes depending on the layout of the burners, oven, the designs built in the clay, and the colors used in the finishing (SCC-Vi Agroforestry, 2010).

For the brooder version, extra bricks, an old blanket, a metal sheet, dry soil and old wooden boards (off-cuts) are needed. For the hatchery version, an extra metal can and some lining materials are used (SCC-Vi Agroforestry, 2010).

2.7.2 Mud Rocket Stove

The rocket stove is a wood-burning outdoor cooking stove that was developed by Dr. Larry Winiarski in the 1980s as a safe, effective, environmentally conscious alternative to open fires for impoverished people in developing countries. Compared with traditional open fires (also called “three-stone fires”), rocket stoves can be healthier and more efficient. They reduce smoke and harmful emissions, use less fuel wood, and increase the amount of energy from the wood that is turned into heat energy. In countries like the Democratic Republic of the Congo, energy-efficient rocket stoves reduce air pollution, allow for more efficient cooking, provide employment opportunities, prevent widespread deforestation, and help refugees and internally displaced people cook meals when fuel is not readily available or is not safely procured (Aprovecho, 2005).

Beyond that, rocket stoves can be an inexpensive means of slowing climate change. A basic rocket stove consists of a few components: An insulated rocket elbow, formed of a horizontal fuel chamber that fits into a vertical combustion chamber (also referred to as a “chimney”), a stove body that surrounds the elbow, made of mud, with a small opening, a fuel grate, placed inside the fuel chamber, on which the fuel wood rests, a pot skirt, a sheet metal shield that surrounds the cooking vessel, creating a gap, to ensure that more heat from the flue gases enters the vessel as shown in Figure 2.1 illustrating the rocket principle .

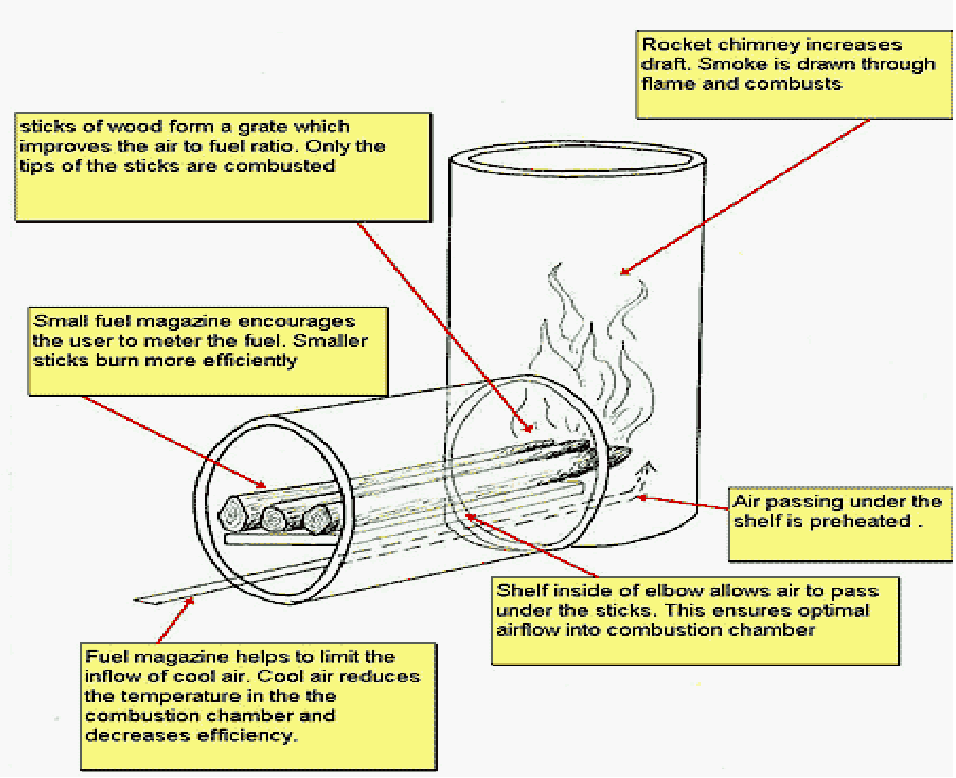


Figure 2.1: The Rocket Principle
Source: Aprovecho, 2005

In open fires unlike rocket stoves, only a small percentage of the heat energy released from the burning wood makes it into the cook pot. With a rocket stove, only the tips of the fuel wood are burned, eliminating that waste and eliminating smoke. Rocket stoves can use most dry plant matter, not just wood — leaves, twigs, and brush will work as well. Fresh air enters the fuel chamber from beneath the burning wood resting on the grate, allowing the air to be preheated before it enters the combustion chamber, which in turn leads to cleaner combustion. The small fuel entry not only demands less fuel wood, but also limits the amount of cold air that can get in. The combustion itself is confined to a small, insulated space, so most of the energy in the wood is converted to heat for cooking. The cook pot sits directly on top of the combustion chamber, so the hot gases contact it immediately after combustion, reducing smoke. The pot skirt that surrounds the vessel further improves efficiency by increasing the temperature of the flame that contacts the pot, and by directing the gases to scrape the sides of the pot as well as the bottom, increasing heat transfer (Aprovecho, 2005).

2.7.3 Cheprocket Stove

The Cheprocket is a hybrid of rocket stove and Chepkube stove. It uses the rocket principle illustrated in Figure 2.1 above for combustion and also it is fitted with food warmer like the Chepkube and a brooder. This stove is found majorly in Mt. Elgon region and Cherangani regions of Kenya. There is no standard size of constructing Cheprocket stove. The common feature of Cheprocket is that the firing chamber has an elbow like shape and uses the rocket principle to improve on gas combustion efficiency; some Cheprockets have food warming compartments while others do not have but they must have a chick brooder fitted (SCC-Vi

Agroforestry, 2010). Some Cheprocket stoves are single burner; others have two burners, while others have three burners.

One of the greatest advantages of Cheprocket stove over some Chepkube models and the MRS is its height from the ground. Cheprocket stove is raised from the ground up to a height of 75 cm to 1 m (SCC-Vi Agroforestry, 2010). Increased stove height helps in reducing emissions exposure by reduction of periods cooks bend over directly above the fire during cooking. Stove types are among many kitchen characteristics found to influence personal exposures of PM and CO in Bukina Faso (Yamamoto *et al.*, 2014).

2.8 Improved Stoves and Personal Exposure

Until recently, there has been very limited research on effectiveness of improved stoves in reducing personal exposure (Manuel, 2003). Replacing the traditional open fire with more efficient cooking technologies has long been an option to reduce indoor air pollution, as well as to decrease fuel consumption, greenhouse gases emissions, and deforestation (Ruiz-Mercado *et al.*, 2011). Use of an improved biomass stove in Mexico in actual field conditions, has been shown to achieve average reduction of 70% in indoor air pollution concentrations (Zuk *et al.*, 2007), 56% reduction in household fuel consumption (Berrueta *et al.*, 2007), and 74% reduction in greenhouse gas emissions (Johnson *et al.*, 2008) compared with open fires. Significant reductions in indoor air pollution and personal exposures have been observed following installation of improved chimney stoves in Peru (Schwartz & Zanobetti, 2009), implying that the stoves could be a key to solving the health problems arising from biomass fuels use. There is need to generate more evidence in Kenya and other parts of Africa, given the behavioural and cultural complexities that surround cooking patterns. Two studies in India for instance found no association in exposure levels between traditional and improved stove users (Parikh *et al.*, 2002). A study in Kenya (Ezzati & Kammen, 2002) reported significant reduction in exposure when improved stove was used but no health outcome.

2.9 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 addressing this issue 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.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter describes information on the location, size, climatic conditions, vegetation type and demographic information of the two main study Counties that include Trans Nzoia and Bungoma. It also gives the research design, sample size and sampling design and data collection methods.

3.2 Study Site

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

3.2.1 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 3.1. 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).

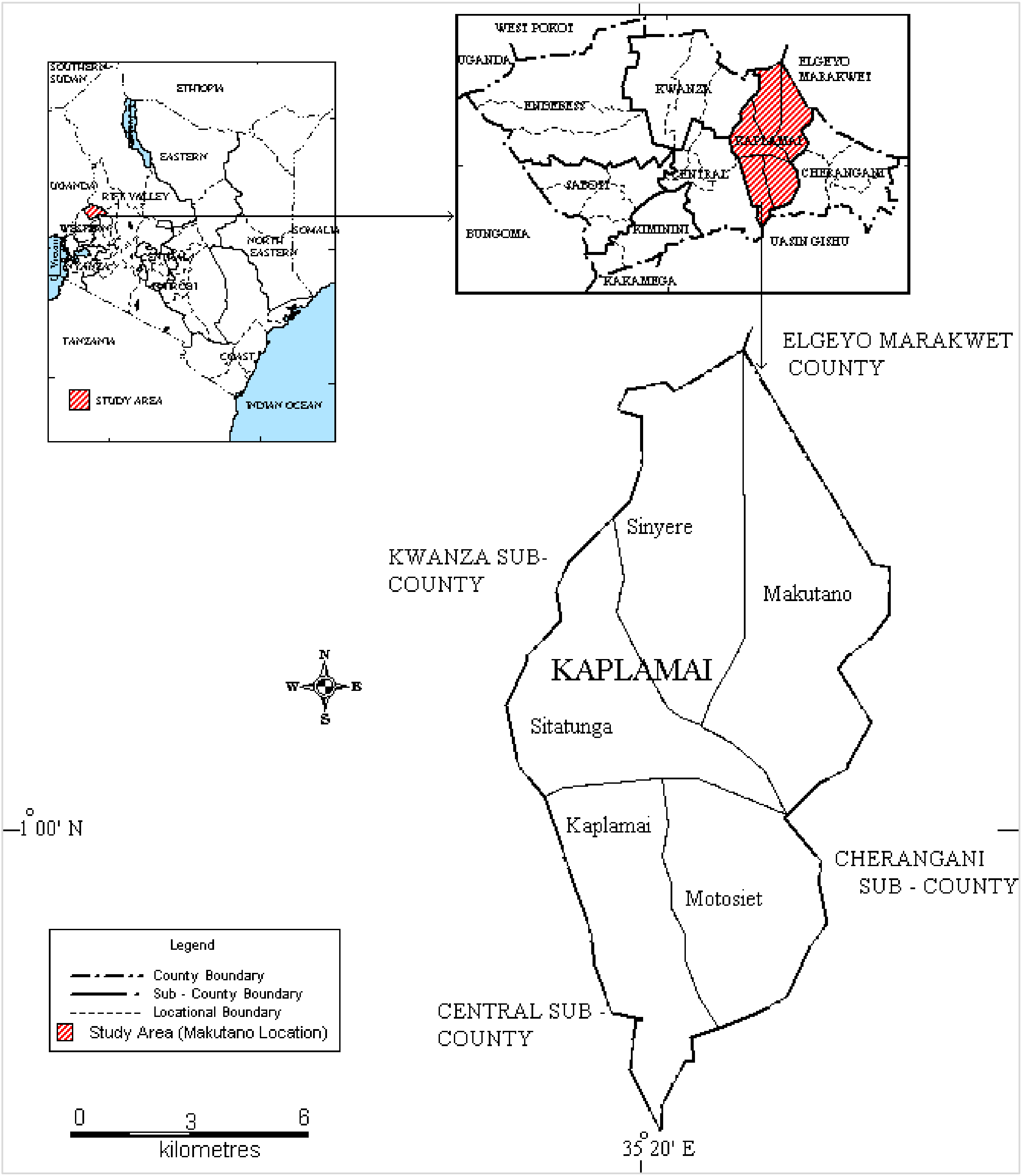


Figure 3.1: Trans Nzoia County indicating Location of Kaplamai Sub-county
Source: Moi University, 2017

3.2.2 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 not 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.

3.2.3 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).

3.2.4 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 3.1 shows the population projections for the years 2015 and 2017 both at county level and for Kaplamai sub-county (GoK, 2013a).

Table 3.1: Trans Nzoia County and Kaplamai Sub-county Population

Region	2015			2017		
	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: Trans Nzoia Development Plan, 2013

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.

3.2.5 Vegetation Cover of Trans Nzoia County

The County has over 18% of the total county surface area forest cover as compared to the country which has a cover of 1.7% (GoK, 2010). This puts the county at an enviable position in Kenya as one of the top 10 forested counties. The main forest types in the County are indigenous forests, plantation forests, bamboo, moorland and grass. The main forest areas by Sub-county are as shown in Table 3.2.

