ASSESSMENT OF WOODFUEL UTILIZATION AND EFFICIENCY OF COOKING STOVES IN LIKIA, NJORO SUBCOUNTY, KENYA.

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A Thesis submitted to the Graduate School in partial fulfilment of the requirement for the award of a Master of Science Degree in Natural Resource Management of Egerton University.

EGERTON UNIVERSITY

27 June 2016

DECLARATION AND RECOMMENDATION

I declare that this Thesis is my original work and has not been submitted to any other University for an award of a Degree.

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ABSTRACT

Over 2.6 billion people of the world's population prepare their food and heat their homes with biomass fuel mainly woodfuel. Wood fuel is used as a major source of energy without a replacement plan and is partly the cause of deforestation. Among the interventions identified as crucial to slowing down deforestation include promoting alternative sources of energy and using efficient stoves to reduce pressure on forest resources. This study examined wood fuel utilization and efficiency of cooking stoves among the rural population of Likia location, Njoro Sub County. A survey was conducted through a questionnaire administered to respondents from the study area. An experiment using the Water Boiling Test with Split Plot in Randomized Complete Block Experimental Design was used to study the heat gain and efficiencies of the stoves. The heating stoves were the sub plot factor and the sources of energy, the main plot factor. The study variables included temperature changes with time, heat gained during cooking and the efficiencies of the stoves. The mean heat gains and mean efficiencies were treated to ANOVA at 95% confidence level. Correlation analysis was used to study the effect of time on temperature change during cooking. Ninety percent of the respondents used woodfuel for cooking, while the three stone stove was used by 71% of the respondents. There was an acute wood fuel shortage that put pressure on the adjacent Mau forest. The highest mean heat gain was 288.9kJ ± *SD* 0.00 with the *Olea africana*/ceramic stove while the lowest mean heat gain was 58.6kJ ± *SD* 0.00 with the waste paper briquettes/wood ceramic stove and the corresponding mean efficiencies were 69% ± *SD* 0.00 and 14%± *SD* 0.00 respectively. Not all cooking stoves/woodfuel combinations were able to boil one litre of water within ten minutes. There was significant correlation between the cooking time and temperature changes at 95% confidence level. The LSD, found significant differences in mean heat gained due to the woodfuel used but not due to all the stoves used. There were significant differences in the mean efficiencies of the cooking stoves due to the fuel type, the stoves and interaction between the fuel and the stoves. The study recommends the promotion of on-farm forestry for woodfuel and timber production and creating awareness about the key ecological services provided by forest ecosystems. The promotion of improved energy saving stoves, the improvement of biomass briquette burning properties, the possibility of a subsidy provision for the people to enable their acquisition of alternative sources of energy such as solar energy panels is also recommended. These results are expected to promote sustainability in the wood fuel use and contribute to the slowing down of deforestation of the adjacent Mau Forest.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CBO	Community Based Organization
CCT	Controlled Cooking Test
CFA	Community Forest Association
CV	Calorific value
FAO	Food and Agriculture Organization
FRA	Forest Resources Assessment
GCV	Gross calorific value
GPS	Geographic Positioning System
GVEP	Global Village Energy Partnership
ICRAF	International Centre for Agro forestry Research
IGADD	Intergovernmental Authority on Drought and Development
KCS	Kenya Ceramic Stove
KEMA	Kayole Environmental Management Association
KFS	Kenya Forest Service
KFWG	Kenya Forestry Working Group
KPT	Kitchen Performance Test
KWDP	Kenya Wood fuel Development Programme
LSD	Least Significant Difference

LPG	Liquefied Petroleum Gas
MDGs	Millennium Development Goals
NCV	Net calorific value
NGO	Non-Governmental Organization
SPSS	Statistical Package for Social Sciences
TPES	Total Primary Energy Supply
UNEP	United Nations Environmental Programme.
UN	United Nations
VITA	Volunteers in Technical Assistance
WBT	Water Boiling Test

CHAPTER ONE

1.0 INTRODUCTION

1.1 Summary of the Chapter

This chapter covers an introduction to the study and the study area. It also covers the importance of the wood fuel resource and the need for its conservaton . The objectives hypotheses and the justification for this study are also covered. Woodfuel utilization was covered by questionaire and three hypotheses tested through an experiment .

1.2 Background to the Study

Forests cover thirty percent of the earth's total area (UNEP, 2007), with total forested area under 4 billion hectares in 2005. On the global average, more than one-third of all forests are considered primary forests, defined as forests where there are no clear visible indications of human activity and where ecological processes are not significantly disturbed. Forests and woodlands in Africa occupy an estimated 650 million hectares, accounting for 16.8% of global forest cover (Hogan, 2007). Many of the African forests are severely fragmented due to encroachment of an increasing human population leading to an increasing demand for woodfuel and extensive conversion of land to agricultural use (UNEP, 2002). In East Africa, forest cover has dropped by 9.3% between 2001 and 2009. Large areas of evergreen forest have been lost resulting in carbon emissions, reduced habitat for forest dependent biodiversity and reduced availability of essential ecosystem services, (Burgess *et al.,* 2012). In Kenya, forest resources are of immense importance for the environmental and ecosystem services they provide, for their contribution to economic development and their contribution to rural livelihoods (Kinyanjui & Walubengo, 2010). Six million hectares of primary forests are lost every year globally due to deforestation and modification through selective logging and other human interventions, among which are wood fuel needs especially in developing countries.

Wood fuel originates from a wide range of forestry and agricultural land-use systems, including agricultural plantations, agroforestry, trees outside forests, tree plantations, secondary and primary forests. It is either produced as a by-product of sustainable timber production or as a forest management objective in itself (Sepp *et al.,* 2014). Wood fuel is used by 75% of the population of the developing world accounting for 34% of total energy consumption (FRA, 2010). In Kenya, it is estimated that about 80% of the population lives in the rural areas characterized by limited access to affordable and convenient energy sources (ROK, 2003; Muchiri, 2008; Mbuthi, 2009) which is argued to be amongst the greatest impediments to social and economic development of the rural populations. Other energy sources are electricity, which is too expensive; liquefied petroleum gas whose appliances are too expensive; kerosene, mainly used for lighting but proves relatively expensive when used for cooking (ROK, 2003).

Harvesting of wood as fuel is associated with increasing levels of deforestation (UNEP, 2007; Muchiri, 2008; Gathui & Mugo, 2010; FAO, 2014). The declining supplies lead to further loss of vegetation cover, deterioration of environmental stability, diversion of agricultural residues from agricultural use and increased expenditure of time and effort on wood fuel gathering (Labelle *et al.,* 1988; UNEP, 2007; Gathui & Mugo, 2010; Sepp *et al.,* 2014). The Kenya government biomass policy objective seeks to ensure sufficient biomass supplies to meet demand on a sustainable basis while minimizing associated negative environmental impacts (Mbuthi, 2009). Efforts to address the wood fuel problem have included the promotion of “improved” cook stoves. The ceramic stove, the wood ceramic stove and the open fire stoves are commonly used (Kammen, 1993).

Likia location in Njoro Sub county lies within the Eastern Mau. Wood fuel is the most common form of energy used and the adjacent Likia Forest is the most reliable source of wood fuel available for the residents of Likia. Due to the need for sustainability in wood fuel use, this study assessed the wood fuel utilization patterns and the efficiency of heating/cooking stoves used in the study area.

1.3 Statement of the Problem

The residents of Likia location depend on woodfuel as a major source of energy for cooking. The high population growth rate and the increased demand for woodfuel have led to rising levels of vegetation depletion with the potential to escalate the degradation of land. The current wood fuel consumption levels coupled with the indifference of the second generation of settlers to plant trees on their farms has precipitated a wood fuel crisis. Serious deforestation and degradation of land continues to occur as the communities turn to the forest to meet their needs of wood fuel and an income from sales of wood products. Other sources of energy are either beyond the means of this rural population or are totally unavailable. There is absence of documentation of information on the efficiencies of woodfuel stoves used in Likia location compared with the performance of modern improved stoves. It was therefore necessary to initiate the sustainable exploitation of wood fuel as a source of energy, through the assessment of the efficiency of the available wood fuel stoves and the wood fuel utilization of the population of Likia location.

1.4 Objectives

1.4.1 Broad Objectives

An Assessment of the woodfuel utilization and efficiency of cooking stoves to enhance the sustainable utilization of the woodfuel resource and contribute to reduced deforestation of the Mau Forest and to sustainable environmental management.

1.4.2 Specific Objectives

The specific objectives of the research were to;

i) Assess the wood fuel utilization in the study area.
ii) Evaluate the amount of energy dispersed per stove by the commonly used fuel sources.
iii) Measure the time and energy requirement per cooking stove to heat 1 litre of water.
iv) Assess the efficiency of the stoves used.

1.5 Research Questions

Specific objective no 1 was covered by the questionnaire. The specific objective was to access woodfuel utilization in Likia. The research questions were

i) What were the forms of fuel used for cooking?
ii) What was the mode of woodfuel acquisition?
iii) Which were the types of cooking stoves used?
iv) Which were the most preferred woodfuel tree species?

1.6 Hypotheses

Ho_1: There is no significant difference in mean heat gained values.

$Ho_1: \mu_1 = \mu_2 = \mu_3 = \mu_4$

The hypothesis addressed specific objective ii.

Ho_2: There is no significant correlation between the mean wood fuel burning time and temperature change.

Ho_2: þ = 0

The hypothesis addressed specific objective iii

Ho_3: There is no significant difference in mean efficiency values for stoves.

Ho_3: $\mu 1 = \mu 2 = \mu 3 = \mu 4$

The hypothesis addressed specific objective iv

1.7 Justification

In Kenya, biomass is the largest form of primary energy consumed, accounting for 68% of the total national primary energy supply (Muchiri, 2008; Mbuthi, 2009). The principal drivers of biomass energy demand are population growth, lack of access to biomass energy substitutes and the growing incidence of poverty among Kenyans. Thus the biomass energy demand stood at 34 million tons compared to an estimated sustainable supply of 15 million tons creating a biomass energy supply and demand imbalance (ROK, 2003). This severe imbalance between supply and demand was also noted by (Mbuthi, 2009) stating that against the background of increasing wood fuel supply deficits, there was need for a strategy to ensure a sustainable supply to meet the demand as well as maintain ecological balance. According to The Kenya Forestry Working Group (2001) and Kabiru (2005), the Mau Forest Complex had decreased in area by approximately 10% between 1964 and 2000, and that the Mau Complex Belt within which Likia location of Mau Nark Ward in Njoro Sub County lies was the largest remaining forest in East Africa that forms the upper catchment of most of the rivers west of the Rift Valley.

This study thus evaluated the thermal efficiency of the cooking stoves in Likia alongside the commonly used fuel type as a contribution to information on the evaluation of stove performance. The study aims at easing the pressure on forest resources and promote sustainability in resource use. Institutions concerned with conservation of natural resources such as the Kenya Forest Service, Kenya wildlife Service are likely to have their conservation mandates enhanced by the prudent use of the woodfuel resource through the use of fuel efficient stoves. CFA's are expected to play a major role in the advocacy of the use of improved cooking stoves therefore reducing pressure on the Mau Forest as a source of woodfuel. This study also aims at alerting policy makers on the need to preserve environmental stability for sustainability in production activities such as agriculture that are important sectors of Kenya’s economy

Since the extraction of biomass energy is associated with increasing levels of deforestation and its associated environmental degradation, the study of wood fuel utilization and the efficiency of cooking stoves used in Likia location (the study area) was one of the intervention measures that aimed at addressing the wood fuel shortage crisis while enhancing environmental sustainability.

1.8 Scope and Limitations

1.8.1 Scope

The study focused on Likia location Njoro Sub county Nakuru County. The study covered wood fuel utilization and assessment of the efficiency of only the cooking stoves used in the area. The wood fuel used in the area was also studied including both charcoal and fuel wood. The *Olea africana* fuel wood and charcoal where chosen as a commonly favoured and indigenous species of the area. In this study the Water Boiling Test was used to test the efficiency of the stoves. The stoves were also tested to ascertain whether they could achieve a specific cooking task within a given time period (boil one litre of water within ten minutes)

Local Boiling Temperature: The boiling point of water decreases by approximately 1^{o}C for every increase of 1000 feet in altitude (Earl, 1990; Ekkapat & Jigme, 2008). The local boiling point for Likia as determined and used in this study was 91^{0}C.

1.8.2 Limitations

Terrain: The terrain of Likia is such that there are many hills. Covering the terrain was a challenge. This was overcome by beginning the exercise very early at 7a.m setting time for work break during the questionnaire administration.

Language barriers: Due to the different ethnic groups in the area it was necessary to engage assistants who could communicate in local languages.

1.9 Definitions of Study Variables

Calorific Value This is the heat locked up in a fuel. Calorific values of wood fuel were obtained from literature (Appendix 5).