Table 3.2: The Main Forests Areas by Sub-county

Sub county	Forest area	Size in Ha.
Kaplamai	Kapolet trust land forest	746.7
Cherangani	Kapolet forest	1551.60
Sub-total		**2,298.30**
Saboti	Saboti forest	10,035.20
Endebess	Sosio forest	10,035.20
Central	Kitale township forest	401
	Kitalale forest	2037.2
Sub-total		**22,508.60**
Kwanza	Suam forest	2390.00
	Kimothon forest	11,024.00
	Kiptogot forest	10,243.00
Sub-total		**23,657.00**
Grand total		**48,463.90**

Source: GoK, 2008

The total area of gazetted forest in the county is 45, 454.37 ha and the area of non-gazetted forest is 252.53 ha. In addition, there are many other undocumented forest areas under private and institutional ownership including the Mount Elgon National Park (GoK, 2013a). Most indigenous forests are harvested green and stack in kitchens to dry up as indicated in Plate 3.1.

Green firewood stack on the kitchen roof to dry up in Kapolet Village, Trans Nzoia County

Plate 3.1: Stack of firewood from Kapolet Forest
(Source: Author, 2016)

High demand for forest products especially energy resources has necessitated non-governmental organizations to put interventions to conserve forests such as introduction of energy saving biomass stoves. In Trans Nzoia County, 90.4% of the households use firewood for cooking, 18.4% use charcoal, 4.9% use paraffin, 3.7% use crop residue (although this proportion varies with season), 0.8% use gas and 0.9% of the households use electricity. Another 1.0% uses other sources of energy for cooking (GoK, 2002).

3.2.6 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 3.2.

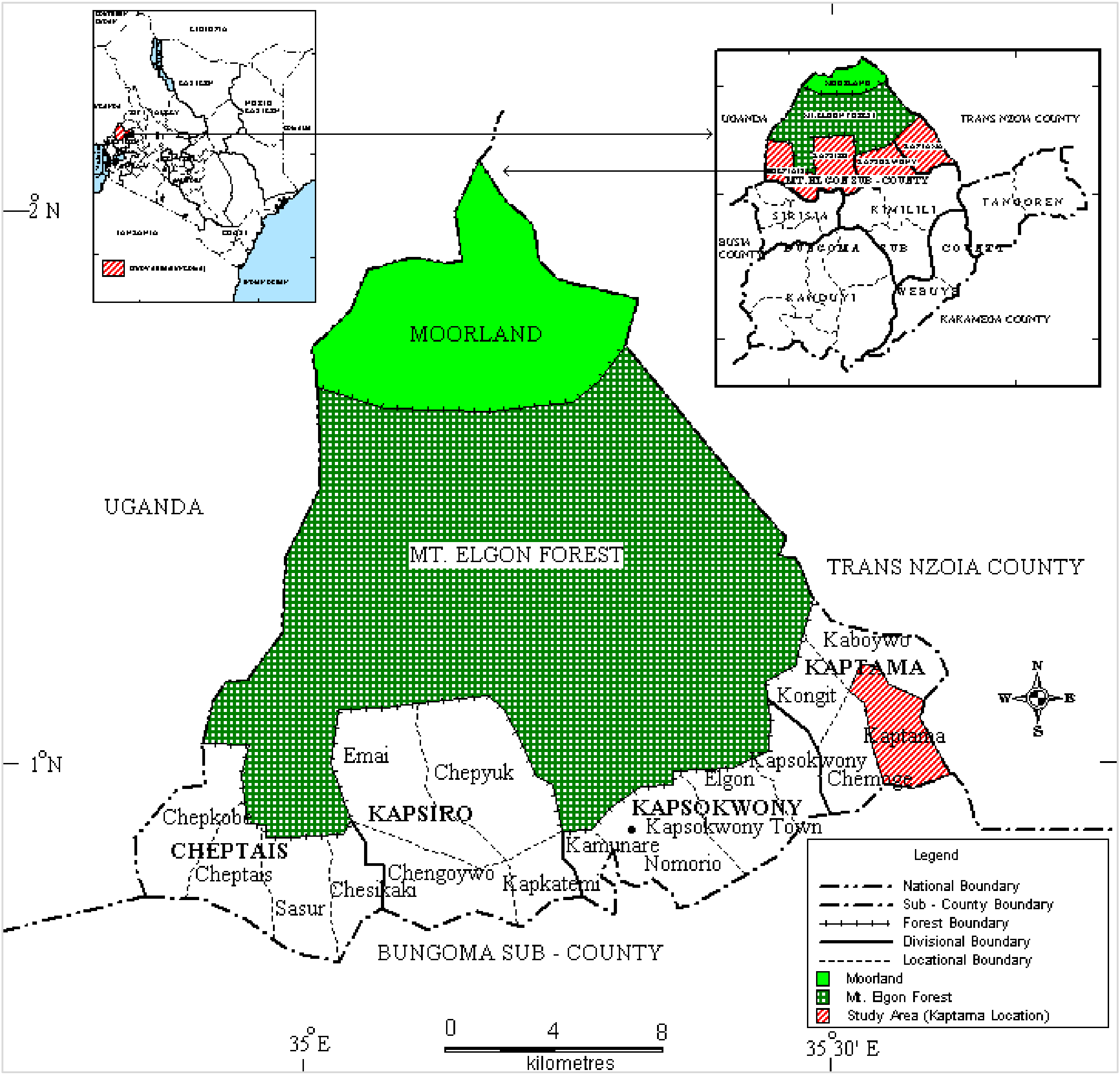


Figure 3.2: Location of Mt. Elgon Sub-county in Bungoma County
Source: Moi university, 2017

3.2.7 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.

3.2.8 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 3.3: 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: Bungoma County Development Plan, 2013

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 as indicated in Plate 3.2.

Stored crop residues for use as fuelwood at a homestead in Biwut Village, Bungoma County

Plate 3.2: Stored Crop Residues for fuel purposes
(Source: Author, 2016)

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).

3.2.9 Vegetation Cover in Bungoma County

The County has only one gazetted forest, the Mt. Elgon forest reserve which measures 618.2 km^2, and one National park, which measures 50.683 km^2. It is the source of major rivers including the Nile (indirectly), Nzoia, Kuywa, sosio, Kibisi and Sio-Malaba/Malakisi (GoK, 2013b). Other small scale forests and woodlands are owned by individuals and institutions such as Webuye Rai Paper Mills (GoK, 2013b). Mt. Elgon community engage deforestation through selling of firewood from the forest to communities living farther away.

3.3 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 and comparing these levels against WHO safe limits. 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 shown in Figure 3.3.

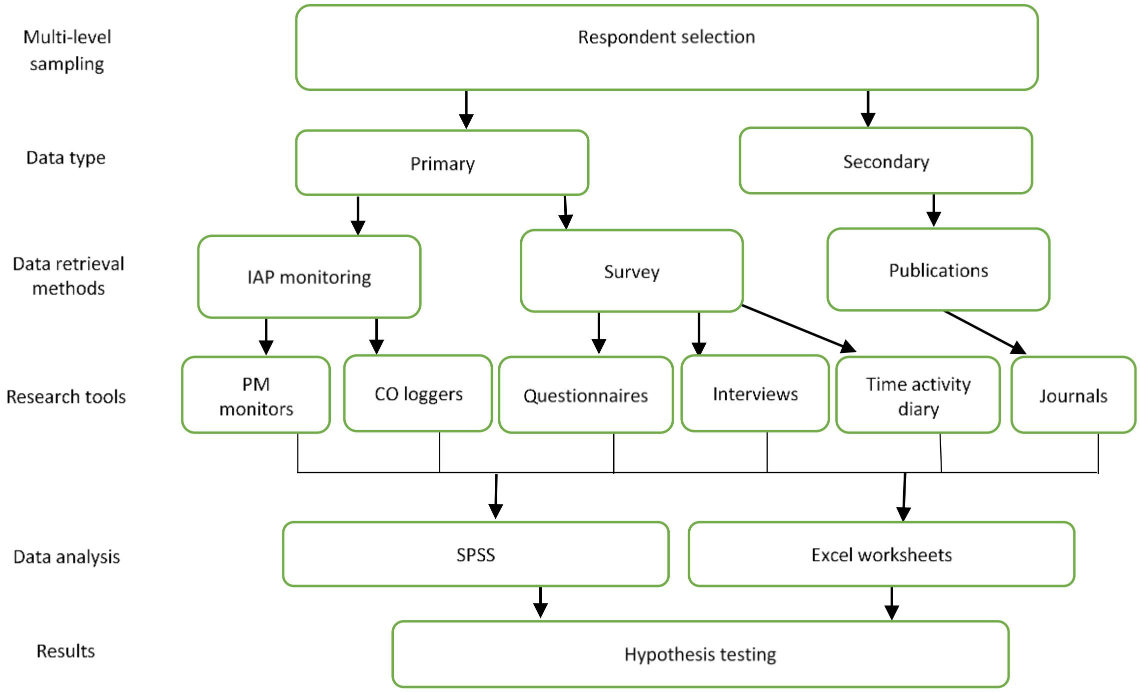


Figure 3.3: Schematic Diagram of the Research Design

3.4 Sampling method

A multi-stage sampling technique was used in this study as illustrated in Figure 3.4. Trans Nzoia and Bungoma Counties were selected purposively because both have major ecosystems where efforts have been made to promote biomass stoves aimed at ecosystem conservation and indoor air pollution reduction. Kaplamai Sub-county in Trans Nzoia county and Elgon Sub- county in Bungoma count were selected using cluster sampling method because in these sub-counties, divisions where stove promotion was undertaken are found. 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.

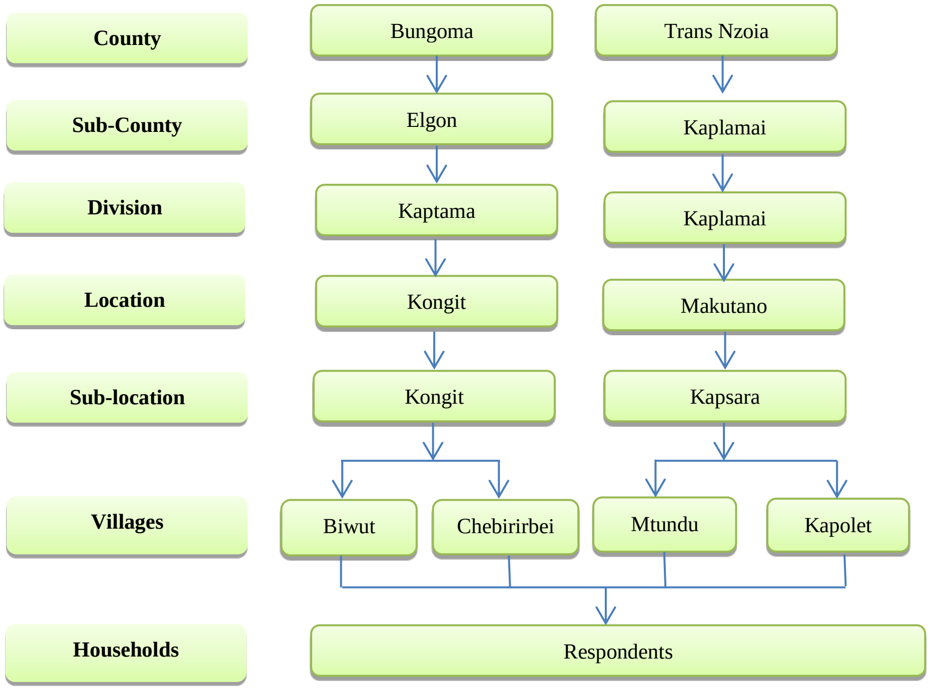


Figure 3.4: Multi-stage Levels of Sampling Design

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.

3.5 Data Collection

3.5.1 Questionnaire Surveys

Questionnaires shown in Appendix 1 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 that determine exposure, for instance demographic characteristics, fuel use, housing type, cooking patterns, stoves use and ventilation parameters.

Interviews using key informant guide indicated in Appendix II 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.

3.5.2 Focus Group Discussion

Focus group discussions using guide questions indicated in Appendix III 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. A total of 4 FGDs were held. 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 exposure levels. The FGDs were also helpful in validating related questionnaire responses.

3.5.3 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 in Appendix IV 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.

3.5.4 Kitchen Performance Test

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.

3.5.5 Kitchen Air Pollution Monitoring

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).

3.5.6 Personal Exposure Assessment

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

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

$$MDI = (CA \times IR \times 24)/BW \text{ ....Equation 1}$$

Where;

MDI – Maximum daily intake

CA – contaminant concentration

IR – Inhalation rate (m^3/hr)

24 – hours/day

BW – body weight (kg)

Assumptions

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

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

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

Where: EC_j ($\mu g/m^3$) = average exposure concentration for exposure period j;

CA_i ($\mu g/m^3$) = contaminant concentration in air in ME_i;

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

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

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

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

Assumptions

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

3.5.7 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 ECs for each pollutant, an appropriate RfD values for each inhaled contaminant was selected using WHO values given in Table 3.4.