Conductivity: The ability of a body or material to transmit heat

Efficiency of Cook Stoves Efficiency of Cook stoves is the proportion of energy in the fuel which is used for heating to the total energy generated by the fuel and computed from the basic formula

$$Efficieny = heat\ output/heat\ input \times 100$$

$$\varepsilon_1 = \frac{\sum_{i=1}^{n}\{(M_{pi}C_{pi} + M_{mi}C_{mi} + M_{fi}C_{fi})(T_{ci} - T_a) + M_{fi}K_{fi}\}}{[M_w E_w - M_r E_r]} \qquad Equation\ 1$$

Source (Dutt & Geller, 1997; Bailis *et al.*, 2007)

$$Heat\ gained = MC\theta \qquad Equation\ 2$$

Mass of Wood fuel Used. The difference in mass between the initial mass of the wood fuel (at lighting of the stove) and the mass of any wood fuel recovered at the end of cooking was the mass of wood fuel used.

Local Boiling Point This is the point at which the temperature no longer rises no matter how much heat is applied. This temperature depends on altitude and was determined once for this study.

Specific Heat. This is the heat required to raise the temperature of a body through 1 Kelvin.

Temperature Readings. During the experiments, temperature changes were expected. The changes in temperature were an indication of heat transmission from the energy source to heating water. In each experiment the temperature change readings (the final temperature less the initial water temperature).

Time Intervals. Time intervals between temperature readings of 5 minutes initially then 1 minute up to maximum 10^{th} minute. These were used to develop trend of heating curves (curves of temperature against time) and computation of correlations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Sumary of the Chapter

This chapter consists of the literature review in relation to this study. The forest resource situation, global woodfuel utilization, other forms of biomass energy and renewable energy, the perffomance and efficiency of cooking stoves, the woodfuel energy problem in the Mau Complex and the importance of the Mau Forest Complex were covered.

2.2 Forest Resource Situation

Forests are the world's most important source of renewable biomass energy. Across the world, forests, trees on farms, and agroforestry systems play a crucial role in the livelihoods of rural people by providing employment, energy, nutritious foods and a wide range of other goods and ecosystem services with a tremendous potential to contribute to sustainable development and to a greener economy (Sepp *et al.*, 2014). According to FAO (2014), the forest formal sector employs 1.32 million people, contributes to the shelter of at least1.3 billion and provides wood fuel that is used by over 2.4 billion people to cook their food. However, worldwide deforestation continues at an alarming rate of about 13 million hectares per year (UNEP, 2007; FRA, 2010) and coupled with difficult ecological conditions in several parts of the world seriously reduce forest cover in many countries.

Most deforestation takes place in tropical countries, the situation is exacerbated where low rainfall slows forest regeneration and reforestation and where forestland is subject to pressures from shifting cultivation, livestock grazing and the uncontrolled gathering of wood fuel. In these countries, natural and planted forest land is critical to rural communities, and the loss of forest productivity and biological diversity is a serious threat to livelihoods (FAO, 2014). According to FAO, (2010), Low Forest Cover Countries (LFCCs), had less than 10% of their area classified as forest, e.g. Kenya with forest cover at 6.6% (Muraya, 2013; FAO, 2014). These countries found in arid and semi-arid zones of Africa and the Near East, often reflected severe ecological degradation that directly affected people's lives (FRA, 2010).

In Kenya, forests produce about 45% of the biomass energy resources while the balance is derived from farmlands in the form of woody biomass as well as crop and animal residues. By 1990, there was a widening gap between supply and demand for wood fuel observed by (Kamfor, 2002) in that the sources of fuel wood for household consumption were 47%, from agricultural land, 25% from gazetted forests and 28% from rangelands. While in 2000, the main sources were 64% from agro forestry, 8% from trust land, 8% from gazetted lands and 20% purchased outside the household. Although there are apparently large wood volumes available from the various vegetation types in the country, not all of it is accessible for energy. The socio economic benefits from forests constitute basic human needs and improvements in the quality of people's lives (a higher order of needs) that are satisfied by the consumption of goods and services from forests and trees The consequences of the pressure exerted on forestry resources by both food and wood fuel demands are far-reaching (Bett *et al.*, 2009).

2.3 Global Wood fuel Utilization

Wood energy is often the only energy source in rural areas of less developed countries and is especially important for poor people. Its use is also increasing in developed countries aiming to reduce their dependence on fossil fuels (FAO, 2014). The world's wood fuel consumption accounts for 6% of the Total Primary Energy Supply (TPES). In Africa wood fuel accounts for 27% of TPES and also accounts for approximately 92% of total African wood consumption (Bailis, 2004). However wood fuel consumption differs between urban and rural households, high and low income groups within a country as well as among countries in a region (FAO, 2014). Fuel choice and consumption is influenced by socio cultural, economic and technical parameters. Evidence from many countries does not support the notion that the transition from wood fuel consumption to modern fuels followed a regular pattern but, rather it displays a complex process in which economic and technical aspects are interlinked with cultural and social issues (Sepp *et al.*, 2014).

There is evidence that limited access to wood affects the level of consumption of wood fuel. The price is also an important factor but because the demand for wood fuel is relatively inelastic a price increase may not necessarily influence fuel switching (Sepp *et al.*, 2014; FAO, 2014). In urban settings, the availability of substitution fuels (LPG, Kerosene), higher education levels and thereto related higher incomes provide momentum for fuel switching. Within rural areas, substitution of fuel wood with charcoal occurs whenever people can afford to as charcoal is more convenient to use, produces less noxious fumes when burnt, is easier to transport and may be purchased in small quantities on a daily basis. The poorer segments of the populations switch to crop residues cow dung and other burnable materials when wood fuel becomes scarce.

In the horn of Africa, wood fuel energy is used largely for cooking in either a stove or an open fire. In Ethiopia, access to modern forms of energy was extremely constrained and up to 85% of the population relied primarily on wood, charcoal, cattle dung, and agricultural wastes as their fuel source for cooking Intergovernmental Authority on Drought and Development (IGADD, 2002). Tanzania's energy consumption was dominated by biomass mainly fire wood and charcoal. In Uganda, there was a large amount of wood-fuels, mainly charcoal entering Ugandan urban centres to satisfy the needs of households, tertiary, commercial and industrial sectors (IGADD, 2002).
As of 2007, biomass energy in Kenya i.e. firewood charcoal and agricultural wastes contributed up to 70% of the country's final energy demand and provided for almost 90% of the rural household energy needs(Energypedia, 2014; Gathiomi *et al.*, 2011). Fire wood is mainly used for cooking, water heating, house heating, lighting and other home businesses. It was estimated that the annual household consumption was approximately 6.5tonnes/household/year by (Gathiomi & Oduor, 2012). Wood fuels play a major socio economic role in almost all parts of the country. Within the family women are generally the most concerned by fuel wood issues since they devote a lot of their time to fuel wood gathering and cooking tasks (KWDP, 2005; Muchiri, 2008). According to ICRAF (1992), a typical household required about 8.5 kg of dry wood fuel every day, while FAO (2014) assessed the wood fuel annual demand at 11.96 m^3 for a house hold of six persons. Charcoal production and marketing on the other hand are more formalized and male specific, providing jobs and substantial revenue for rural urban people. About 47% of Kenyan households use charcoal with 82% of urban households using charcoal compared with 34% of rural households (GVEP, 2010).

Rural and urban households often consume a mix of both traditional and conventional energy types depending on household income. In densely populated areas such as the highlands of Western Kenya, wood fuel scarcity was widespread at the same time, tribal taboos denied women access to and control over trees on family land, which was inherited from father to son (KWDP, 2005). For example a wife was not allowed to plant trees on her husband's land as this was viewed as claiming the land; the same was true for any management, such as cutting, pruning, and indeed harvesting for fuel wood. Higher income families rely more on modern (electricity and LPG) energy sources. Wood may be burnt as it is or be converted to other solid fuels like charcoal or wood pellets (FAO, 2014). Charcoal is produced by controlled burning of wood in the absence of air (pyrolysis) resulting in almost pure carbon with a much greater energy density of 29 GJ/t compared to15-20 GJ/t for wood, (McMullan *et al.*, 1990). Charcoal is safer to use, as it is not highly flammable or explosive and if burned at temperatures less than 600^0 C, has less toxic carbon monoxide and nitrogen oxides generated (Plaskett & White, 1981). Charcoal is more environment friendly than the other wood fuel because of the smokeless burning process thus suitable for indoor cooking (Adegbulugbe & Bello, 2010) quite different from the smoky conditions in a typical rural kitchen (Plate 2.1).

Figure 2.1: Cooking conditions in typical rural Kenyan home

2.4 Other Forms of Biomass Energy

Briquettes can provide an alternative and in some cases more sustainable form of biomass energy. Briquetting involves the collection of combustible materials that are not usable as such because of their low density, and compressing them into a solid fuel product of any convenient shape that can be burned like wood or charcoal, with a higher bulk density, lower moisture content, and uniform size, shape and material properties (O'Connell, 2007; GVEP, 2010).

The raw material of a briquette must bind during compression so that when the briquette is removed from the mould, it does not crumble. Improved cohesion can be obtained with a binder or under high temperature and pressure, since some materials such as wood bind naturally. Binders used must not cause smoke or gummy deposits, nor create excess dust. Suitable binders include starch (5 to 10%) or molasses (15 to 25%) although their use can prove expensive (Klundert & Lardinoir, 1993). It is important to identify additional, inexpensive materials to serve as briquette binders in Kenya and their optimum concentrations. Fuel briquettes can be made from sawdust, urban waste, waste paper, sugarcane bagasse and charcoal dust.

Sawdust is waste material from all types of primary and secondary wood processing and 10 to 13 % of a log is reduced to sawdust in milling operations. Sawdust is bulky therefore expensive to store and transport while its calorific value is quite low. Briquetting it is an ideal way to reduce the bulk, to increase the density, and to increase its calorific value. The burning of 1 kg of sawdust fuel briquettes produces 18,000 KJ caloric power (O'Connell, 2007). Due to present limitations of equipment currently available in Kenya, locally produced sawdust briquettes have suboptimal densities, causing excessive smoke due to incomplete carbonization (partial pyrolysis) of the feedstock or the finished briquette (GVEP, 2010).

Solid waste disposal is one of the most serious urban environmental problems in developing countries including Kenya. The lack of public awareness on waste management, absence of sufficient capacity for waste processing and recycling, and non-implementation of environmental laws pertaining to waste disposal compound the problem. Open or crude dumping is the most common disposal method used and poses a health hazard when wastes lie scattered in the streets and at the dumping sites. It is now an accepted environmental philosophy that wastes have value and should be utilized based on the four "R"s "Reduce, Reuse, Recover and Recycle". Waste paper and leaves, in particular, provide a potentially important, alternative source of cooking fuel after they are moulded into cylindrically shaped briquettes using simple hand operated equipment. Conversion of organic wastes into cylindrical fuel briquettes is being undertaken by several Non-Governmental Organizations (NGOs) and Community Based Organizations (CBOs) in the country. Both at Nairobi's Millennium Fuel Project and at the Kayole Environmental Management Association (KEMA), briquette making as an alternative source of cooking energy and a viable opportunity for income generation is a priority activity. Three dried briquettes burned for at least 3 hours and were sufficient to prepare tea and a traditional Kenyan meal such as githeri (a mixture of potatoes, maize and beans (Legacy Foundation, 2003).

Surplus bagasse presents a disposal problem for many sugar processing factories. For example, at Nzoia Sugar Factory in Western Kenya, the average tonnage of excess bagasse produced per year is over 24,000 tons (Keya, 2000) and using a bagasse-to-briquette conversion ratio of 5:1, 4845 tons of bagasse charcoal briquettes could be produced. The pilot briquetting technology remains simple, applicable and of benefit to surrounding communities and the product is sold under the trade name Cane Coal. It is less expensive than regular charcoal and its use conserves diminishing forest resources in Western Kenya. Its marketing strategy is to produce lower-cost briquettes that light quickly and burn longer without producing sparks, smoke or unpleasant odours. According to (GVEP, 2010) one of the barriers likely to prevent the increase in the use of sugarcane bagasse in briquette making is the fact that bagasse smokes badly when burnt and producers lack the skills/equipment to carbonize it thus reduce smoke.

Nyeri Briquette Dealers manufacture briquettes from a mixture of charcoal dust and soil. Charcoal dust is collected from charcoal sellers at a cost and mixed with soil at a ratio of 1:5 (soil: charcoal dust) to make briquettes. The soil is basically a binding material which when mixed with water and charcoal dust forms a sticky mass that is fed into the briquette making machine and the extrude dried in the sun (Plate 2.2). These briquettes are used on stoves that are used with charcoal. The briquette making machines are designed and fabricated at the site in Nyeri. The machines are either electrically driven or manually operated (personal observation).

Plate 2.2: Drying Charcoal Dust Briquettes

Charcoal dust briquettes are used like charcoal and are credited with properties that compete well with charcoal (plate 2.3). These briquettes remove from the environment of charcoal dust which is often left behind after charcoal use and litters the environment.