Table 3.4: 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 µg/m^3)	10 µg/m^3

Source: WHO, 2010

Hazard quotients were estimated by use of the Equation 3 to indicate whether there was any health risk.

$$\mathrm{HQ} = \mathrm{EC}/\mathrm{RfD}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 3}$$

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.

3.7 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.

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.

One-way ANOVA was used to compare the variation of quantified kitchen and personal PM and CO concentrations from different stoves to WHO thresholds and further multiple tests of mean separation were done according to Tukey’s test of significance at $p < 0.05$. Graphs, tables and means were used to present results.

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.

3.8 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.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents the results of each objective. It gives the social demographic characteristics of the population, fuel type use, quantities of fuel use, and kitchen concentrations for both $PM_{2.5}$ and CO using different fuels in different stoves. The chapter further presents the short-term personal exposure for both $PM_{2.5}$ and CO emissions under different microenvironments using different stoves and predicts the long-term exposures as well. Finally, presentation of kitchen characteristics and how they influence $PM_{2.5}$ and CO kitchen concentrations was done.

4.2 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 4.1. 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 4.1: 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

4.3 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 4.2. Crop residues are seasonal and mainly used during the dry season after harvesting crops or when available.

Table 4.2: 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 4.3.

Table 4.3: 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 4.4.

Table 4.4: 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 4.5. 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 4.5: Determinants of Fuel Use

	Stoves			
Determinant	**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.

4.4 Indoor Air Pollution

Kitchen concentrations of particulate matter and carbon monoxide using both improved and traditional biomass stoves for wood and crop residue biomass fuels were provided.

4.4.1 Kitchen $PM_{2.5}$ Concentrations

At 95% CI, average 24-hour kitchen $PM_{2.5}$ concentrations from all the stoves were significantly ($p = 0.000$) higher than stipulated WHO threshold. Three stone stove had the highest average 24-hour PM emissions at 6022.245 µg/m^3 ($p = 0.000$) using crop residues as fuel and 4272.414 µg/m^3 ($p = 0.000$) using firewood as indicate in Figure 4.1. Particulate matter concentration was least from Chepkube stove using firewood at 682.646 µg/m^3 ($p = 0.000$) while Cheprocket produced the least $PM_{2.5}$ emissions when crop residues were used as fuel at 5773.531 µg/m^3 ($p = 0.000$) as fuel as shown in Figure 4.1.

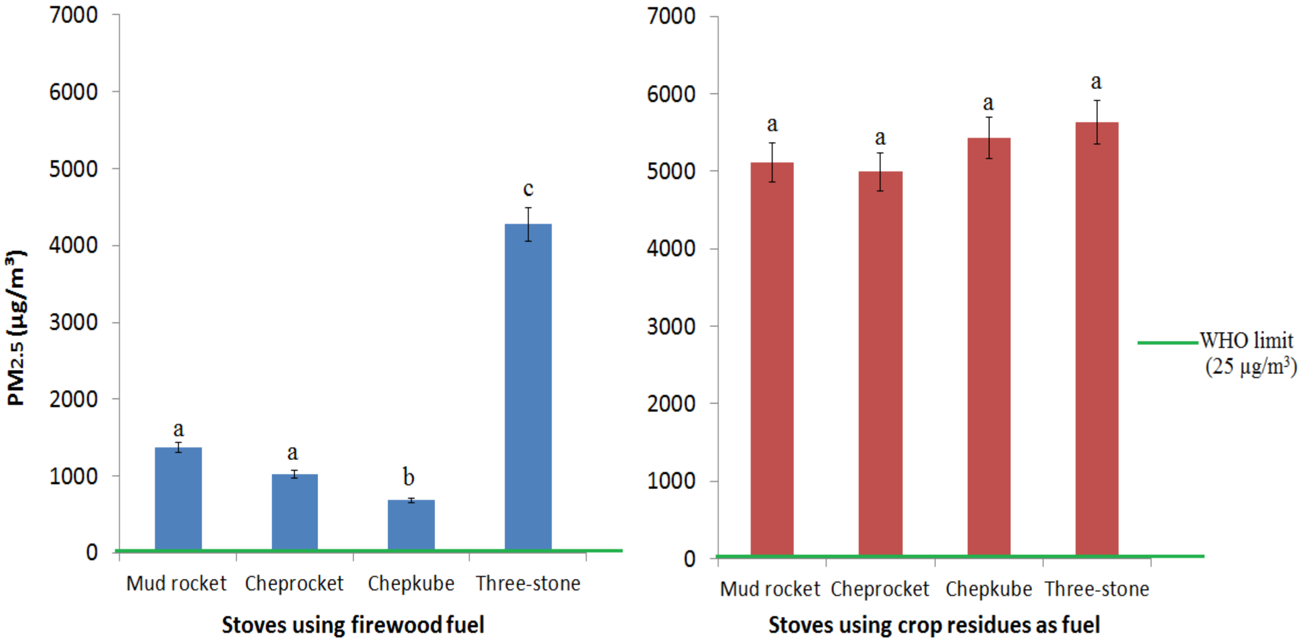


Figure 4.1: Mean 24-hr Kitchen $PM_{2.5}$ Concentrations
NB: Bars designated with same letter within a fuel type are not statistically different at $p < 0.05$ based on Tukey's test.

There were diurnal variations in the manner in which PM emissions were emitted from various biomass stoves and fuel type. Particulate matter emissions were high in kitchens using mud rocket stove (MRS) using crop residues during simmering period at approximately 5,000 µg/m^3 ($p < 0.001$) while maximum recorded kitchen concentration $PM_{2.5}$ emissions was close to 30,000 µg/m^3 (min – 4,663.6 µg/m^3, IQR – 149.814 µg/m^3, $p < 0.001$) and approximately 16,000 µg/m^3 (min – 791.0 µg/m^3, IQR – 241.479 µg/m^3, $p = 0.000$) using crop residues and firewood fuels respectively. Periodic variations also indicate that there were three major meals cooked in the households as indicated in Figure 4.2.

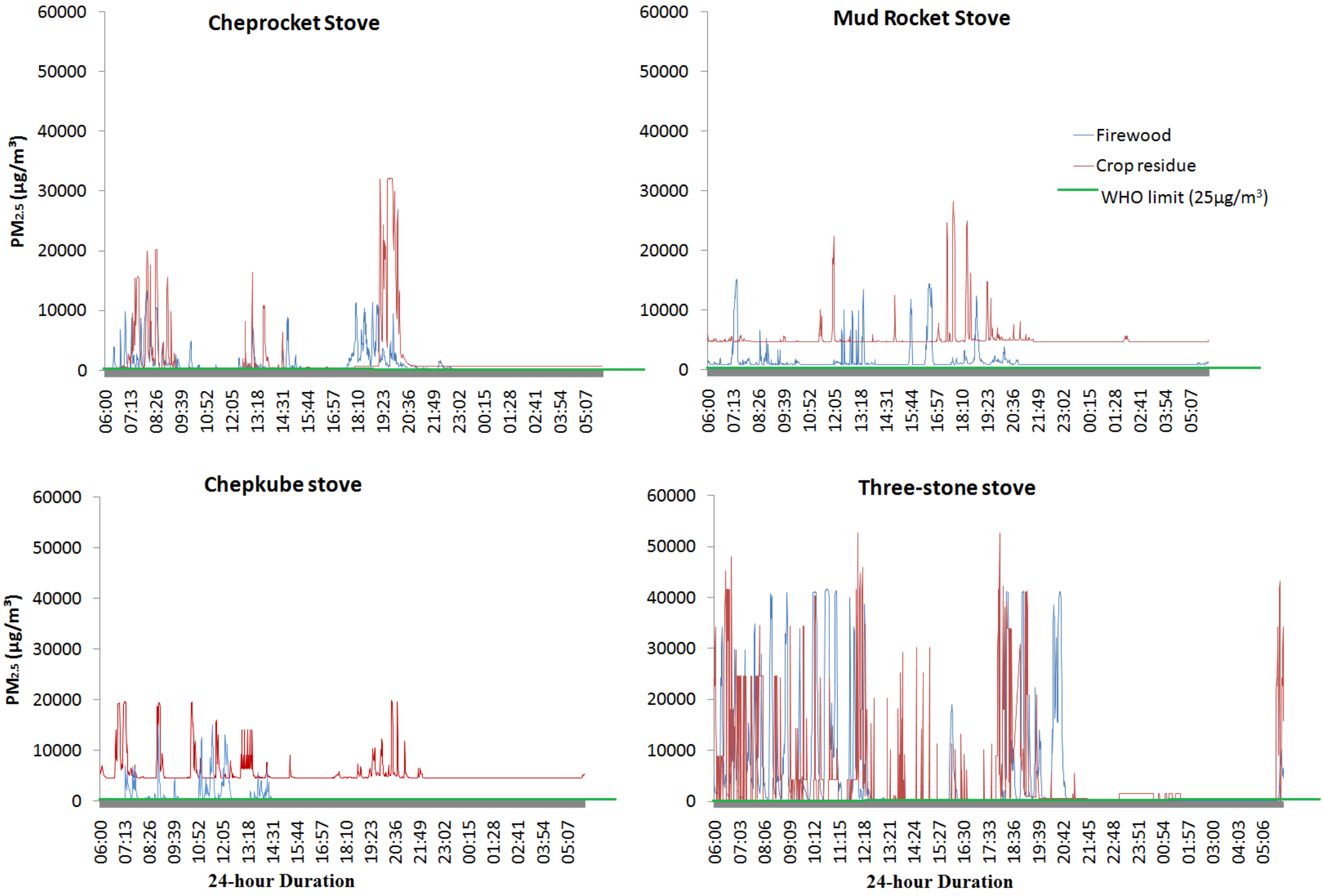


Figure 4.2: Diurnal Variation of $PM_{2.5}$ using Different Biomass Stoves

Diurnal variations in Figure 4.2 indicated that simmering period in the Chepkube stove using crop residues was higher compared to firewood. Maximum kitchen $PM_{2.5}$ concentration recorded using Chepkube stove was approximately 20,000 µg/m^3 (min – 4,529.5 µg/m^3, IQR – 281.33 µg/m^3, $p < 0.001$) and approximately 15,000 µg/m^3 (min – 215.5 µg/m^3, IQR – 49.30 µg/m^3, $p < 0.001$) using crop residues and firewood fuels respectively. Maximum kitchen $PM_{2.5}$ concentration recorded using Cheprocket stove was approximately 16,000 µg/m^3 (min – 210.4 µg/m^3, IQR – 524.511 µg/m^3, $p < 0.001$) and approximately 32,000 µg/m^3 (min – 387.8 µg/m^3, IQR – 280.574 µg/m^3, $p < 0.001$) using firewood and crop residues fuels respectively.

Kitchen $PM_{2.5}$ concentrations using three-stone fire was continous during the day whether crop residues or firewood were used as fuel as indicated in Figure 4.2, which contributed to the high levles of $PM_{2.5}$ recorded. The highest recorded kitchen $PM_{2.5}$ concentration using crop residues was from three-stone fire approximately 50,000 µg/m^3 (min – 5.0 µg/m^3, IQR – 4062.221 µg/m^3, $p < 0.001$) and approximately 40,000 µg/m^3 (min - 19.7 µg/m^3, IQR - 2531.871 µg/m^3, $p < 0.001$).

4.4.2 Kitchen Concentration of Carbon Monoxide

At 95% CI, three-stone stove had the highest average kitchen CO concentrations at 75.441 ppm ($p < 0.001$) using crop residues as fuel while Chepkube stove had the least average 24-hour kitchen CO concentrations of 8.8171 ppm ($p < 0.001$)as indicate in Figure 4.3. Chepkube stove recorded the least kitchen CO concentrations using wood as fuel at 8.7224 ppm ($p < 0.001$) as indicated in Figure 4.3.