Plate 2.3: Charcoal briquettes in Kenya Ceramic Stove

2.5 Renewable Energy in Developing Countries

Renewable energy projects in many developing countries have demonstrated that renewable energy can directly contribute to poverty alleviation by providing the energy needed for creating businesses and employment, and indirectly by providing energy for cooking, space heating, and lighting. Energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, are renewable (naturally replenished). About 16% of global final energy consumption comes from renewable sources, with 10% coming from traditional biomass, which is mainly used for heating, and 3.4% from hydroelectricity. Renewable energy sources (small hydro, modern biomass, wind, solar, geothermal, and biofuels) accounted for another 2.8% and are growing very rapidly. The share of renewables in electricity generation is around 19%, with 1% of global electricity coming from hydroelectricity and 3% from new renewable sources, (Minter, 2011).

Africa achieved the largest percentage increase in renewable energy investment among developing regions excluding the big three economies (China, India, Brazil). Total investment on the continent rose from $750 million to $3.6 billion, largely as a result of strong performances from Egypt and Kenya (Minter, 2011).

According to Minter, (2011) the renewable energy sector in Kenya is among the most active in Africa and investment grew from virtually zero in 2000 to US$1.3 billion in 2010. This included funding for wind, geothermal and small hydro capacity of 724MW, and for 22 million litres per year of bio fuels such as ethanol production. Geothermal was the highlight, with local electricity company KenGen securing debt finance for additional units at its Olkaria project.

Wind power in Kenya contributes only a small amount of the country's electrical power but the country targets to generate 2,036MW of wind power or 9% of the country's total capacity by 2030. The country plans to add 5,000 MW of power to the national grid by 2020 which is expected to insulate the country's power tariff by providing low cost and consistent power source making electricity accessible to a majority of Kenyans (Mushakavanhu, 2015).

Solar energy potential in Kenya is high, with the country receiving daily insolation of 4 – 6 KWh/m^2. Solar utilization is mainly for photovoltaic systems (PVS), drying and water heating. The solar PVS are mainly for telecommunication, cathodoic protection of pipelines, lighting and water pumping. Current installed capacity is approximately 4 MW. There are approximately 140,000 solar water heating systems currently in the country.

However among the various alternative renewable energy sources, biomass energy remains the most accessible. Biomass is a renewable energy source because the energy it contains comes from the sun, through the process of photosynthesis where plants capture the sun's energy. When the plants are burnt, they release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy.

2.6 Improved Cook Stoves Programmes

A cook stove can be defined as a portable or fixed appliance that burns fuel to provide heat for cooking (Kammen, 1993). Since the energy crisis of the 1970s, international aid organizations have targeted the improvement of traditional cooking stoves as a simple and affordable way to address the environmental, economic and energy issues posed by the home fire. Several hundred projects spread throughout dozens of countries have promoted the "improved" cook stove, a more efficient adaptation of the metal or clay implements on which many of the world's families cook their daily meals. These efforts range from national initiatives that have introduced more than 120 million stoves into homes in rural China to village training programmes in East Africa in which small groups of women learn to build and maintain their own stoves. Cook stove programmes follow closely the model for technology development and adoption of stoves that are affordable and can be produced and maintained locally. The improved stove industry has become a significant source of livelihood for a number of Kenyans. In 2002, the adoption level of KCS was found to be about 47% while that of the improved efficient woodstove was 4% (Kamfor, 2002).

2.7 Cook Stoves in Kenya

In Kenya, the metal stove (Plate 2.4), a traditional cooking implement, directs only a portion of the heat to the pot with a large portion of the heat said to be lost through the stove's metal sides, and another portion escapes as carbon monoxide, methane and other flue gases (Kammen, 1993).

Plate 2.4: Metal Stove

The Kenya Ceramic Stove (Plate 2.5) is the result of research on stove design, efficiency, and patterns of usage initiated in the 1970's and actively continued through the 1980's (Kinyanjui & Minae, 1982; Openshaw, 1982; Kammen, 1993 & Barnes *et al.*, 1994).

Plate 2.5: Kenya Ceramic Stove

The KCS has been promoted by local and international agencies. There were over 700,000 KCS's in use in Kenya (Walubengo, 1995) the stoves were found in over 50% of all urban homes, and roughly 16% of rural homes. The general features of the KCS programme and the stove design itself have both been utilized in formulating improved biomass stove programmes in a number of African nations.

The KCS also reduces emissions of products of incomplete combustion (carbon monoxide, nitrogen and sulphur oxides and various organic compounds), as well as particulate matter, the latter of which contributes to acute respiratory infection, the leading cause of illness in developing nations. Quantifying the degree of emissions reductions in actual home conditions is an ongoing area of study, with estimates of 20% in the literature (Karekezi & Ranja, 1997).

The KCS is a portable improved charcoal burning stove consisting of an hour-glass shaped metal cladding with an interior ceramic liner that is perforated to permit the ash to fall to the collection box at the base. A thin layer of vermiculite or cement is placed between the cladding and the liner. A single pot is placed on and rests at the top of the stove. The $2 to $5 (Kammen, 1993) stove price proved too high for many households that had the option of collecting their own firewood and cooking over open fires. For city dwellers, who sought ways to cut their unavoidable fuel costs, stoves that were more efficient held a greater allure. Village residents may be willing to spend that amount, some observers reasoned if there are undeniable benefits for an implement that will diminish the drudgery of collecting wood for hours on end and that will reduce the acid smoke in cooking huts from open fires. In Kenya charcoal use among a sample of families using the KCS fell from 0.67 to 0.39 kg/charcoal/day. This totals over 600 kg of charcoal/year for an average family, and a savings of over $US 60/year. A study in Rwanda prior to the war found charcoal use fell from 0.51 kg/person/day to 0.33 with the use of improved stoves. Personal incomes in Kenya and Rwanda average $300 - 400/year (Karekezi & Ranja, 1997).

Open fire (three stone stove) used for cooking in the millions of rural homes is thought to transfer heat to a pot inefficiently (Plate 2.6). With the three stone stove, a small proportion of the heat is regarded as going to the cooking utensil, while the rest is released to the environment.

Plate 2.6: Three Stone Stove

The first improved stoves began to appear in the early 1980s and were designed by aid groups such as UNICEF and CARE-Kenya. After much trial and error, it turned out that an extensive investigation of stove physics and engineering design was needed. This analysis revealed that the largest loss of heat from the fire, about 50 to 70%, occurs from radiation and conduction through the metal walls. Makers of some of the first stoves took measures to deliver more of the fire's energy directly to the pot.

Various governmental and international aid groups, however, continued to work with a loose consortium of crafts people, called *Jua Kali*, or "Informal Sector" to try to rectify the problems. Better stove designs gradually came about during the mid-1980s. At that time, a number of academics began to publish serious analyses of optimal stove combustion temperatures and of the insulating properties of the ceramic liner materials. One of the most notable contributions to enhanced design came through the responses of several women's organizations that had formed around such issues as community health and protection of the environment (Walubengo, 1995). These groups were part of a feminist movement spreading throughout the developing world. In Kenya, it was women who suggested recasting the metal bucket design, with its unstable narrow base, into an hourglass shape. That alteration prevented the new stove from tipping over, a constant danger when food was vigorously stirred in the earlier designs. These design changes, along with extensive training programmes established by aid groups and women organizations, caused dramatic gains in acceptance for the more efficient stoves. Schools, churches and businesses were among the first owners and helped to spark the interest of individual buyers. Today hundreds of Informal Sector manufacturers provide stoves to some 20,000 purchasers every month.

The Wood ceramic stove borrows the insulating element from the ceramic stove without the metal outer covering (Plate 2.7). The ceramic liner is set down in the middle of the open fireplace; it is then reinforced with mud and stones. The wood ceramic stove costs as little as KES 300.00 today.

Plate 2.7: Wood Ceramic Stove

According to Walubengo (1995), improved stoves were found in over 50% of all urban homes, and roughly 16% of rural homes however current statistics are not clear. Almost all rural and many urban families in Kenya rely solely on wood for their cooking needs and others on charcoal as the standard cooking fuel, which is obtained from woody vegetation. Almost all rural and many urban families in Kenya rely solely on wood for their cooking needs and others on charcoal as the standard cooking fuel, which is obtained from woody vegetation.

2.8 The Performance of Cooking Stoves

During the testing of stove performance a number of parameters are measured as indicators of the stove's performance (Bryden *et al.,* 2004; Bailis *et al.,* 2007). They include the fuel use efficiency of the stove, specific fuel consumption of the stove, the thermal efficiency of the stove, the time required to accomplish a specific cooking job (e.g. time to boil a specific volume of water) and the fire power of the cooking stove.

Stove performance varies greatly and the performance of a specific stove is often different in the laboratory and in the field. Testing stove performance allows stove designers to know how well a stove performs and quantifies improvements expected in fuel use efficiency, thermal efficiency and emissions testing.

2.9 Efficiency of Cook Stoves

Efficiency is a dimensionless quantity which is indicative of fuel economy. The efficiency of a stove tells how much of the energy in the fuel is given for cooking when the stove is used (Dutt & Geller, 1997). The analysis of cooking efficiency involves some normalization in addition to that used for specific fuel or specific energy consumption. In particular, cooking efficiency takes into account the foods being cooked and the manner in which they are cooked (Dutt & Geller, 1997; Bryden *et al.,* 2004). Thus, the determination of cooking efficiency facilitates comparison of fuel economy. The three standard tests developed were the Water Boiling Test (WBT), the Controlled Cooking Test (CCT) and the Kitchen Performance Test (KPT), (VITA, 1985; Dutt and Geller, 1997; Bryden *et al.,* 2004; Bailis *et al.,* 2007 & McCarty *et al.,* 2010).

The Water Boiling Test is a simplified simulation of the cooking process. It evaluates stove performance while completing a standard task (boiling or simmering of water) in a controlled environment to investigate the heat transfer and combustion efficiency of the stove. Water boiling tests are the easiest and fastest to conduct and reveal the technical performance of a stove and not necessarily what the stove can achieve in real household as described by the authors listed.

The Controlled Cooking Test (CCT) is a field test that measures stove performance in comparison to traditional cooking methods when a cook prepares a local meal. The CCT is designed to assess stove performance in a controlled setting using local fuels, pots and practice. It reveals what is possible in households under ideal conditions but not necessarily what is actually achieved by households during daily use.

The Kitchen Performance Test is a field test used to evaluate stove performance in real world settings. It is designed to assess the actual impacts on household fuel consumption. KPT are typically conducted in the course of an actual dissemination effort with real populations cooking normally and give the best indicators of performance (Bryden *et al.,* 2004; Bailis *et al.,* 2007).

Improving the heat transfer efficiency of energy from the fire to the cooking vessel through cook stoves reduces the amount of energy wasted, thus reducing the amount of wood needed. Fuel efficiency can be increased by improving the heat transfer from the fire to the cooking vessel. The crucial factor in improving stove efficiency is having the hot air and gas released from the fire contact the cooking vessel in the largest possible surface area (Baldwin, 1986; Bryden *et al.,* 2004). This is accomplished through the use of a pot skirt that creates a narrow channel forcing hot air and gas to rub along the bottom and sides of the cooking vessel. Increasing heat transfer can also be accomplished through the use of wide pots. Using a wide pot creates more surface area to increase the transfer of heat. Increasing the speed of the hot gases that rub against the pot can improve heat transfer. Improved stoves are insulated and lifted off the floor preventing childhood burns.

Cooking efficiency is normally defined as the fraction of the energy in the fuel consumed which has been usefully employed during cooking. The energy usefully employed during cooking can be defined as the energy used to heat the pot, the cooking medium, and the food to the cooking temperature(s) plus the energy absorbed by food as it cooks. According to Dutt & Geller (1997), this definition is reasonable for foods which are simmered in water (grains, legumes and boiled vegetables).
A general formulation of cooking efficiency as just described is given in the equation below:

$$\varepsilon_1 = \frac{\sum_{i=1}^{n}\{(M_{pi}C_{pi} + M_{mi}C_{mi} + M_{fi}C_{fi})(T_{ci} - T_a) + M_{fi}K_{fi}\}}{[M_w E_w - M_r E_r]} \qquad \textit{Equation } 1$$

(Dutt & Geller, 1997; Bailis *et al.,* (2007) The efficiency ε_1 applies to one complete cooking cycle. The summation in Equation is over the different food items. For each item i, M_{pi}, M_{mi}, and M_{fi} are the masses and C_{pi}, C_{mi}, and C_{fi}, are the specific heats of the pots, cooking media, and foods respectively. T_a is the initial temperature of the pots, cocking medial and foods (normally the ambient temperature) and T_{ci} is the cocking temperature of item i. K_{fi} is the energy required for the chemical reactions which take place during cooking a unit of item i. M_w and E_w are the mass and calorific value of the fuel wood consumed and M_r and E_r are the weight and calorific value of any wood fuel recovered upon completion of cooking.

The measurement and calculation of efficiency is simplest when water is the 0 cooking medium (Bailis *et al.,* 2007). In this case, the cooking temperature is approximately equal to 100^0C at a pressure of one atmosphere. In order to calculate the efficiency using the equation above, the following measurements or estimates have to be made that is the weights of the pots, cooking water, foods, fuel consumed, and any charcoal reclaimed upon completion of cooking; the temperatures of ambient air, cooking water at the start of cooking, and the contents of the pots during cooking; calorific values of the fuel.

Thus, a scale and a thermometer are the only instruments needed to measure efficiency beyond those used for measuring or estimating calorific value. The specific heats which may be needed to calculate efficiency include C_{upid} = 0.88 kJ/ kg ºC for clay pots, C_{pi} = 0. 92 kJ/ kJ/ kg ºC for aluminium pots, and C_{mi} = 4.18 kJ/ kg ºC for water. Although the chemical reactions in food during cooking have been well-studied (Dutt & Geller, 1997; Bailis *et al.,* 2007) these studies do not provide the energy absorbed by food during the cooking process (K_{fi}) in a convenient form.

2.10 Fuel Energy Problem in the Mau and the Importance of the Mau Complex

Like other parts of Kenya, the rural communities found within the Mau complex like Likia rely mainly on wood fuel to meet their energy needs. The acute nature of wood fuel shortage is visible by the presence of large quantities of wood fuel in the local market centres for sale, the high demand and the high prices at which local residents are willing to pay to access it. In extreme cases families are forced to reduce cooking fuel use to the minimum necessary a situation that has adverse effect on the nutritional status of the communities (Muchiri, 2008). Frequently crop residues such as maize cobs and stover are used as wood fuel rather than remaining in the field to enhance the soil organic matter content, (UNEP *et al.,* 2005). For communities that live adjacent to forests, charcoal conversion though an illegal activity continues to a considerable extent thereby accelerating the pace of land degradation by continuous removal of woody vegetation without replacement. Mau Forest Complex has an area of 273,300 hectares and lost 107,000 ha to encroachment (ROK, 2009b).

The Mau Forest Complex forms the largest closed canopy forest ecosystem of Kenya. It is the single most important water catchment in the Rift Valley and Western Kenya, and is a natural asset of national importance whose condition has a major impact on the agricultural, tourism and energy sectors. Its forests provide critical ecological services to the country in terms of water storage, river flow regulation, flood mitigation, recharge of ground water, reduction in soil erosion and siltation, water purification, conservation of biodiversity and microclimate regulation. Through these ecological services, the Mau Forest Complex supports key economic sectors in the Rift Valley, Western Kenya and Nyanza regions including energy, tourism, agriculture and industry. In addition the Mau Forest Complex is the source of water supply to urban areas for domestic and industrial use and supports the livelihoods of millions of people living in the rural areas (Geller, 2009).

The market value of goods and services generated in the agricultural, tourism and energy sectors alone to which the Mau Forest Complex has contributed is in excess of KES 20 billion a year. This does not reflect provisional services such as water supply to urban areas (Bomet, Egerton University, Elburgon, Eldama Ravine, Kericho Molo, Narok and Njoro). The estimated potential hydropower generation of the Mau Forest Complex is 535 MW (ROK, 2009b).
Despite its critical importance for sustaining current and future economic development, The Mau Forest Complex has been impacted by extensive irregular and ill planned settlement as well as illegal forest resources extraction.

The Mau. forms the upper catchments of all (but one) main rivers west of the Rift Valley, including; Nzoia River, Nyando River, Sondu River, Mara River, Kerio River, Molo River, Ewaso Nyiro River, Njoro River, Nderit River, Makalia River and Naishi River. Mau Complex is also key to major conservation areas where a great diversity of flora and fauna can be found (UNEP *et al.,* 2005).

Mau forest is also important for biodiversity conservation. It has been designated as an important bird area according to BirdLife International because it hosts several avifauna of global conservation concern e.g. Ayres Eagle, African Crowned Red Eagle, African Grass Owl, Cape Eagle Owl, Grey Winged Robin, Red Chested Avlet, Least Honey guide, Purple Throated Cuckoo_Shrike (Bennun & Njoroge, 1999).

It is also home to other wildlife species such as Yellow-backed Duiker, African Golden Cat, Mountain Fruit Bat, African Elephant, Giant Forest Hog and the Bongo. Because of this biodiversity value, it has also been designated as a biodiversity hotspot by Conservation International and is part of the Eastern Afromontane Biodiversity hotspot.

2.11 Gaps in Knowledge

Although several studies using the Water Boiling Test (WBT) have been done on testing of stove performance (Dutt &Geller 1997; Bryden *et al.*,, 2004; Bailis *et al.,* 2007; Michael, 2011; MarCarty *et al.*, 2010; Defoort*, et al.*, 2016), the studies concentrated on the evaluation of the stove performance without the incorporation of field working conditions. The WBT 4.0 protocol suggested the incorporation of field operating conditions into WBTs such as fuel moisture, fuel feeding rate into the stove, and fuel type to evaluate stoves.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sumary of the Chapter:

In this chapter, the location of the study area is shown, the geology, soils, vegetation and climate are also included. The reseach design covering the survey and experiment that were carried out in this study were covered.

3.2 Description of Study Area

3.2.1 Physical Location of Study Area

Likia location is located in Mau Narok ward of Njoro Sub-County within Nakuru County (Figure 3.1) at coordinates 25, 07’51$^{''}$ S; and 35^{0} 48$^{'}$50$^{''}$ E. It lies at an altitude of between 2527 and 2693m a.s.l. Likia is located 30km SW of Nakuru town.

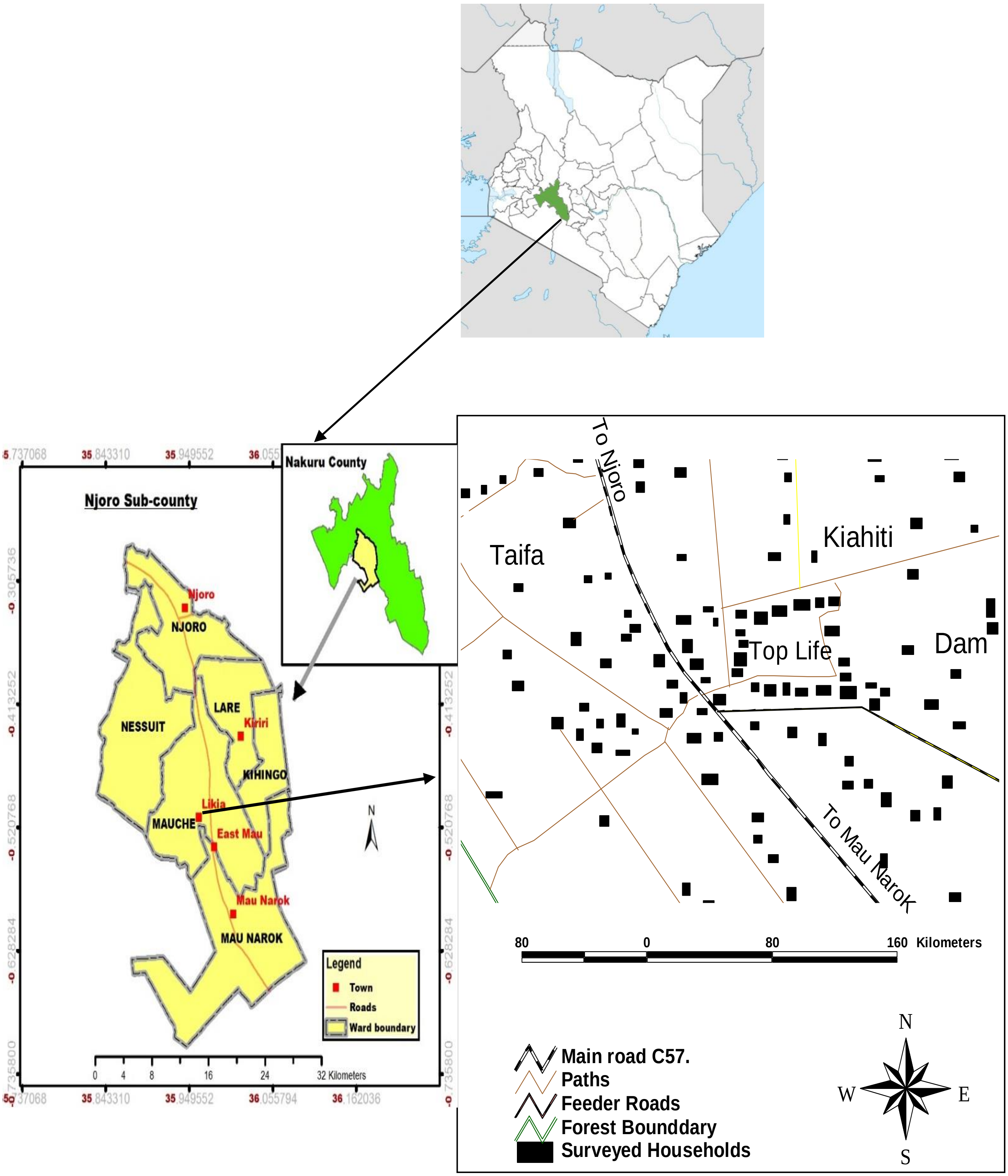

Figure 3.1: Location of Study Area

3.2.2 Geology, Soils, Vegetation and Climate

The geology and soils of Likia are influenced by ancient volcanic activity. The area lies within the central Rift Valley on the East Mau escarpment. In general, the area is dominated by soils which have been developed from ashes and other pyroclastic rocks of recent volcanoes and can be described as mollic Andosols (Mbugua, 2009).These soils are well drained deep to very deep, dark reddish brown, friable and smeary, silt to clay, with humic topsoil. The common types of vegetation found in the area are evergreen broadleaf planted forest (e.g. *Eucalyptus saligna*), evergreen needle leaf planted forest (e.g. *Pinus spp, Cuppressus spp*), mixed natural forest (e.g. *Olea africana, Dombeya torrida, Juniperous procrera and Croton megalocarpus).*

Annual rainfall ranges from 975 – 1474 mm in the settlement area and 1475 – 2474 mm in the forest area. Generally, there is a remarkable reduction in rainfall over the last 15 years and the rainfall reliability estimated at 60% (Mbugua, 2009). The temperature ranges between 14.9^{0}C to 12.6^{0}C.

3.2.3 Socio Economic Profile

According to the KNBS, (2010), the population of Likia locations was 4750 persons. The major ethnic groups include the Kikuyu, the Kalenjin and the Maasai.

The agricultural sector is the most productive based on food and cash crop production. Maize, beans, cabbages, peas, carrots, pyrethrum are the major crops, while wheat farming is practiced by few farmers with larger acreages. The average farm holding is 4 acres (ROK, 2009b). Livestock production is also an economic activity with local poultry, dairy animals and sheep rearing practiced. Declining productivity of agricultural resources, unreliability of rainfall and shortage of land due to population increase is reducing the people's dependence on agriculture as it cannot meet the year round economic needs of the farmers. As a result, the community has impacted on the adjacent Likia forest (a forest fragment of the larger Mau Forest) in diverse ways and varying magnitude.

Likia is served by the main Nakuru Mau Narok road classified as C 57, linking the area to Narok and Nakuru, with a number of feeder roads. This major access road plays a role in the transportation of wood fuel (charcoal and firewood) to Nakuru and other urban centres.

The main sources of energy used in Likia are wood fuel for cooking and kerosene for lighting. Electricity use is limited to residents in the township area based on ability to pay for it.

3.3 Research Design

This study was done in two parts   a survey then experiment. The survey sought to establish how wood fuel was utilized in Likia from responses given to structured questions on woodfuel utilization and the cooking stoves used (Appendix 6). The experiment was to measure the heat gained during cooking, whether the cooking stoves with the different fuels could accomplish a specified cooking task within a given time (boil one litre of water within ten minutes) and assess the efficiencies of the cooking stoves used.

3.4 Sampling Procedure

3.4.1 Survey

The population of Likia Location is 4750 persons (KNBS, 2010). Food was prepared for households rather than individuals. The average household size for Likia was seven persons (MOA, 2009). From a population of 4750 persons and an average household size of 7 persons, there were 4750/7 = 678 households (the study respondent population for the survey). Assuming that the sample was genuinely random, with a margin of error 9% and at 95% confidence level, a sample size of 100 households was obtained using the online sample size calculator software (Creative Research Systems, 2012).Likia location consists of four villages which were considered as the four strata from which respondents were selected. Twenty five respondents were randomly selected from each village thereby comprising the required sample size of 100 respondents.

3.4.2 Experiment

For the experiment, Split Plot in Randomized Complete Block Design was used. The fuel types (*Olea africana* charcoal and firewood, Paper waste briquettes, charcoal dust briquettes) were considered the main plot factor while the sub plot factor were the cooking stoves (three stone stove, ceramic stove, wood ceramic stove and the metal stove). The experiment was replicated four times (Figure 3.2).

For the experiment, there were twenty treatments, from five types of fuel and four types of cooking stoves for each of the four blocks. Within each block there was randomization with each of the treatments assigned once. There were a total of eighty replicates for the experiment.