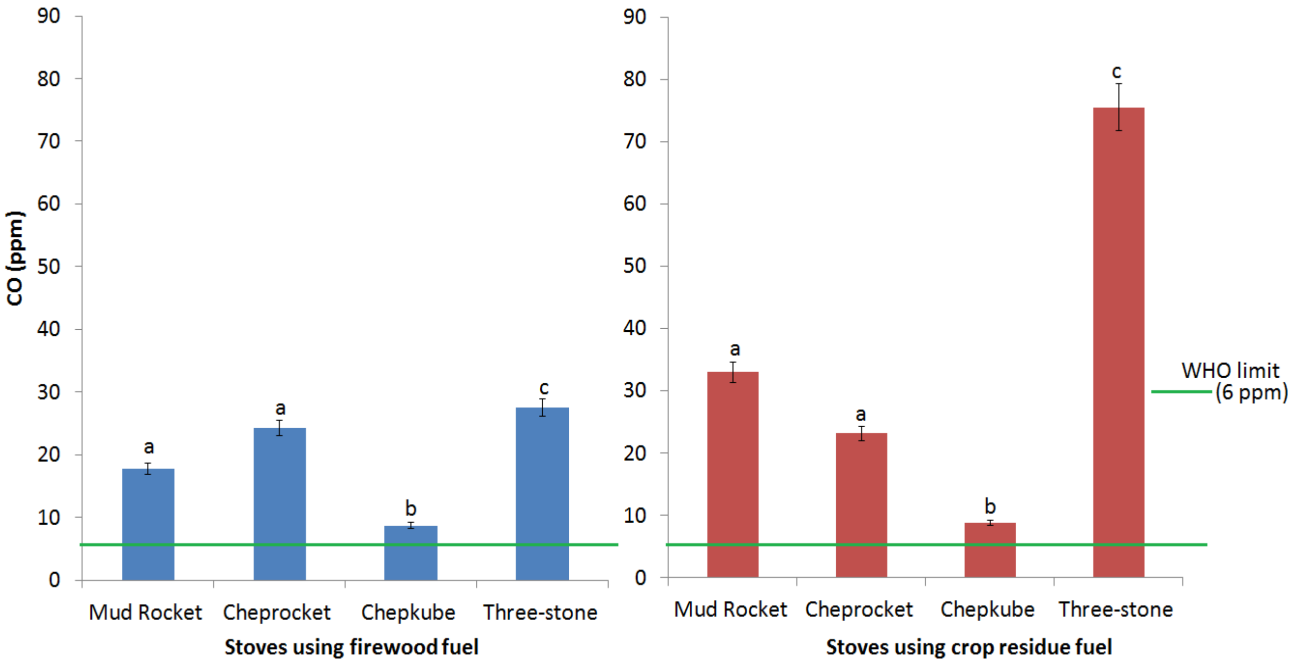


Figure 4.3: Average 24-hr Kitchen CO Concentrations using Different Biomass Stoves
NB: Bars designated with same letter within a fuel type are not statistically different at $p < 0.05$ based on Tukey's test.

The highest recorded kitchen CO emission was from Cheprocket stove at 658 ppm (min – 0.00 ppm, IQR – 3.50 ppm, $p < 0.001$) and 304 ppm (min – 0 ppm, IQR – 12.5 ppm, $p < 0.001$) using crop residues and firewood fuels, respectively.

Kitchen CO concentrations recorded from MRS were 466.6 ppm (min – 0 ppm, IQR – 27 ppm, $p < 0.001$) and 163.5 ppm (min – 0 ppm, IQR – 19.25 ppm, $p < 0.001$) using crop residues and firewood fuels, respectively. There were several peak CO emissions from all the biomass stoves using both crop residues and firewood as fuel that exceeded both WHO safe guideline of 30 ppm and warning level of 50 ppm as indicated in Figure 4.4.

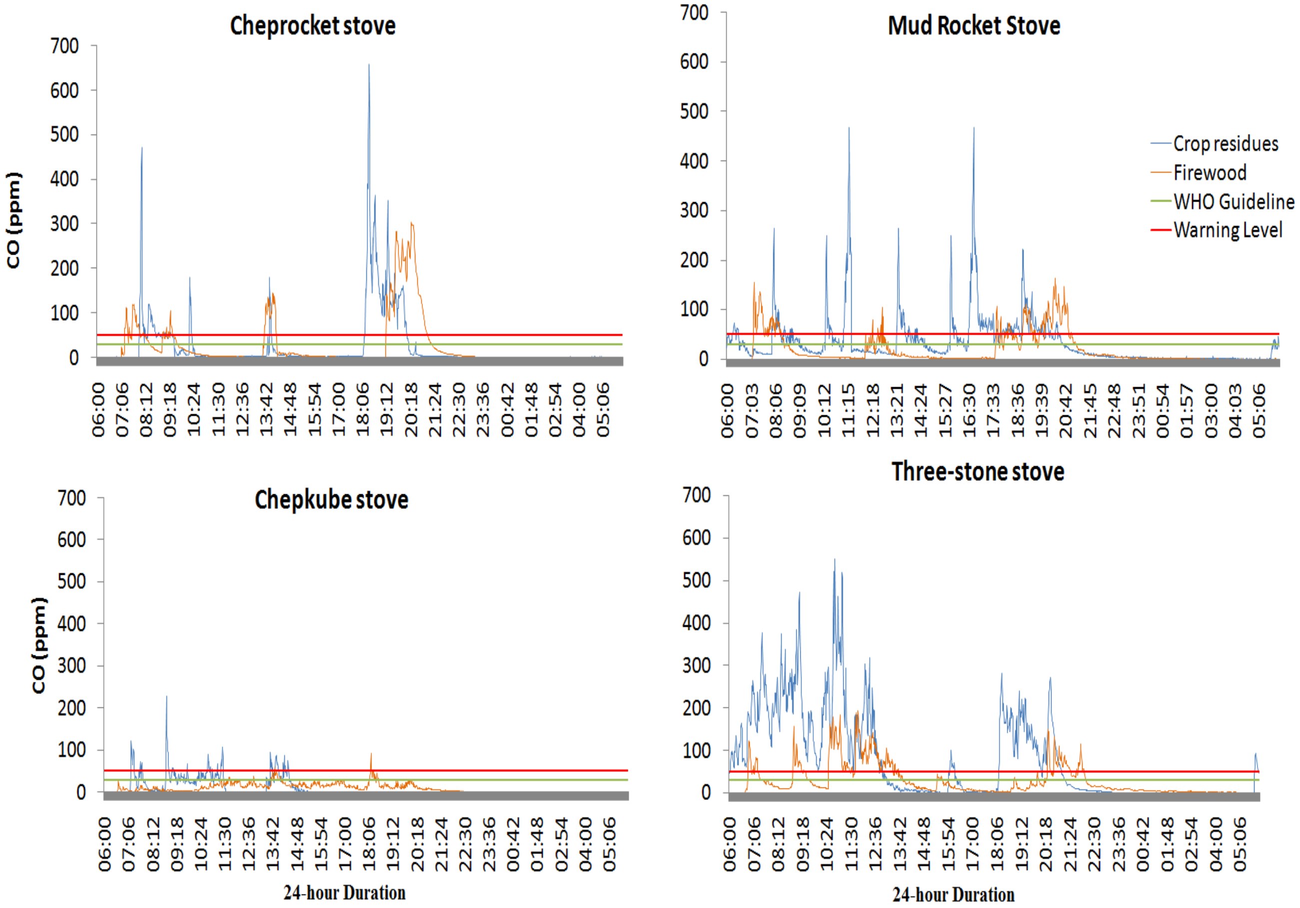


Figure 4.4: Diurnal Variation of CO using Different Biomass Stoves

Maximum kitchen CO concentration from Chepkube stove was 277.5 ppm (min – 0 ppm, IQR – 2.5 ppm, $p < 0.001$) and 91 ppm (min – 0 ppm, IQR – 14.5 ppm, $p < 0.001$) using crop residues and firewood fuels, respectively. As shown in Figure 4.4, most kitchen CO concentration using firewood were within the WHO safe limits using Chepkube stove.

At 95% CI, peak kitchen CO concentration from three-stone stove using crop residues was 594 ppm (min – 0 ppm, IQR – 138.5 ppm, $p < 0.001$) and 192 ppm (min – 0 ppm, IQR – 36 ppm, $p < 0.001$) using crop residues and firewood fuels, respectively. Like in all other stoves, there were several peak concentrations that exceeded both safe WHO limit and warning level as indicated in the periodical 24-hour variations in Figure 4.4.

4.5 Personal Exposure

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

At 95% CI, Maximum Daily Intake (MDI) of $PM_{2.5}$ was higher using crop residues compared to wood fuel. Maximum daily intake using MRS was 889.889 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 3,646.5 µg/m^3 ($p < 0.001$) and 2,768.5 µg/m^3 ($p < 0.001$) using crop residues and firewood fuels, respectively. While Cheprocket stove produced a daily exposure of 661.8 µg/m^3 ($p < 0.001$) and 2,791.8 µg/m^3 ($p < 0.001$) using firewood and crop residues fuels, respectively as indicated in Figure 4.5.

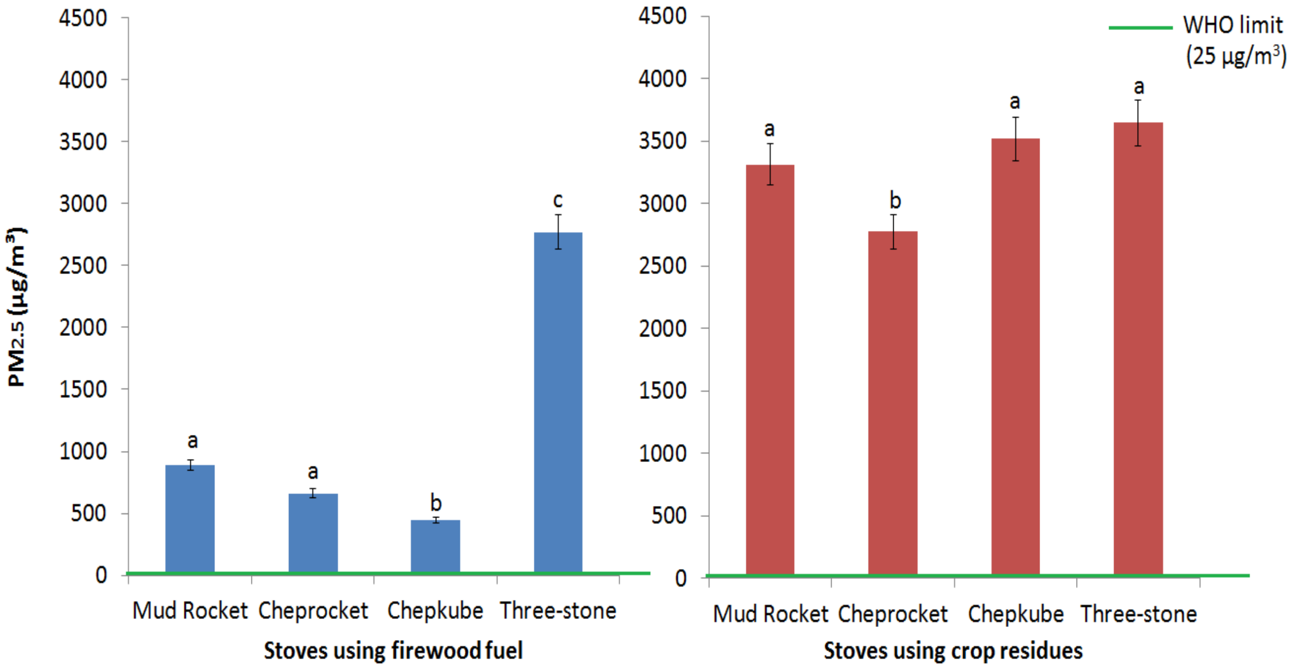


Figure 4.5: MDI of $PM_{2.5}$ using Different Biomass Stoves
NB: Bars designated with same letter within a fuel type are not statistically different at $p < 0.05$ based on Tukey's test.

4.5.2 Short-term CO Personal Exposure

At 95% CI, cooks using three-stone stove had highest MDI of 48.886 ppm ($p < 0.001$) and 17.79 ppm ($p < 0.001$) using crop residues and firewood fuels, respectively while those using the Chepkube stove had the least MDI at 5.713 ppm ($p < 0.001$) and 5.652 ppm ($p < 0.001$) using crop residues and firewood fuels, respectively as indicated in Figure 4.6.

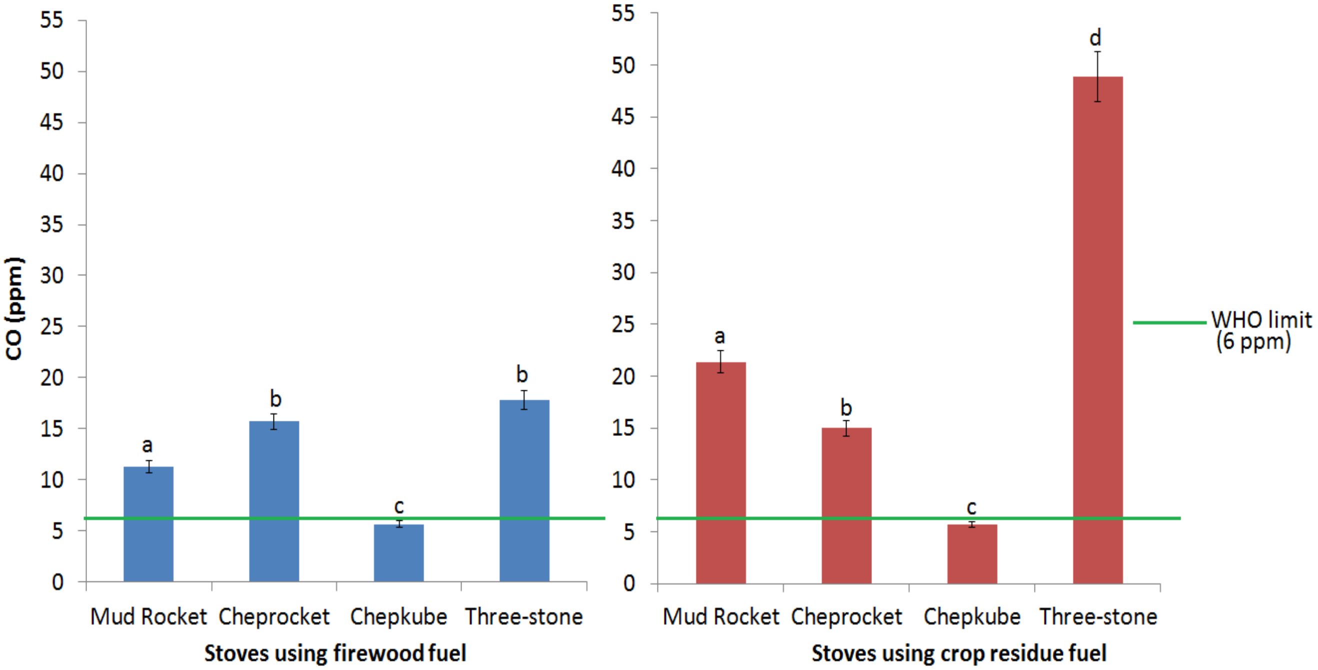


Figure 4.6: MDI of CO using Different Biomass Stoves
NB: Bars designated with same letter within a fuel type are not statistically different at $p < 0.05$ based on Tukey's test.

Maximum daily intake using mud rocket stove was 21.355 ppm ($p < 0.001$) and 11.264 ppm ($p < 0.001$) using crop residues and firewood fuels, respectively. Daily exposure using the Cheprocket stove was 14.980 ppm ($p < 0.001$) and 15.705 ppm ($p < 0.001$) using crop residues and firewood fuels, respectively.

4.5.3 Long-term Exposure of $PM_{2.5}$

Three-stone stove recorded the highest overall chronic Exposure Concentration (EC) of 1941.873 µg/m^3, (ME_1 – 876.869 µg/m^3, ME_2 – 1026.990 µg/m^3, ME_3 – 38.014 µg/m^3, $p < 0.001$) and 1576.25 µg/m^3 (ME_1 – 665.735 µg/m^3, ME_2 – 908.061 µg/m^3, ME_3 – 2.454 µg/m^3, $p < 0.001$) using crop residues and firewood respectively, while Chepkube stove recorded the least EC at 235.959 µg/m^3 (ME_1 – 106.371 µg/m^3, ME_2 – 102.721 µg/m^3, ME_3 – 26.867 µg/m^3, $p < 0.001$) and 1201 µg/m^3 (ME_1 – 846.101 µg/m^3, ME_2 – 298.863 µg/m^3, ME_3 – 56.463 µg/m^3, $p < 0.001$) using firewood and crop residues respectively. Chronic exposures of $PM_{2.5}$ from all biomass stoves were significantly higher than WHO safe limit of 10 µg/m^3 as indicated in Figure 4.7.

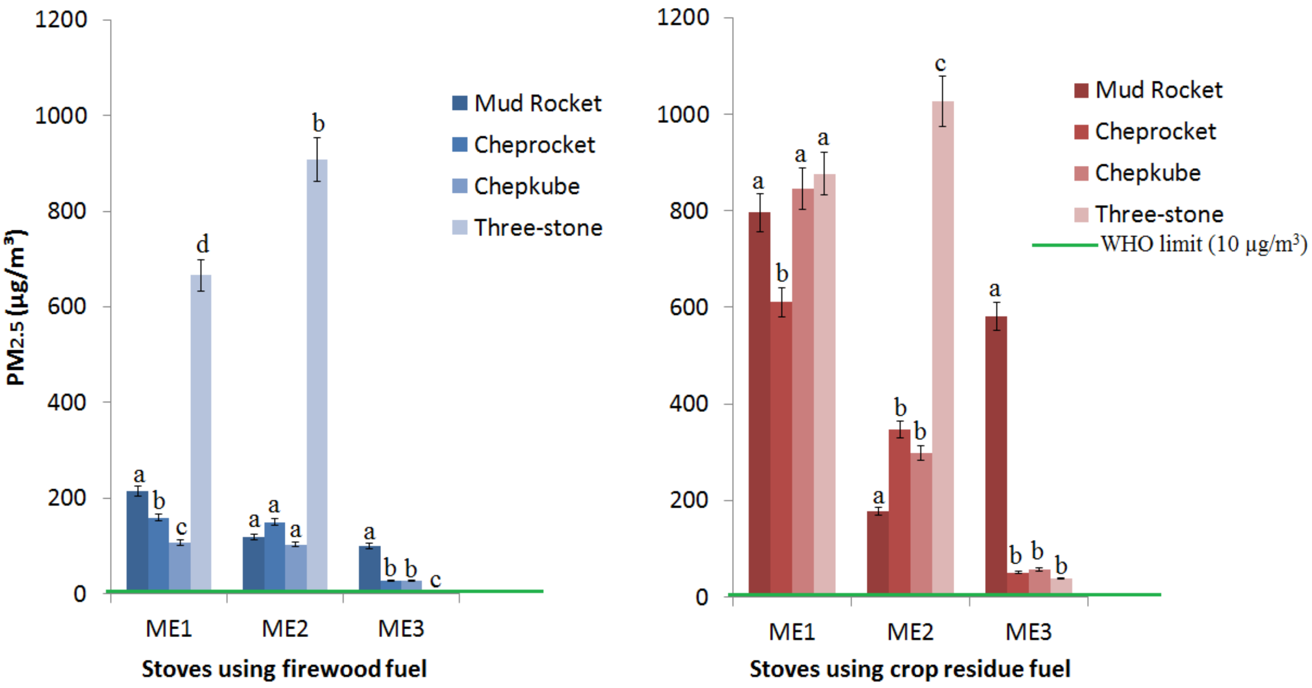


Figure 4.7: Long-term $PM_{2.5}$ Exposure using Different Biomass Stoves
NB: Bars designated with same letter within a specific microenvironment (ME) are not statistically different at $p < 0.05$ based on Tukey's test.

Mud rocket stove had a long-term EC of 431.693 µg/m^3 (ME_1 – 213.988 µg/m^3, ME_2 – 118.353 µg/m^3, ME_3 – 99.352 µg/m^3, $p < 0.001$) and 1555.277 µg/m^3 (ME_1 – 796.357 µg/m^3, ME_2 – 177.567 µg/m^3, ME_3 – 581.353 µg/m^3, $p < 0.001$) using firewood and crop residues as fuels, respectively. Further, Cheprocket stove produced a long-term EC of 334.58 µg/m^3 (ME_1 – 159.140 µg/m^3, ME_2 – 149.207 µg/m^3, ME_3 – 26.233 µg/m^3, $p < 0.001$) and 1050.117 µg/m^3 (ME_1 – 652.635 µg/m^3, ME_2 – 346.463 µg/m^3, ME_3 – 51.019 µg/m^3, $p < 0.001$) using firewood and crop residues as fuels, respectively.

4.5.4 Long-term Exposure of CO

Chronic CO exposure using MRS and three-stone stove using crop residue fuel were the highest at 10.303 ppm (ME_1 – 6.544 ppm, ME_2 – 3.386 ppm, ME_3 – 0.373 ppm, $p < 0.001$) and 18.119 ppm (ME_1 – 9.115 ppm, ME_2 – 8.568 ppm, ME_3 – 0.436 ppm, $p < 0.001$) respectively. The local innovation; Chepkube stove had the least chronic CO exposure concentrations at 3.116 ppm (ME_1 – 2.259 ppm, ME_2 – 0.857 ppm, ME_3 – 0 ppm, $p < 0.001$) and 2.006 ppm (ME_1 – 0.389 ppm, ME_2 – 1.617 ppm, ME_3 – 0 ppm, $p < 0.001$) using wood and crop residues as fuels, respectively as indicated in Figure 4.8.

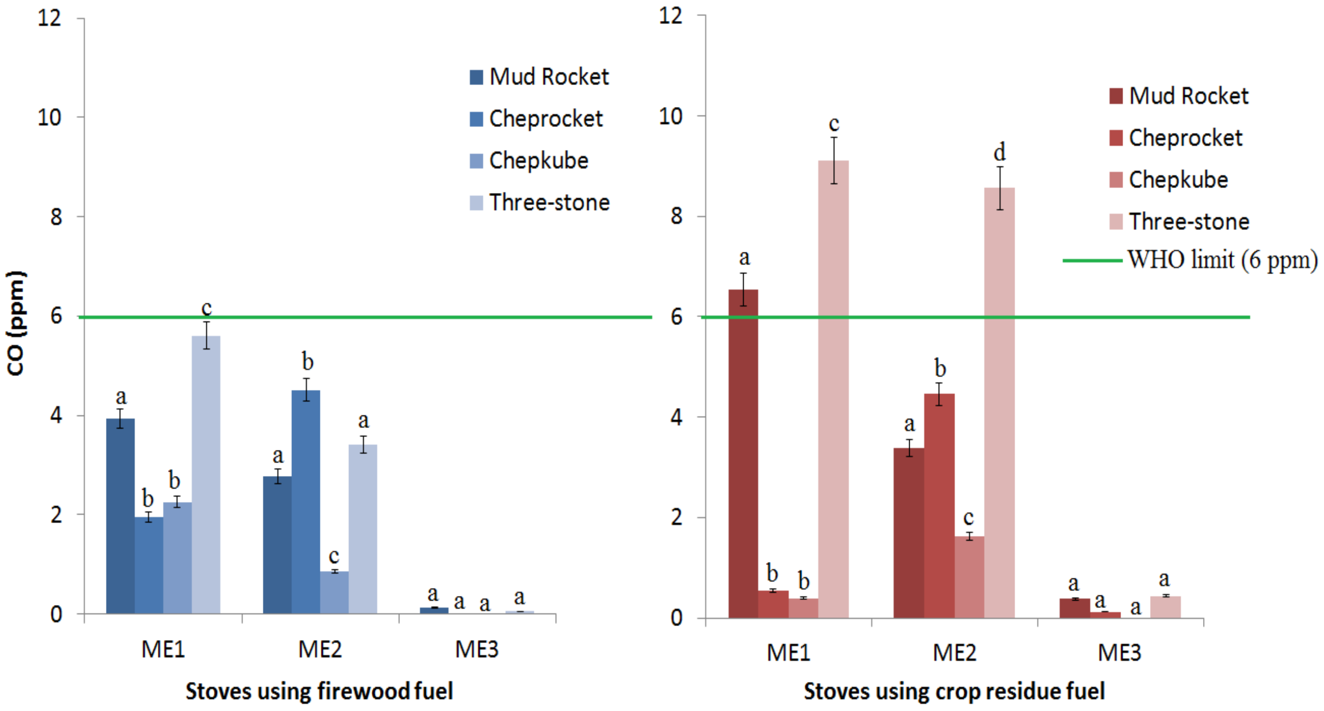


Figure 4.8: Long-term CO Exposure using Different Biomass Stoves

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

Chronic exposures to CO from all biomass stoves using firewood were significantly lower than WHO safe limit of 6 ppm. However, long-term EC of CO using crop residues using mud rocket and three-stone stoves during burning period and 1-hour peak period for three-stone stove were significantly higher than the recommended daily limit of 6 ppm as indicated in Figure 4.8.

4.6 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 4.6.

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 4.6, 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 4.6: Short-term and Long-term $PM_{2.5}$ and CO HQs

		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	Wood	35.5	1.8	0.09	43.1
Rocket	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 4.6. 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.