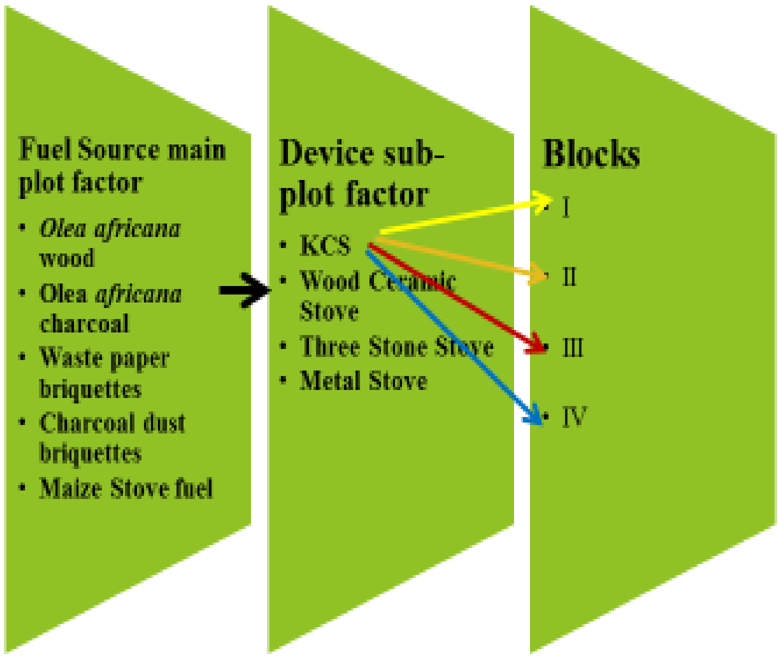

Figure 3:2: Experimental Design

3.5 Operationalization of Study Variables

During the experiments, temperature changes were expected. These were measured using a thermometer. The changes in temperature were an indication of heat transmission from the energy source to heating water. In each experiment the temperature change readings (the final temperature less the initial water temperature) were used to compute the heat gained by the water. Hence the heat gained was computed using the basic formula

$$Heat\ Gained = MC\theta \qquad Equation\ 2$$

Where M = mass of water (kg); C = the heat capacity of water; θ = the change in temperature (^{0}C)

Time intervals between temperature readings of 5 minutes initially then 1 minute up to maximum 10^{th} minute. These were used to develop trend of heating curves (curves of temperature against time) and computation of correlations.

The difference in mass between the initial mass of the wood fuel (at lighting of the stove) and the mass of any wood fuel recovered at the end of cooking was the mass of wood fuel used.
Efficiency of Cook stoves is the proportion of energy in the fuel which is used for heating to the total energy generated by the fuel and computed from the basic formula

$$Efficiency = \frac{Heat\ output}{Heat\ input} \times 100 \qquad Equation\ 3$$

Where, heat output is the heat gained by the water i.e. Heat Gained = MCθ. Heat input is the calorific value of the wood fuel.

Table 3. 1 Determination of Local Boiling Point

Temperature^{0}C	Time In Minutes
90.9	0(First Boiling Temperature)
91.0	1
91.0	2
91.0	3
91.0	4
91.0	5

Local boiling temperature = 90.9 + 91.0/2= 90.95 = 91^{0}C

One kilogram sample of specific wood fuel(*Olea africana* fuel wood; *Olea africana* charcoal; maize stover; waste paper briquettes; charcoal dust briquettes) was collected and weighed for each of the cooking stoves(Kenya ceramic stove; wood ceramic stove; metal stove; three stone stove). The cooking pan (aluminium pot) with 1 litre of water weighed. Using the relevant types of fuel the cooking stoves were lit and the lighting duration of each stove was recorded. The initial temperature of the water before heating was measured. 1 litre of water was heated and temperature recorded after an interval of 5 minutes first, then after one minute until the tenth minute. The pan was removed from the fire and immediately another pan of water placed on the same fire and temperatures recorded like previously stated. The procedure was repeated for a third and a fourth pan until the changes in temperature were notably too low indicating that the heat in the fuel as having been transferred to the heating water. The procedure was repeated for all the remaining cooking stoves/fuel type combinations.

3.6 Data Collection

3.6.1 Survey

For the survey, the study population comprised of 678 households (the study respondent population for the survey). Assuming that the sample was genuinely random, with a margin of error 9% and at 95% confidence level, a sample size of 100 households was obtained using the online sample size calculator software (Creative Research Systems, 2012). The sampled households were visited and respondents requested to respond to structured questions. The responses were recorded during the interviews for analysis.

3.6.2 Experiment

For each experiment a data collection sheet was used to record temperatures during the experiments as shown (Table 3.2).

Table 3.2 Experiment Data Collection Sheet Olea africana charcoal/ceramic stove

Mass of fuel used Kg		1 kg	
Volume of water heated (l)		1 litre	Change In Temperature (^{0}c)
Stove lighting duration (Minutes)		7 minutes	
Initial water temperature(^{0}C)		23	
First pan Temp of heating water ^{0}C	0 min	23	
	After 5 min	52	
	After 6min	58	
	After 7 min	62	78 – 23=55
	After 8 min	66	
	After 9min	72	
	After 10 min	78	
Second pan Temp of heating water ^{0}C	0 min	23	
	After 5 min	60	
	After 6min	64	89 – 23=66
	After 7 min	75	
	After 8 min	79	
	After 9min	85	
	After 10 min	89	
Third pan Temp of heating water ^{0}C	0 min	23	
	After 5 min	64	
	After 6min	71	90 – 23=67
	After 7 min	77	
	After 8 min	81	
	After 9min	86	
	After 10 min	90	
Fourth pan Temp of heating water ^{0}C	0 min	23	
	After 5 min	54	
	After 6min	60	80 – 23=57
	After 7 min	66	
	After 8 min	71	
	After 9min	75	
	After 10 min	80	

From the data sheets for each experiment change in temperatures were computed as the difference between the final temperature and the initial temperature (Appendix 2). From changes in temperature, heat gains and the efficiencies of the stoves were computed.

3.7 Data Analysis

Table 3.3 shows the data collected and data analysis tools used based on the specific objectives of the study.

Table 3.3 Data Analysis

Objective	Data Collected	Data Analysis Tool
Assess the wood fuel utilization in the study area.	Information on woodfuel utilization	Descriptive analysis, Frequencies using bar charts and pie charts.
Evaluate the amount of energy dispersed per stove by the commonly used fuel sources	Temperature changes	ANOVA and LSD at $\alpha = 0.05$.
Measure the time and energy requirement per cooking stove to heat 1 litre of water.	Time and temperature changes	Correlation analysis.
Assess the efficiency of the stoves used.	Temperature changes	ANOVA and LSD at $\alpha = 0.05$.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Summary of the chapter

The results of this study are contained in this chapter. Woodfuel was found to be the main form of energy used alongside the three stone stove. The availability of woodfuel was also found to be constrained therefore putting pressure on the adjacent Mau forest to provide the required woodfuel. The maize stover fuel was the easiest to light, while the waste paper briquettes were the hardest to light. From the experiments and ANOVA procedure, there were significant differences in the mean heat gained during cooking due to the woodfuel type used but not due to all the cooking stoves used. Some stoves could achieve a cooking task within a shorter time than others. There was significant correlation between time and temperature during cooking. There were significant differences in the mean efficiencies of the cooking stoves due to the type of wood fuel used, the cooking stove used and the interaction between the stove and the woodfuel.

4.2 The Wood fuel Utilization Patterns

4.2.1 Forms of Energy Used For Cooking

From the analysis of the questionnaire administered, the following responses were obtained. All the respondents interviewed used wood fuel as source of energy for cooking with 90 % of the respondents using it in the form of fuelwood (Figure 4.1).

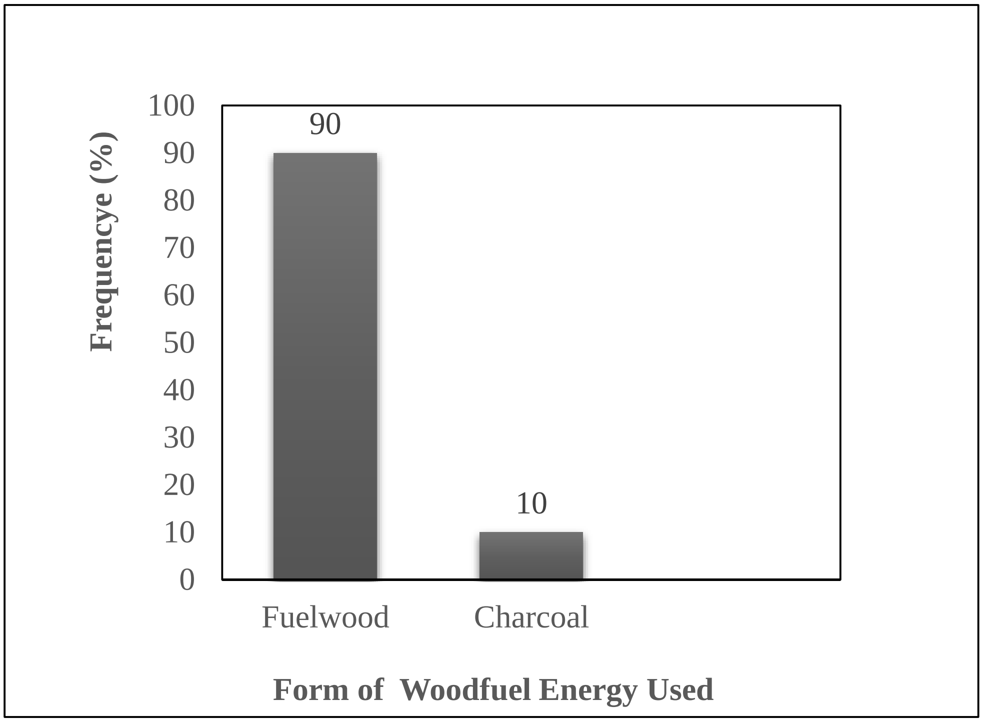

Figure 4.1: Form of Energy used for Cooking

Only 10% of the respondents used charcoal for cooking. Although there were high rates of charcoal conversion activities within the area, most of the charcoal produced was sold rather than used for cooking. Bicycles loaded with bags of charcoal heading away from Likia either towards Njoro or Mau Narok were are a common site. This generally implied a continuous supply required to satisfy the demand hence the substantial conversion of vegetation to wood fuel. The extensive use of woodfuel had impacted negatively on the environment as continued removal of vegetation cover without adequate replacement left the land susceptible to soil erosion and ultimately land degradation. This situation was similar to that described by (UNEP *et al.*, 2005) generally and by (Bett *et al.*, 2009) in a study carried out in Njoro district.

4.2.2 Time Spent Fetching Woodfuel and Amounts Fetched In One Fetching

Thirty percent of the respondents spent a whole day fetching wood fuel (Figure 4.2). The time spent on fetching fuel was influenced by the distance to collection points and transport back to the homesteads.

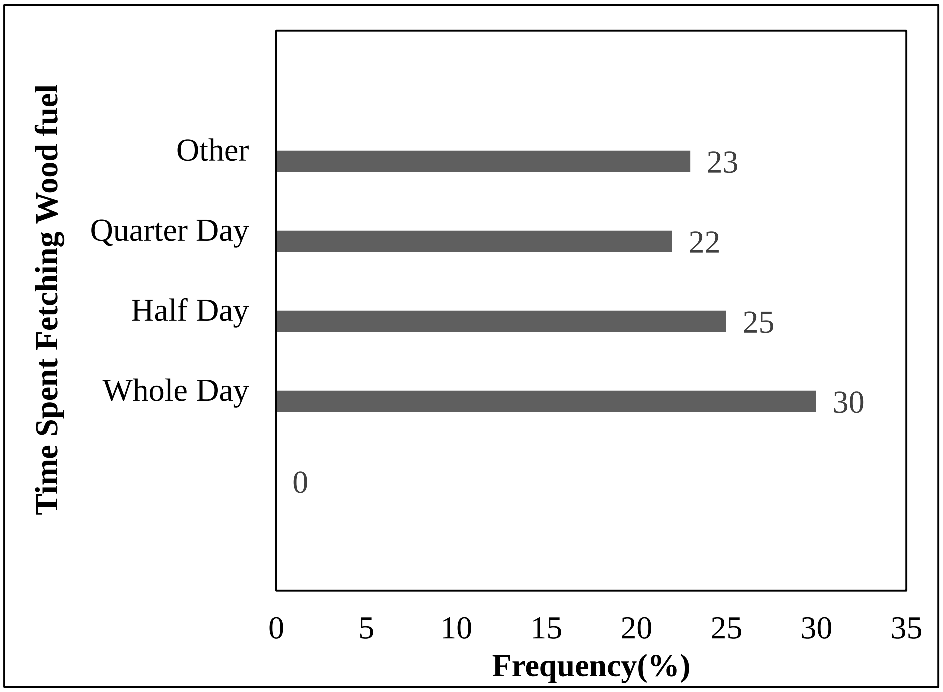

Figure 4.2: Time Spent Fetching wood fuel

This was attributed to the fact that wood fuel was not available in the vicinity of their homes, but had to be fetched from far away which also limited the number of trips to fetch wood fuel. This was consistent with the findings by (Muchiri, 2008; Gathui & Mugo, 2010) which showed that as fuel became scarce women were forced to travel longer distances and spend more time and physical energy in search of fuel.

Eighty eight percent of the respondents fetched over 10 kg of firewood (Figure 4.3). For those who fetched less than 10kgs, wood fuel fetching had to be done more often.

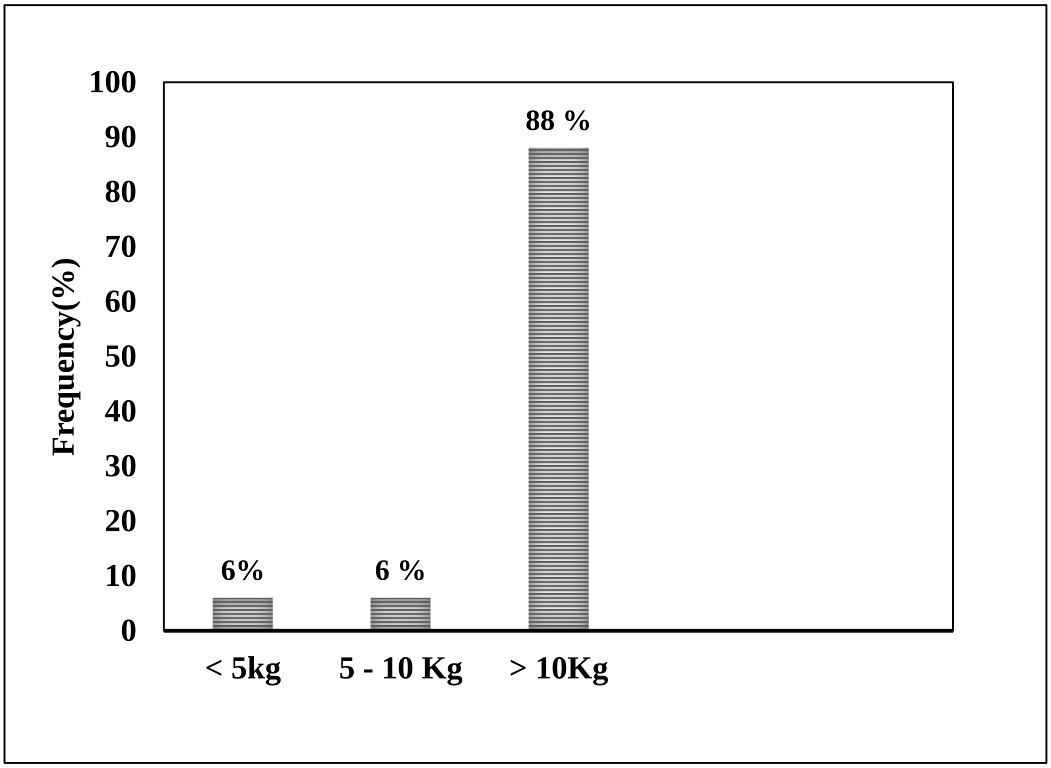

Figure 4.3: Amount of Woodfuel Fetched

4.2.3 Time One Day's fetching Lasts and State of Fuel When Fetched

Forty five percent of the respondents' fetched fuel which lasted more than four days, while 13% of the respondents had to fetch fuel every day (Figure 4.4). A lot of time was spent fetching wood fuel which affected the completion of other chores scheduled for the day. Generally in Kenya, women were finding their daily domestic chores increasingly difficult to accomplish as they were compelled to walk longer distances to fetch fuel wood (Muchiri, 2008; Gathui & Mugo, 2010). Women were also largely responsible for ensuring adequate food production for their families. The time spent in collection and gathering of wood fuel did not auger well for ensuring food security.

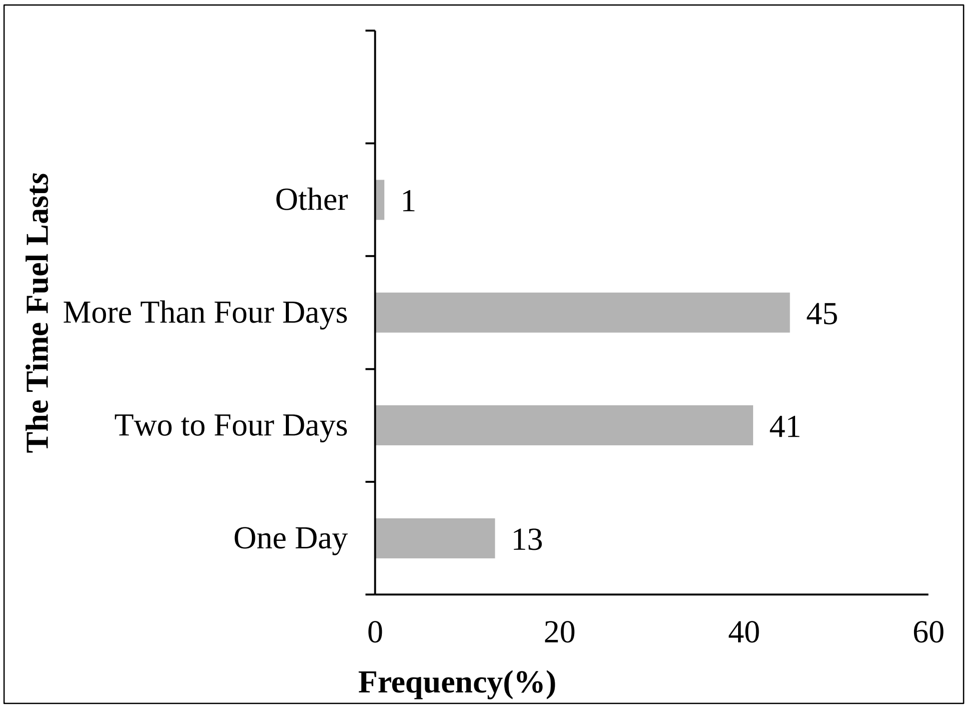

Figure 4.4: The Time Fuel lasts

Ninety four percent of the respondents' fetched dry fuelwood which was obtained either from the forest or purchased directly from vendors. Six percent of the respondents their wood wet (Figure 4.5).

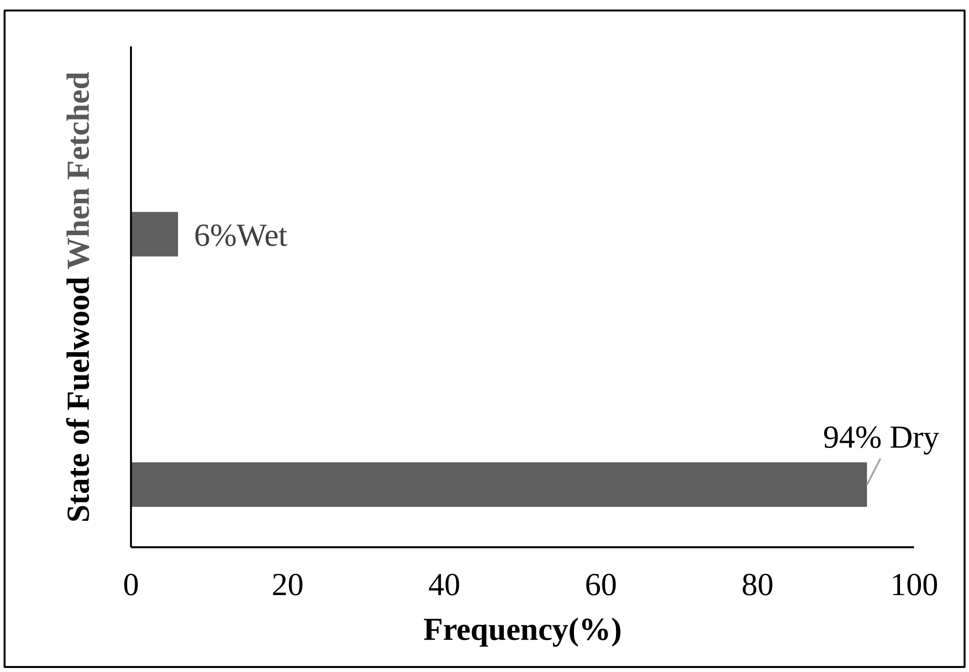

Figure 4.5: State of Fuelwood when Fetched

For respondents who fetched their wood fuel when wet, it was mostly harvested from their own farms from felling or pruning of trees. This wood fuel had to be dried before it was used.
Though the residents of Likia had ample opportunity to ensure an adequate supply of wood fuel through the incorporation of agroforestry practices on their farms, few farmers planted trees thus putting a lot of pressure on the adjacent Mau Forest for the supply of woodfuel required. This situation was similar to that reported by (Gathiomi *et al.*, 2011) in a study carried out in Central Kenya where farmers had failed to plant trees despite their constant need for wood fuel to cook their food.

4.2.4 Mode of Acquisition and Responsibility for Fetching Woodfuel

Sixty nine percent of the respondents purchased woodfuel (Figure 4.6). Among these respondents were those that had paid the requisite fee to the Community Forest Association (CFA) which allowed them access to the forest to collect wood fuel for a one month period, and those respondents that directly purchased woodfuel from vendors. The source of all the woodfuel purchased was the Mau forest. The wood fuel was available as a result of thinning and pruning operations carried out as regular management activities of the various forest blocks.

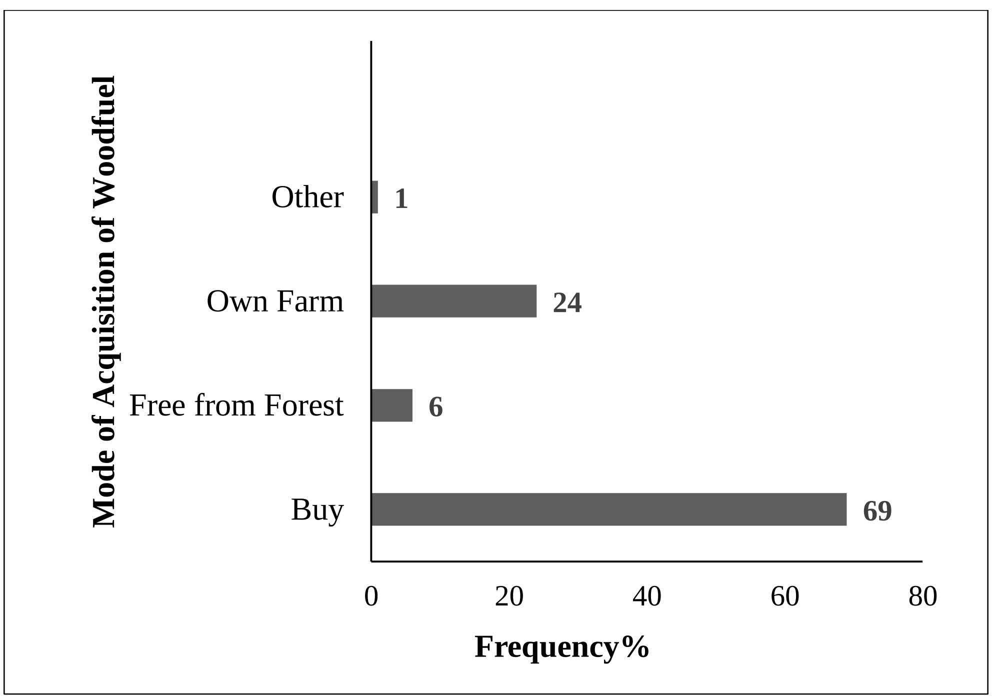

Figure 4.6: Mode of Acquisition of Woodfuel

Dependence on the forest for continuous supply of woodfuel was affecting efforts at conservation of the adjacent Mau Forest. Twenty four percent of the respondents obtained wood fuel from their farms. These were farmers who had embraced agro forestry and planted trees alongside their other enterprises to ensure a sustainable supply of wood fuel. According to Tengas, (1994), agroforestry has the potential for alleviating the shortage of woodfuel than any other form tree or forest management. Six percent of the study population illegally obtained wood fuel free from the forest which was normally collected from the edges of the forest as non-payment of the agreed levy to the CFA restricted their entry into the forest to fetch wood fuel in adequate amounts. This compared fairly well with the 2% reported by (Kuria, 2011) in a study carried out in Nakuru County where wood fuel was fetched free from Dundori Forest. According to Desclee *et al*, (2013) the incorporation of agroforestry into livelihood strategies was a major forest conservation initiative. This was the case in the Congo forests where growing woodfuel trees alleviated stress on the native forests of the Congo basin.

Fetching of wood fuel was mostly done by adult females for 71% of the respondents and 16% by adult males (Figure 4.7).