4.7 Relationship between Kitchen Characteristics and Indoor air Pollution

4.7.1 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 4.7.

Table 4.7: Correlation of $PM_{2.5}$ and CO Concentrations

	Firewood		**Crop residues**	
Stoves	***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.

4.7.2 Kitchen Characteristics

The most popular biomass stove type was the traditional three-stone at 52.1%, followed by Chepkube stove illustrated in Figure 4.9 at 30.8%, then Cheprocket stove (Plate 4.1) at 8.9% and mud rocket stove (Plate 4.2) was least used at 8.2%. Chepkube stove had increased air inlet compared to MRS and Cheprocket stoves as indicated in Figure 4.9.

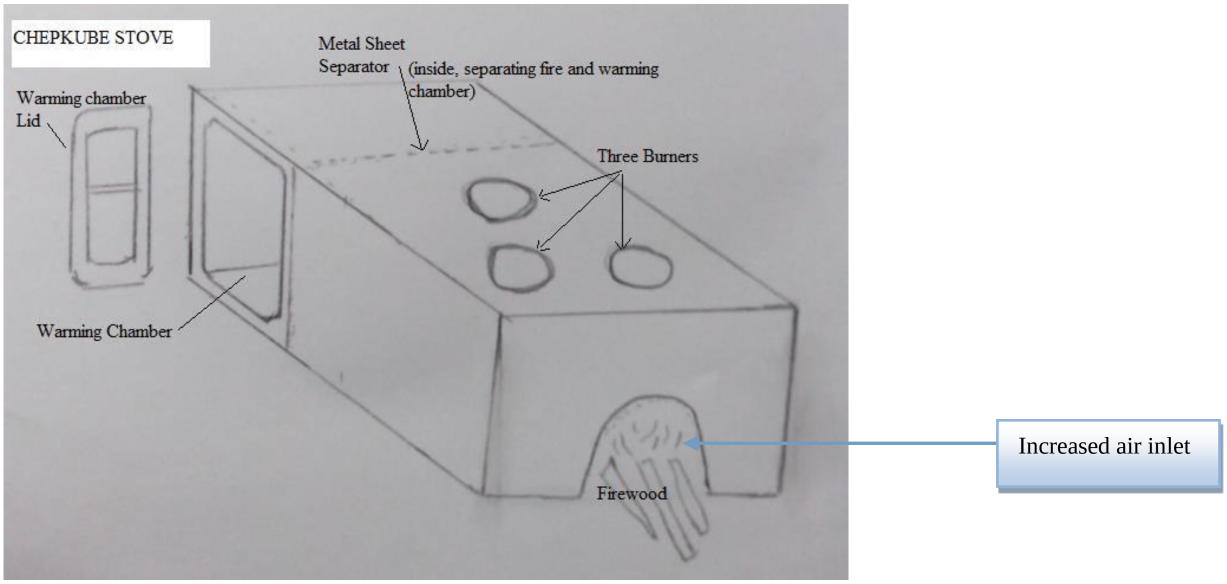


Figure 4.9: Schematic Diagram of Chepkube Stove

Cheprocket stove had an increased height due to installation of a chick brooder below the combustion chamber as illustrated in Plate 4.1.

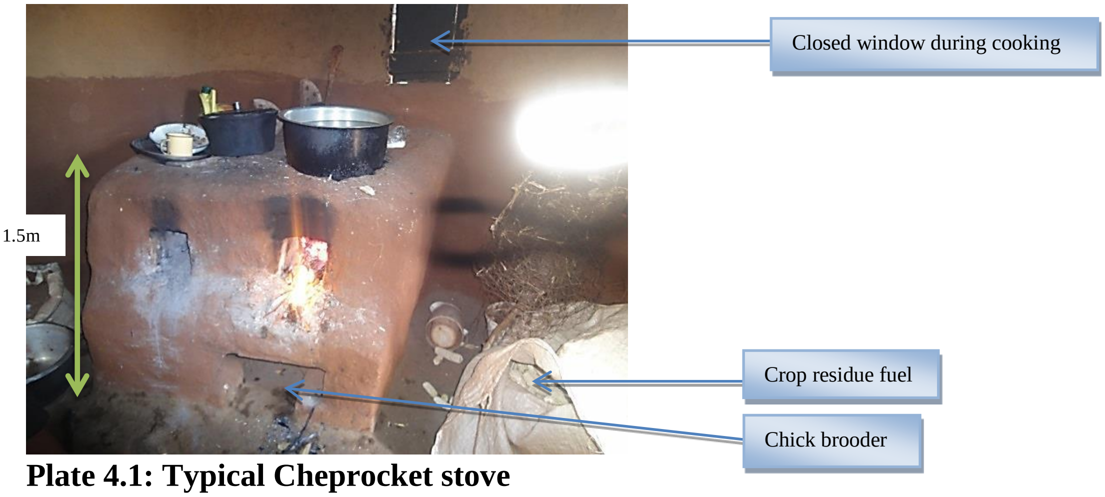
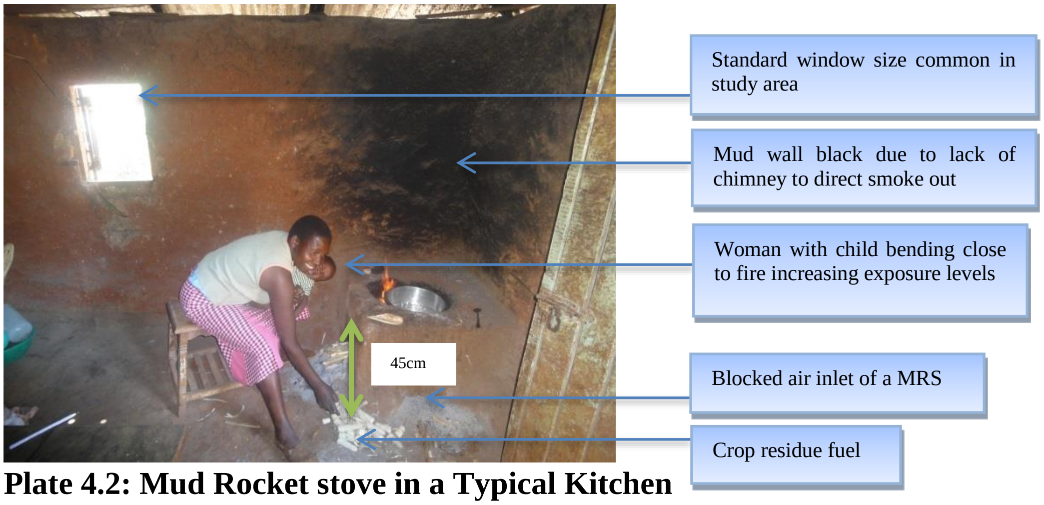


Plate 4.1: Typical Cheprocket stove
(Source: Author, 2016)

The height of MRS was lower compared to the Cheprocket stove and therefore necessitated bending during cooking as illustrated in Plate 4.2.



Standard window size common in study area

Mud wall black due to lack of chimney to direct smoke out

Woman with child bending close to fire increasing exposure levels

Blocked air inlet of a MRS

Crop residue fuel

Plate 4.2: Mud Rocket stove in a Typical Kitchen
(Source: Author, 2016)

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 4.8. 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 4.8. 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 4.8: 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
Size of the kitchen	6M by 6M	(1) 8.3	(6) 30.8	(21) 33.3	(29) 27.0	(51) 24.9
	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

4.7.3 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 4.9.

Table 4.9: 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		
	B	Std. Error	*p* value	B	Std. Error	*p* value	B	Std. Error	*p* value	B	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 (B = 2.556, SE = 1.646, *p* = .036) using Cheprocket stove; (B = 5.090, SE = 2.261, *p* = .026) using three stone; (B =1.484, SE = .050, *p* = .005) using mud rocket stove; (B = .083, SE = 019, *p* = .000) using Chepkube stove, with cemented floors (B = -12.898, SE = 4.525, *p* = .005) using three stone stove; (B = -.091, SE = .026, *p* = .001) using Chepkube stove and higher number of windows (B = -4.475, SE = 2.841, *p* = .031) using Cheprocket stove; (B = -6.705, SE = 1.445, *p* = .000) using three stone; (B = -.446, SE = .042, *p* = .030) using rocket stove; (B = -.045, SE = .010, *p* = .000) using Chepkube stove were associated with lower kitchen $PM_{2.5}$ concentrations as indicate in Table 4.9. 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 (B = 7.318, SE = 4.042, *p* = .015) using Cheprocket stove; (B = 1.118, SE = .995, *p* = .007) using three stone; (B =0.089, SE = .023, *p* = .021) using rocket stove; (B = .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 (B = -18.845, SE = 6.412, *p* = .581) using Cheprocket stove; (B = -.019, SE = .009, *p* = .330) using Chepkube stove; (B = -.228, SE = .048, *p* = .993) using mud rocket stove, duration taken in warming water (B = 2.913, SE = .081, *p* = .958) using mud rocket stove; (B = .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 4.9.

4.7.4 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 4.10.

Table 4.10: Association of Kitchen Characteristics with CO Concentration

	Three- stone stove			**Chepkube stove**			**MRS**			**Cheprocket stove**		
	Unstandardized coefficients			Unstandardized coefficients			Unstandardized coefficients			Unstandardized coefficients		
	B	Std. Error	*p* value	B	Std. Error	*p* value	B	Std. Error	*p* value	B	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 4.10.

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This study undertook a KPT to evaluate fuel use efficiency of the different biomass stoves. It also monitored the levels of 24-hour kitchen $PM_{2.5}$ and CO from various biomass stoves with an aim of assessing performance of improved stoves in IAP reduction compared to traditional stoves, analyse kitchen characteristics influencing pollutant concentrations and analyse significance of exposure levels to public health. Discussions in the subsequent sections of this chapter critically examined the study findings in light of previous related studies as outlined in the background and literature review sections, and made judgments about the implications of the findings.

5.2 Fuel Use Efficiency of Different Biomass Stoves

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. Also 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.

5.3 Kitchen Concentrations of $PM_{2.5}$ and Carbon Monoxide

Average 24-hour $PM_{2.5}$ concentrations in the kitchens using all the stoves were significantly higher than the recommended World Health Organization (WHO) threshold of 25 $\mu g/m^3$. The least recorded kitchen $PM_{2.5}$ concentration was from Chepkube stove; an indigenous innovation among the Kalenjin community compared to mud rocket stove and Cheprocket stoves that are considered improved biomass stoves with superior combustion technologies according to SCC-VI agroforestry (2010). Although Chepkube stove produced the least kitchen $PM_{2.5}$ concentrations, the levels were 25 times higher than the recommended WHO guideline. Three-stone stove as expected had the highest kitchen $PM_{2.5}$ concentrations using both firewood and crop residues as fuel with peak emissions above 52,000 $\mu g/m^3$ recorded. Particulate matter concentrations in kitchens were up to 200 times higher than the 24-hour WHO safe air quality standard.

The extremely high $PM_{2.5}$ concentrations recorded in the kitchens were comparable to concentrations found in other studies conducted in regions where biomass fuel use is highly prevalent (Ezzati *et al.,* 2000; Kilabuko *et al.,* 2007). Smith *et al.* (2000) estimated household concentrations of total suspended particles in Gujarat, India, and found that indoor concentrations of TSPs in these rural huts could be as high as 10,000 $\mu g/m^3$. Results from this study corroborated with the findings of Ezzati (2000) who recorded peak kitchen PM concentrations above 55,000 µg/m^3 in Central Kenya. However, $PM_{2.5}$ levels reported in this study were higher than average kitchen PM concentrations of 609 µg/m^3 recorded by Kalpana *et al*. (2013) in India and comparatively low kitchen concentrations of 360 µg/m^3 recorded in rural Peru. Bartington *et al.* (2017) recorded a mean 48-hour kitchen PM concentration of 418 µg/m^3 and peak concentration of 1384 µg/m^3 in Nepal. More recently, Johnson *et al.* (2011) performed a Monte-Carlo analysis of a single-zone box model of indoor $PM_{2.5}$ concentrations from stove emissions and predicted that only about 4% of homes using wood fuel in a rocket stove; a widely known cleaner and more efficient stove, would achieve WHO annual $PM_{2.5}$ guidelines.

The observed temporal variation in kitchen $PM_{2.5}$ patterns is consistent with reported findings from comparable settings with similar kitchen and stove characteristics (Ezzati *et al.*, 2000). Overall diurnal pollutant patterns were similar in pattern but higher in magnitude than those reported from the Sarlahi District of Nepal, where average 24-hour pollutant concentrations of $PM_{2.5}$ 650 µg/m^3 was measured (Klasen *et al.*, 2015) suggesting possible differences in local cultural cooking practices. Measured differences in $PM_{2.5}$ concentrations during peak and non-peak cooking sessions were also lower than those obtained for $PM_{2.5}$ average concentrations reported in low-income settings (Clark *et al.*, 2010; Commodore *et al.*, 2013).

The excessive kitchen $PM_{2.5}$ levels recorded compared to India and Peru could be contributed by other sources in the kitchens such as kitchen construction materials like mud which was the main material used to construct walls, earthen kitchen floors, kitchen practices for instance sweeping without wetting the floor to settle the dust, increased temperatures in the poorly ventilated kitchens made it impossible for suspended particulate matter to settle down;

not necessarily from biomass fuels combustion. Further there was behavioral practice of leaving kitchen windows open throughout the day. Due to draught, there was continuous motion of air in contaminated kitchens making particles difficult to settle down. Another reason was, since the study was conducted during the dry season, and people were generally preparing land in readiness for planting, outdoor particulates could have been blown through the windows in to the kitchens thus increasing kitchen PM concentrations. Poor air supply in to the combustion chamber among the rocket stove and Cheprocket stove contributed to high smoke levels during burning and simmering period compared to Chepkube stove whose air inlet is enlarged thus improving combustion.

One of the greatest factors leading to the high pollutant concentrations and exposures is the high usage of solid biomass fuels at 97% wood and 80% crop residue in all households monitored for IAP. Although there was a perennial misconception that mud rocket stove can save more fuel compared to Chepkube stove, this study, however, proved that Chepkube stove saved more on fuel which would have contributed to the observed reduced emissions. Fuel consumption using Chepkube stove was 0.33 kg/per capita/day and 0.32 kg/per capita/day lower compared to mud rocket stove and Cheprocket stove, respectively. As expected, three stone stove had the highest fuel consumption at 1.98 kg/person/day. Higher fuel consumption from mud rocket stove and Cheprocket stove could have contributed to the increased kitchen PM emissions compared to Chepkube stove. This finding is supported by Suzanne *et al.* (2014) who found that population living in rural homes in Peru and cooking primarily with solid biomass fuels experienced daily indoor PM concentrations that were 6-fold higher than participants living in the urban households or using lesser solid biomass fuels.

Higher pollutant concentrations were also observed during cooking sessions compared to when the stoves were idle suggesting that the more the cooking; the more the pollutant concentrations in the kitchens. This finding is supported by Yamamoto *et al.* (2014) who recorded higher mean 24-hour PM_{10} concentrations during cooking sessions compared to non-cooking sessions in Burkina Faso. Similarly, a study by Kilabuko *et al.* (2007) in rural Tanzania recorded significantly higher $PM_{2.5}$ concentrations during cooking periods compared to simmering periods. The effects of the extensive use of biomass fuel found in the study area could overwhelm any benefits that might be observed in terms of lower concentrations from improved biomass stoves. In this case, the introduction of fuel subsidies to encourage movement up the energy ladder to liquid petroleum fuels and gas stoves may have a greater impact on reducing overall air pollution exposures and risks to health.

The high levels of kitchen $PM_{2.5}$ concentrations in rural kitchens using biomass fuels imply that indoor air pollution is still a real threat to the public health in the country. Respiratory infections due to indoor air pollution are likely to be rampant especially in rural areas. It was also observed that what is referred to as improved biomass stove such as mud rocket stoves and Cheprocket stoves were associated with higher kitchen PM emissions compared to Chepkube stove. This suggests that although these stoves are referred to as improved, they must drastically improve to meet WHO air quality guidelines through measures such as fitting with chimneys to drive the smoke out of the cooking area.

On average carbon monoxide recorded from different biomass stoves was higher than World Health Organization threshold of 6 ppm in a 24-hour period. Crop residue fuel resulted in higher CO emissions compared to firewood probably because of the fuel properties. Cheprocket and MRS did not have significantly differently CO emissions because they use same combustion principle; the rocket principle. However, the Chepkube had lower CO emissions because of improved air circulation in the combustion chamber.

The highest average 24-hour CO kitchen concentration was from three-stone stove at 75 ppm using crop residues as fuel. The highest 1-hour peak of carbon monoxide kitchen concentration was recorded from Cheprocket stove and mud rocket stove probably due to the poor air circulation in to the combustion chamber. Households using crop residue fuel sources had the highest peak concentrations and greatest variability of CO. The highest recorded peak 1-hour CO concentration (658 ppm) from Cheprocket stove exceeded the WHO AQG 60-min exposure guideline of 30 ppm (WHO, 2010). Peak CO concentrations can be explained by periods such as fire lighting and any disturbance in the fire for example adding more wood fuel during cooking or pushing fuel in to the combustion chamber. A relatively lower CO emission from Chepkube stove compared to other stoves was probably as a result of lower fuel consumption.

The observed temporal variation in 24-hour CO patterns is consistent with findings from comparable settings with similar kitchen and stove characteristics to those reported from central Kenya by Ezzati *et al.* (2000). Overall diurnal CO patterns were similar in pattern but lower in magnitude to those reported from the Sarlahi District of Nepal, where average 24-hour concentrations of CO 9.1 ppm were recorded (Klasen *et al.*, 2015) suggesting possible differences in local cultural cooking practices such as number of meals cooked and kitchen designs.

5.4 Personal Exposure of Particulate Matter and Carbon Monoxide

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

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

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

The unexpected higher CO exposures from mud rocket stoves and Cheprocket stoves compared to Chepkube stove was contributed by high incomplete combustion due to poor air circulation in the firing chambers of the mud rocket stove and Cheprocket stoves since most of their air inlets were clogged with ash from previous fuel combustion as illustrated in Plate 4.2. The height of MRS is low necessitating bending over above the fire during cooking leading to increased exposure. In addition, the high exposures of $PM_{2.5}$ was also as a result of the fuel type used; crop residues specifically maize stalks and maize cobs have low calorific value and hence produce higher amounts of ash and higher smoke levels during combustion. Chepkube stove has enlarged firewood and air supply opening that ensures adequate supply of air as indicated in Figure 4.9. The Cheprocket stove had relatively lower personal exposures compared to mud rocket stove because of its improved design with elevated height which reduces direct bending over above fire during cooking unlike for mud rocket stove as indicated in Plate 4.1.

Therefore, in judging the effectiveness of mud rocket and Cheprocket stoves, there needs to be a clear distinction between the presumed emissions reduction and actual exposure reduction. Improved stoves may improve emission reduction but not necessarily reduce exposure automatically due to kitchen and behavioral and characteristics as it was observed in this study. If improved stove users have to bend over above fire during cooking owing to stove height, although emissions may be reduced, exposure could be increased significantly. Although less smoke may be produced after cooking, longer hours of indoors especially in the evenings after supper chatting around fire meant higher exposures and health impacts resulting from pollutant concentrations already in the kitchens.

5.5 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). 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).

5.6 Health Risk Analysis

Hazard quotients for both long-term and short-term PM exposures were above 1, indicating that chronic obstructive pulmonary infections and other respiratory infections are likely to occur. 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 and Kammen (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. 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.

5.7 Summary of Discussion

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 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 this type of stove. Most cooks using Cheprocket stoves 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 implying that user education was not adequate.

Average 24-hour $PM_{2.5}$ concentrations in the kitchens using all the stoves were significantly higher than the recommended WHO threshold of 25 μg/m^3 and are likely to contribute to increased morbidity, mortality and adverse birth outcomes. Chepkube stove; a local innovation among the Kalenjin community had lower emissions compared to mud rocket stove and Cheprocket stoves that are considered improved biomass stoves with superior combustion technologies. Although Chepkube stove produced the least kitchen $PM_{2.5}$ concentrations, the levels were 25 times higher than the recommended WHO guideline.

High $PM_{2.5}$ concentrations were probably due to kitchen construction materials such as mud; which was the main materials used to construct walls, earthen kitchen floors, kitchen practices such as sweeping without wetting the floor to settle the dust, increased temperatures in the poorly ventilated kitchens made it impossible for suspended particulate matter to settle down. Although there was a perennial misconception that mud rocket stove can save more fuel compared to Chepkube stove, this study, however, proved that Chepkube stove saved on more fuel which would have contributed to the observed lower emissions. High levels of kitchen $PM_{2.5}$ concentrations in rural kitchens using biomass fuels imply that indoor air pollution is still a real threat to the public health in the country.

The average kitchen carbon monoxide concentration recorded from different biomass stoves was higher than World Health Organization threshold of 6 ppm in a 24-hour period. Cheprocket and MRS did not have significantly different CO emissions because they use same combustion principle; the rocket principle. The unexpected higher kitchen CO concentration from the perceived improved biomass stoves compared to Chepkube stove was contributed by poor air circulation in to the firing chamber of the mud rocket stove and

Cheprocket stoves as witnessed during field study; most mud rocket stove like all the other stoves were clogged with ash from previous fuel combustion.

Long-term PM exposures were higher than short-term exposures implying that as the cooks age, the risk of getting upper and lower respiratory infections such as asthma, bronchitis, due to $PM_{2.5}$ exposure are also increased. Cheprocket had relatively lower $PM_{2.5}$ exposures compared to mud rocket stove because of the elevated height which reduces bending over above the fire during cooking unlike for mud rocket stove. If improved stove users have to bend over above the fire during cooking owing to stove height, although emissions may be reduced, exposure could be increased significantly.

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. 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 moderate correlation confirmed that there were other sources of $PM_{2.5}$ present in rural kitchen contributing to the extremely high levels of concentrations.

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 duration increased implying that at old age exposed individuals have higher risk of getting chronic upper and lower respiratory infects.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study concluded that the Chepkube stove, mud rocket stove and Cheprocket stoves led to substantial reduction in fuel consumption compared to traditional three-stone stoves in rural Kenya and thus contribute to environmental conservation.

Household indoor PM and kitchen concentrations associated with biomass fuel combustion in the study area exceeded WHO indoor safe limits and are in the hazardous range for human health. The 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 HAP.

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

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

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

Traditional innovations should not always be branded primitive before due testing and acquiring adequate proof of their performance level. Chepkube stove; a local innovation among the Kalenjin community is an improved biomass technology capable of saving more fuel and emitting lesser PM and CO emissions from biomass combustion compared to mud rocket stove and Cheprocket stoves; long perceived improved biomass stoves.

Indoor air pollution in rural kitchens 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.

6.2 Recommendations

1. A study to be undertaken to understand variations in human exposure from season to season.
2. An epidemiological study should be carried out to assess the linkage between PM exposures and respiratory infections in the region
3. User education is necessary for improved stoves users for behavioural change to reduce PM and CO kitchen concentrations and exposure.

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APPENDICES

APPENDIX I: Household Questionnaire

HOUSEHOLD QUESTIONNAIRE

This PhD research is aimed at investigating the factors that influence the adoption of improved biomass energy technologies and quantification of household kitchen concentrations of PM and CO and personal exposures from utilization of biomass fuels in wider Cherang'ani and Mt. Elgon ecosystems. This can be used for future policy improvements in the regions. The research is a non-profit assignment. All the answers provided are confidential and will not be used to disclose any person's identity without their knowledge.