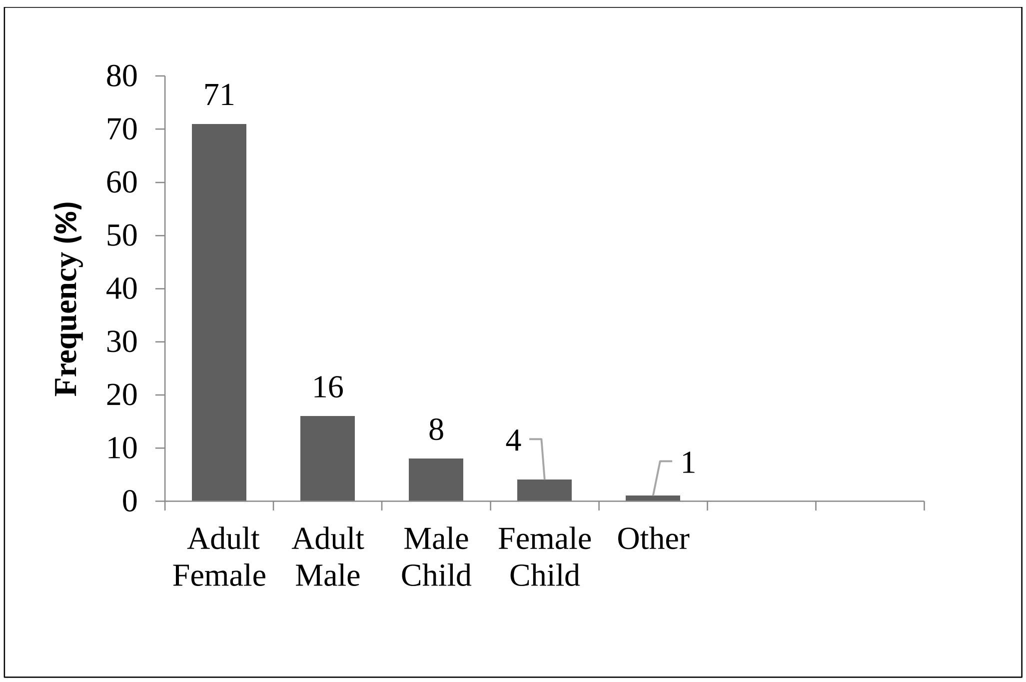

Figure 4.7: Responsibility for Fetching Woodfuel

Generally the findings of this study were consistent with the findings of (KWDP, 2005; Muchiri, 2008; FAO, 2014) which showed that adult females were largely responsible for the preparation of food hence were also expected to ensure a sufficient supply of wood fuel for cooking. The United Nations Status Report on the progress towards achievement of MDGs and specifically MDG 3 stated that women on average spend roughly twice as much more time than men on unpaid domestic and care work, a situation that MDG 3 had failed to address among which was fetching of wood fuel (UN, 2013). Many women and girls also suffer from health problems associated with indoor pollution related to gathering and using traditional fuels (Muchiri, 2008; UN, 2013). In addition to the time and physical burdens involved in gathering fuel, women suffer serious long-term physical damage from strenuous work without sufficient recuperation time. Women, it was reported must worry about falls, threats of assault, and snake bites during fuel gathering. However in the case of Likia adult males and male child took up the responsibility of fetching wood fuel to a greater extent than the female child.

4.2.5 Cost of Fetching fuel and Means of Transporting fuel to Homestead

Seventy nine percent of the respondents incurred a cost of KES. 50 to 150 per fetching of wood fuel (Figure 4.8) more than half of this cost was attributed to transport of the wood fuel.

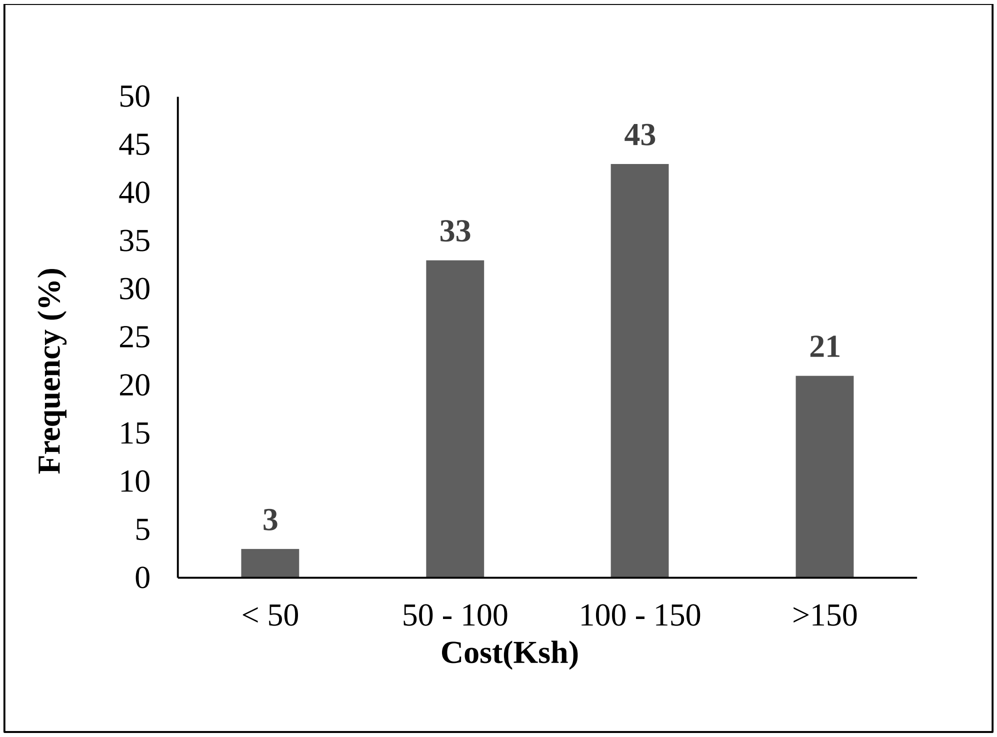

Figure 4.8: Cost of fetching Fuel

The cost incurred in fetching fuel meant that a substantial portion of the household income was spent on the acquisition of wood fuel, which was consistent with the findings by (FAO, 2014). In the FAO study, households globally spent 7.8% of their income on obtaining wood fuel including the cost of transporting it to the site where it was used.

Seventy three percent of the residents preferred to carry the wood fuel home on their backs, which was a normal scene within the study area. Twenty percent of the respondents used donkey pulled carts, which allowed them to carry home a little more wood fuel. Bicycles and motor vehicles were also used to transport the fuel to their homes from the fetching sites. However some of the respondents who transported wood fuel in larger quantities were actually traders who fetched the wood fuel then sold it at the local market as an income generating activity (Figure 4.9) and (Plate 4).

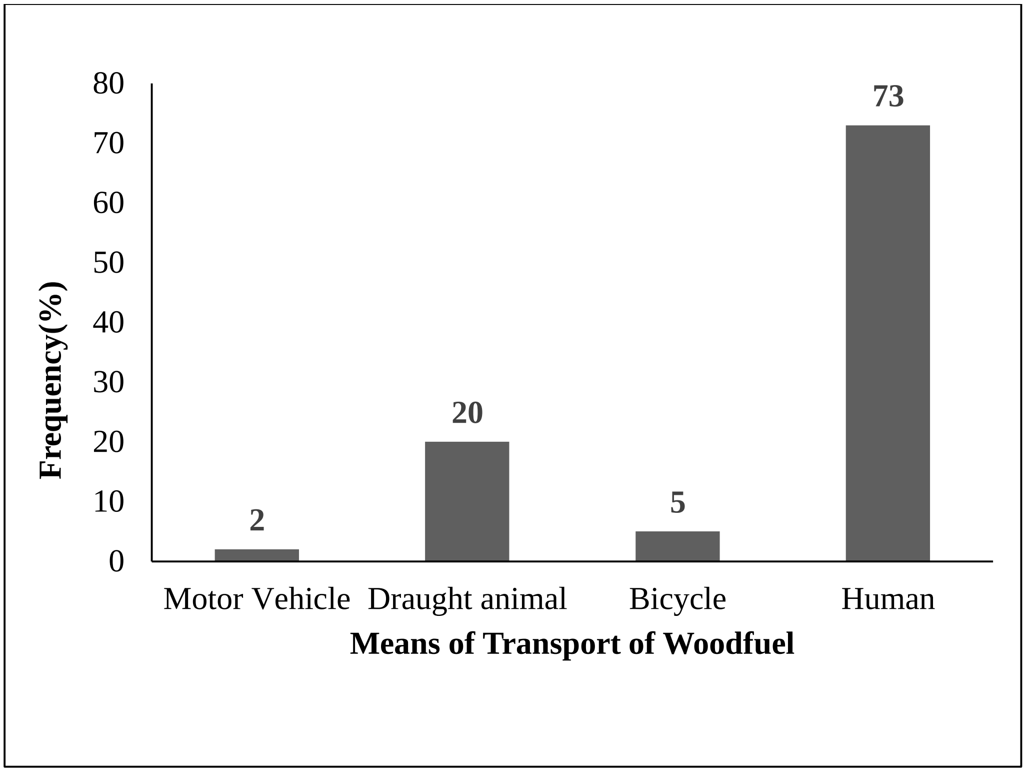

Figure 4.9: Means of Transport of Woodfuel

Plate 4.1: Bicycle loads of fuel wood beeing transported to market centres

4.2.6 Types of Known Stoves and Most Preferred Stoves

Seventy one percent of the respondents were familiar with the three stone stove, and 1% familiar with the other stoves e.g. sawdust stove (Figure 4.10.)

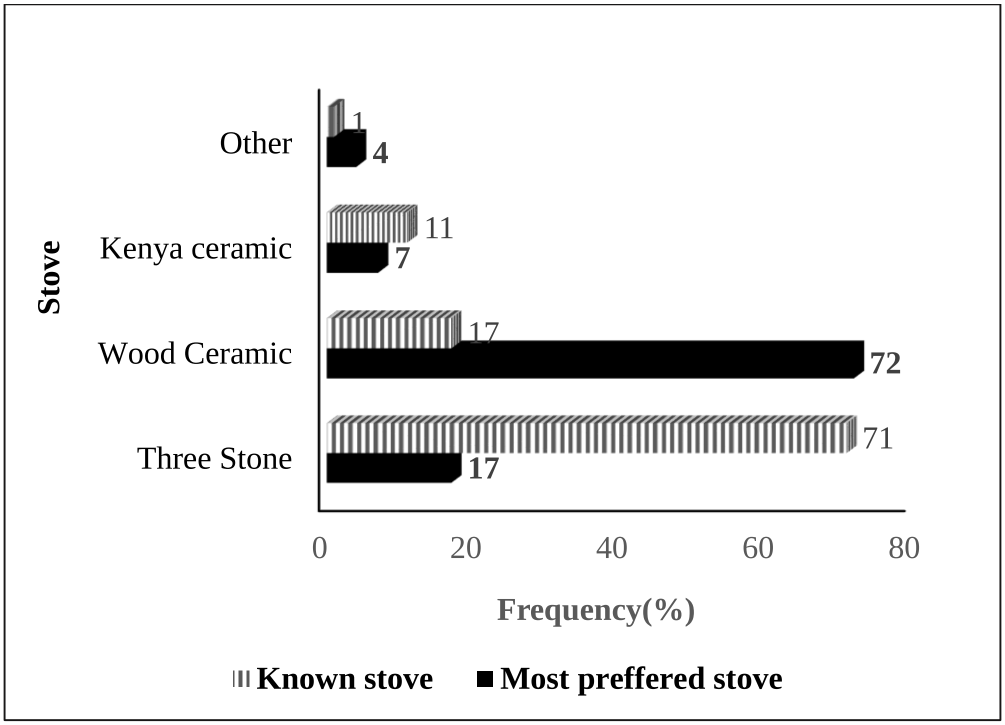

Figure 4.10: Known stove and Most Preffered Stove

The three stone stove was the most known stove by the residents of Likia (Figure 4.10) mainly based on their unwillingness to incur the costs of obtaining improved stoves. However the respondents stated wood fuel shortage was becoming a reality that they urgently needed to deal with. They therefore chose the wood ceramic stove as most preferred.

4.2.7 The Reasons for the Preferred Stoves

The major reason that was given for the most preferred stove was the conservation of fuel by 75% of the respondents (Figure 4.11).