SITE DETAILS

QNS No.	
County	
Division	
Location	
Sub-location	
Village	

SECTION A: HOUSEHOLD CHARACTERISTICS

1. Age__________ (in years)

2. Who is the head of the HH (1) Man-headed (2) Woman-headed (3) Child-headed

3. Marital Status of the HH head: (1) Married (2) Single (3) widowed (4) Orphaned

4. Literacy level of the HH head: (1) Primary school drop-out (2) Secondary School (3) Tertiary education (4) Illiterate (cannot read and write)

5. Household size: ________ (members). Fill in the HH numbers in age brackets provided below.

Age bracket	**Count**
Adults above 60 years	
Adults between 35 – 59 years	
Adults between 18 – 34 years	
Children Between 6 – 17 years	
Children 0 - 5 years	

6. Fill in the source(s) of income for the HH

Occupation	**Description**	**Monthly income (KShs)**
(1) Crop farming		
(2) Livestock farming		
(3) Formal employment		
(4) Business		
(5) Other		

7. What is the material of the roof of the house?
   (1) Mud
   (2) Thatch
   (3) Wood
   (4) Iron sheets
   (5) Cement/concrete
   (6) Roofing tiles
   (7) Asbestos

8. What is the material of the walls of the house?
   (1) Mud/mud bricks
   (2) Stone
   (3) Burnt bricks
   (4) Moulded cement, sand and ballast blocks
   (5) Wood/bamboo
   (6) Iron sheets
   (7) Cardboard

9. What is the main source of drinking water?
   (1) Piped into dwelling or compound
   (2) Public outdoor tap or borehole
   (3) Protected well
   (4) Unprotected well, rain water, stream
   (5) River, lake, pond
   (6) Vendor or truck
   (7) Other ___________________________

10. How long in minutes does it take from house to reach the nearest amenities described?

Amenity	**< 15 min**	**15 ≤ 30**	**31 ≤ 45**	**46 ≤ 60**	**> 60**
A. Supply of drinking water					
B. Food market					
C. Public transportation					
D. Primary school					
E. Secondary school					
F. Health clinic or hospital					

11. What kind of toilet facility does your household use?
    (1) None
    (2) Flush to sewer
    (3) Flush to septic tank
    (4) Pan/bucket
    (5) Covered pit latrine
    (6) Uncovered pit latrine
    (7) Ventilation improved pit latrine
    (8) Other_____________________

12. Does the household own any of the following?

Items	Yes	No
Electric iron		
Refrigerator		
Television		
Mattress or bed		
Radio		
Watch or clock		
Mobile phone		

SECTION B: LAND USE PATTERNS

13. Do you own any land? (1) Yes (2) No
14. If yes, how many acres? (1) 1- 5 (2) 6 – 10 (3) > 10

15. **If No**, what is the ownership of the land the HH lives in? (1) Rented (2) Sharecropped (3) Private land provided free (4) Open access land

16. How many enterprises (e.g. maize, wheat, beans, dairy, poultry etc) do you have at the farm and how much area do you allocate to each?

Enterprise	Area (acres)
1.	
2.	
3.	
4.	
5.	

17. Do you plant trees on your land? (1) Yes (2)No

18. If yes, which types and how much land do you allocate for tree growing?

Tree Types	Land Allocation

SECTION C: FUELWOOD CONSUMPTION DATA

19. Which fuel(s) do you use? For what purpose?

Fuel Type:	Purpose (e.g. cooking, lighting)
Charcoal	
Firewood	
LPG	
Kerosene	
Electricity	
Agricultural crop residue	
Animal wastes	
Others (specify)	

Charcoal Consumption

20. Did you use charcoal during the last month? (1) Yes (2) No

21. If no, why? (1) Expensive (1) low status (2) unavailable (3) Dangerous to health (4) Others (specify) ……………………………..

22. If yes, what quantity do you use per day …………………….. kg

23. How do you obtain your charcoal? (1) Produce in farm (2) purchase (3) Trust land (4) Others (specify)

24. What units of measure did you last use to purchase charcoal?
    (1) 2kg Tin ("gorogoro")
    (2) Debe
    (3) Sack
    (4) Other ……………………………………………..

25. How much did you spend/unit? (KShs/unit) ……………………………

26. How many days does this purchase last? …………………………………

27. List the preferred species

    1. ……………………………………….....
    2. ………………………………………..
    3. ……………………………………………

28. Why? (1) Readily available (2) Longer burning time (3) Less Smoke (4) Little ash

29. Give the prices of the units during the different seasons of the year?

	Price (KShs/unit)	Units used/month
Rainy season		
Dry season		
Circumcision		
Harvesting		

30. Have you experienced any health problems associated with charcoal use? (1) Yes (2) No

31. If yes, specify ……………………………………

<u>Fuel-wood Consumption</u>

32. Who is/are more the responsible for fuel wood supply in your family?
(1) Women (2) Men (3) Children both male and female

33. Who is/are more responsible to prepare food in your family?
(1) Females (mainly the mother and/or daughters) (2) Males

34. Where do you acquire your fuelwood from?
(1) Collect from nearby forest (2) Buy from Vendors (3) Collect from private farm

35. If you buy your fuelwood from vendors, what is the cost per bundle? …………….. KShs

36. How far from home do you walk collect fuelwood?
(1) < 1 kilometre (2) 1 ≤ 3 kilometres (3) 3 ≤ 5 kilometres (4) > 5 kilometres

37. What is the amount of wood used per day ………….. kg

38. What is the amount of wood used per capita …………….. kg

39. What is the average moisture content of the wood ………………… %

SECTION D: BIOMASS ENERGY TECHNOLOGY ADOPTION

40. Have you ever heard of the following biomass energy technologies? **If yes** have you ever used them in your home?

Technology	Aware		Usage	
	Yes	No	Yes	No
Rocket Stove				
Maendeleo Stove				
Chepkube stove				
Envirofit stove				
Three stone stove				
Kenya ceramic jiko				
Metallic charcoal stove				
Biogas burners				
Briquetting stove				

41. From whom did you hear about the above biomass technologies? **Tick correctly**

	Government	NGOs	Traders	Women groups	Friends/neighbours/relatives	Others (specify)
Rocket Stove						
Maendeleo Stove						
Chepkube stove						
Envirofit stove						
Three stone stove						
Kenya ceramic jiko						
Metallic charcoal stove						
Biogas burners						
Briquetting stove						

42. For the biomass technologies used above, rate the following benefits associated with their use

	Envirofit stove	Rocket Stove	Maendeleo Stove	Chepkube stove	Three stone stove	Kenya ceramic jiko	Metallic charcoal stove	Briquetting stove	Biogas burners
Saves fuel-wood									
Faster cooking									
Produces less smoke									
Easy to use (easy to light)									
Safe for the children									
Easy to construct									

Key: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

43. Do you know of any promoters of improved biomass energy stoves in this area?
(1) Yes (2) No

44. **If YES**, name one promoter, type of promotion and the level of support using the scale below;
(1)Highly supportive, (2) moderately supportive, (3) Supportive (4) Least supportive (5) Not supportive

	Promoter	Type of promotion	Level of support
Rocket Stove			
Maendeleo Stove			
Chepkube stove			
Envirofit stove			
Three stone stove			
Kenya ceramic stove			
Metallic charcoal stove			
Biogas burners			
Briquetting stove			

45. What do you consider while adopting / deciding which biomass fuel to use for cooking?

	(1)Very important	(2) important	(3) Somewhat importance	(4) Least important	(5) Not important
Affordability					
Availability					
Smoke production/cleanliness					
Social status					
Cooking time					
Durability					
Fuel consumption					
Cooking practices					

QUANTIFICATION OF HOUSEHOLD BIOMASS SMOKE EXPOSURE

46. What type of cooking stove do you use?
    (1) Open fire/stove without chimney/hood
    (2) Open fire/stove with chimney/hood
    (3) Closed stove with chimney
    (4) Improved biomass stove (Name) ……………………………….
    (5) Other (specify) …………………………………

47. What is the cooking fuel type used
    (1) LPG
    (2) Kerosene
    (3) Dung
    (4) Charcoal
    (5) Firewood

48. Where is the kitchen located?
    (1) Outdoor Kitchen (ODK)
    (2) Separate (often semi-enclosed) outdoor kitchen (SOK),
    (3) Indoor kitchen partitioned from the rest of the living area (IWPK)
    (4) Indoor kitchen without partitions (IWOPK) i.e. common living and cooking areas.
    (5) Other

49. What is the status of kitchen ventilation? *(Based on the availability of windows, ventilation, open eves, and the presence of chimneys and fans inside the kitchen area.)*
    (1) Good (2) Moderate (3) Poor

50. What is the size of your kitchen?

51. What is the floor material of the kitchen?

52. How many windows are present in the kitchen?

53. What is the size of the windows?

54. What is the condition of the windows during cooking?

55. Where is the location of the kitchen in relation to direction of the wind and the rest of the house?

56. Does your kitchen have electricity (1) Yes (2) No

57. What is your staple food?
   (1) Ugali
   (2) Githeri
   (3) Sweet potatoes
   (4) Potatoes
   (5) Matoke

58. How often do you cook?
   (1) Twice in a day
   (2) Thrice in a day
   (3) Four times in a day
   (4) Five times in a day

59. How long in minutes does it take you to prepare meals on a typical day?

Time	**< 15**	**16 – 30**	**31 – 45**	**45 -60**	**> 60**
Breakfast					
Lunch					
Supper					
Warming food					
Warming water					

APPENDIX II: Key Informants Interview guide

1. Name of Organization ……………………………………….………………

2. When did the organization start disseminating improved biomass technologies? ………………. (year)

3. Is there any other organization in this Region dealing with technology? Yes / No

If yes, mention them;
4. What motivated your organization to engage into biomass technology?

5. What were the Project's main objectives? At what level (%) are the objectives met?

6. What was the targeted group of people to be reached by biomass technologies as per your initial plans? …………………………..……………………………

7. At what extent have you met the targeted group?

If not met as Expected, what do you think are the reasons?
8. How many villages in this region have you reached for biomass technology?

9. Do you think many people are aware of biomass technologies in this area?

What percentage of population? …………………………………………..……..
10. How many households in a region have adopted the technologies?

14. What is the percentage of adopters of biomass technologies as per population of the area? ……………

15. If the adopters' percentage is small compared to the expected, what do you think are the factors for people not adopting biomass technology?

16. Are people willing to switch to other biomass fuels? Reasons for No and Yes

17. Are people able to switch to other biomass fuels? Reasons for No and Yes

18. Are people willing to switch to improved stoves using same biomass fuel? Reasons for No and Yes
19. Are people able to switch to improved stoves using same biomass fuel? Reasons for No and Yes

20. What are the major complains received from biomass technology users on the technologies?

22. What have you done or you suggest as remedy to the problems you mentioned in your response to question 18 and 19 above?

23. Did your organisation give any support/ contribution to people who adopted or who intend to adopt biomass technologies? ……………………………..………

24. If yes what kind of support and at what level?

Kind of support	**Level of contribution (%)**
1.	
2.	
3.	

26. What are the strategies your organization use to disseminate biomass technologies?

27. What are the problems facing your organization in disseminating the technologies?

28. What is your opinion on Governments' involvement in biomass technologies Dissemination? ....

29. What support does your organization receive from the Government in technology dissemination efforts?

30. What have you leant as organization about; and your suggestion to the Government on:

(1) Promotion of technology ………..…………………………………………

(2) Affordability of the technology …..……………………………………

(3) Sustainability of the technology……….………………………………

(4) Plant types and sizes ……………………………………………………

31. Any comment on sustainability of your project as far as biomass technologies dissemination is concerned

APPENDIX III: Focused Group Discussion guide Questions

FUELS & STOVES

1. What do you think about cooking with charcoal, firewood, biogas, Liquid biofuel, farm residue? Advantages & disadvantage?

2. What do you think about cooking with other fuel e.g. LPG? Advantages & disadvantages

3. Are you looking for an alternative for the current fuel you are using?

4. What is the biggest barrier for buying an improved biomass stove?

(1) High investment cost of stove

(2) Lump-sum payment of technology.

5. Why do you think people would use improved biomass cookstoves if money weren't an issue?

6. Why are you using more than one fuel at the same time? Why don't you fully switch?

7. Are there any cultural reasons behind that? What foods do you always cook using charcoal, firewood, biogas, Liquid biofuel, farm residue? Why?

8. Are there any foods that cannot be cooked using charcoal/firewood/biogas/Liquid biofuel/farm residue?

9. Are people willing to switch to other biomass fuels? Reasons for No and Yes

10. Are people able to switch to other biomass fuels? Reasons for No and Yes

11. Are people willing to switch to improved stoves using same biomass fuel? Reasons for No and Yes

12. Are people able to switch to improved stoves using same biomass fuel? Reasons for No and Yes

ICS

13. Why would you be interested in ICS?

14. Which ICS are being promoted in this area? By who?

HH INFO

15. If an alternative would arise (ICS) would we have to target women or men? Who makes the financial decisions?

16. Are modern stoves considered 'status symbols?

17. Do you have any other comments, questions, ideas you want to add before we finish the interview?

SECTION E: Institutions Involved in the Conservation of Cherangani and Mt. Elgon Ecosystems

Category	**Name**	**Type of intervention**	**Activities undertaken**	**Intervention area**	**Period of operation**	**Impacts**
Government Departments						
NGO						
CBO						
FBO						
Schools						
Private Sector						

APPENDIX IV: Time Activity Budget

Time	Activity	Location	Who is present
6 a.m – 7 a.m			
7 a.m – 8 a.m			
8 a.m – 9 a.m			
10 a.m – 11 a.m			
11 a.m – 12 p.m			
12 p.m – 1 p.m			
1 p.m – 2 p.m			
2 p.m – 3 p.m			
3 p.m – 4 p.m			
4 p.m – 5 p.m			
5 p.m – 6 p.m			
7 p.m – 8 p.m			
8 p.m – 9 p.m			
9 p.m – 10 p.m			
10 p.m – 11p.m			