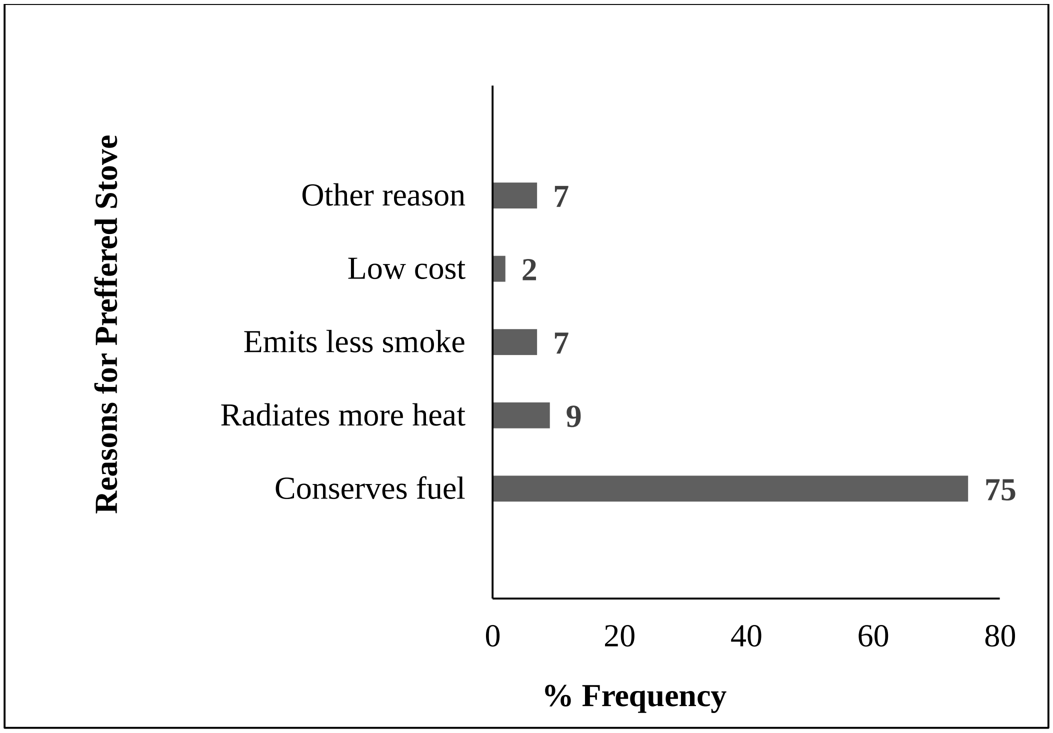

Figure 4.11: Reasons for Preffered Stoves

The area had witnessed rapid land cover changes in the past two decades involving vast clearance of indigenous forests which the farmers used to depend on as a source of fuel wood to create farmland also noted by Bett *et al.,* (2009). The respondents who preferred the three stone stove gave the reason that it enhanced space warming through radiating heat and the family could sit around the fire place during the cold season and also the low cost incurred to acquire it. However, none of the respondents that preferred the three stone fire mentioned the problem of the smoky environment that is known to constantly expose them to indoor air pollution predisposing them to acute respiratory illnesses as documented by (Muchiri, 2008). The reason given for preference of the ceramic stove was that less smoke was emitted and that cooking could comfortably done inside the main house. This was consistent with the findings of (Hawkins,1987; McMullan *et al.,* 1990) that charcoal (the form of wood fuel used with the Ceramic Charcoal stove) when burned at temperatures of less than 600^0 C, had less toxic carbon monoxide and nitrogen oxides generated, also confirmed by (Placket & White, 1981; Hawkins, 1987; Adegbulugbe & Bello, 2010).

4.2.8 Other functions of cooking Stoves

Apart from cooking, 41% of the respondents reported using the stoves to boil drinking water. After cooking the fire that remained was not just left to smoulder until it went off. Twenty nine percent of the respondents gave no other function of the stove apart from cooking and reported leaving the fire to die out after cooking regardless of how hot it still was, which purely wastage of fuel (Figure 4.12).

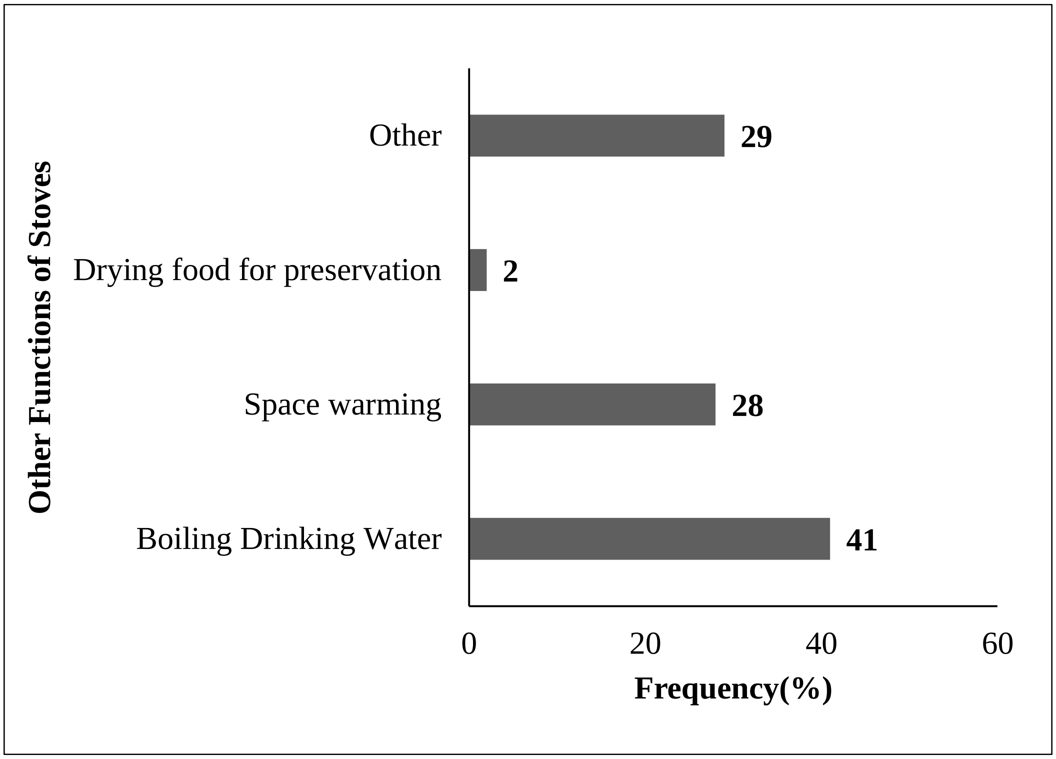

Figure 4.12: Other Functions of Stoves

The findings of studies carried out on wood fuel use in Kenya (Hawkins, 1987; Gathiomi *et al.*, 2011) and (Sepp *et al.*, 2014) globally all indicated that the boiling of water was the second most important function of stoves after cooking which was the case with the findings from this study area.

4.2.9 Location of Stove and Number of Cooking Stoves Used

For 95% of the respondents, cooking stoves were located indoors (Figure 4.13)

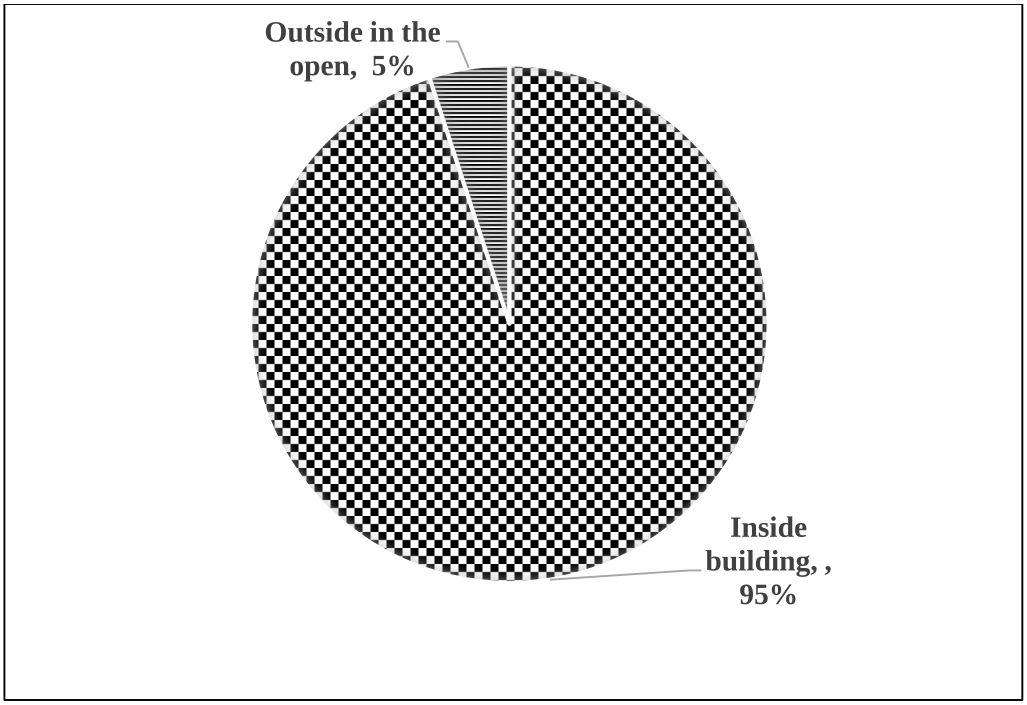

Figure 4.13: Location of Stove

The choice of stove location was due to reduced draught to the stove inside the building that ensured slower burning hence the fuel used lasted longer. However (Bryden *et al.,* 2004; Bailis *et al.,* 2007), note that too little draught (air) being pulled into the fire results in smoke and excess charcoal (wood burned in absence of adequate oxygen) in the combustion chamber thus reducing the combustion efficiency and increasing the cooking time required.

The use of only one cooking stove type was found among 50% of the respondents (Figure 4.14). The lack of access to information on alternative stoves and cost of the stoves were the major reasons given for not adopting improved and energy saving cooking stoves. This situation differed from that reported by (Gathiomi *et al.*, 2010) in a study carried out in Central Kenya where the awareness of improved cooking stoves among the study population was 70%, with an adoption rate of 28%.

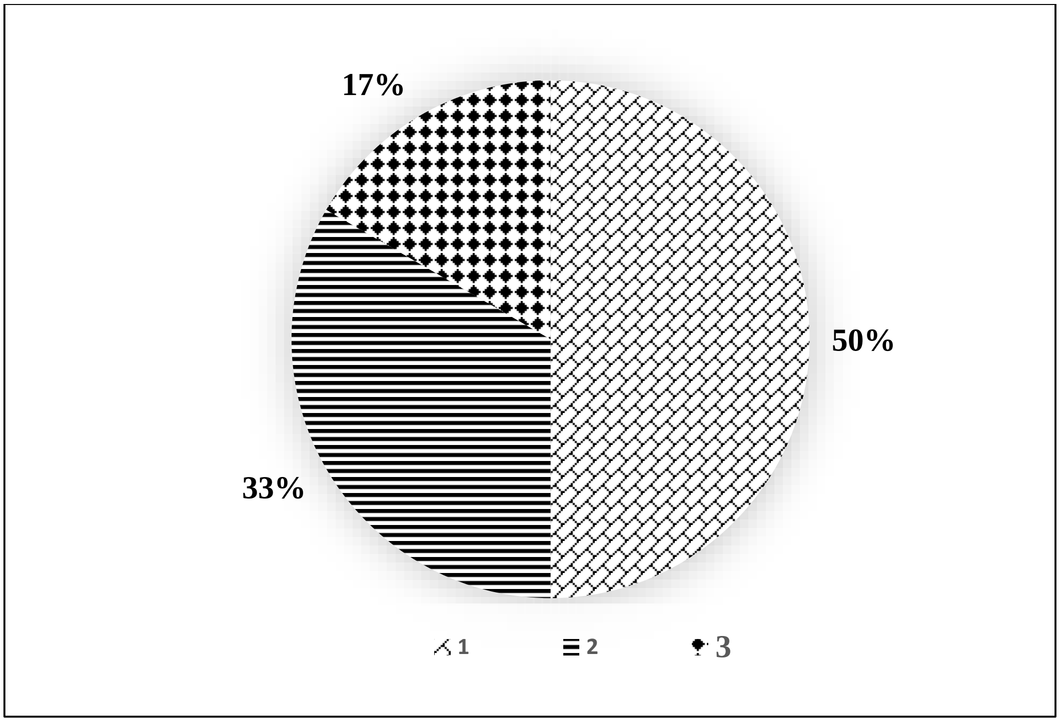

Figure 4.14: Number of StoveTypes Used

4.2.10 Amount of Fuel Used to Prepare One Meal and the Size of Household

Sixty two percent of the respondents used less than 5 kg of wood fuel to prepare one meal, while 40% used more than 10 kg (Figure 4.15).

The small amount of wood fuel used was attributed to two main factors, first was the reduced availability of wood fuels hence preparation of simpler meals that required less energy and less frequent meals. This meant that for example instead of preparing a meal of maize and beans and vegetables, a household would opt to have maize meal and vegetables which required less energy and time to prepare consistent with findings by (Tengas, 1994; Muchiri, 2008; Gathui & Mugo 2010).The constrained availability of wood fuel sometimes compromised the nutritional status of communities' such that the more easily available and affordable protein food like beans that required more fuel to prepare were avoided. It also meant that crop residues were used as wood fuel rather than remain in the field to enhance the soil organic matter. The same aspect was also noted by (Bett *et al.,* 2009; FAO, 2014; UNEP *et al.*, 2005), the use of farm residues as fuel was noted to be approximately 50% among rural households in Njoro (Bett *et al.,* 2009), but was not quantified in this study.

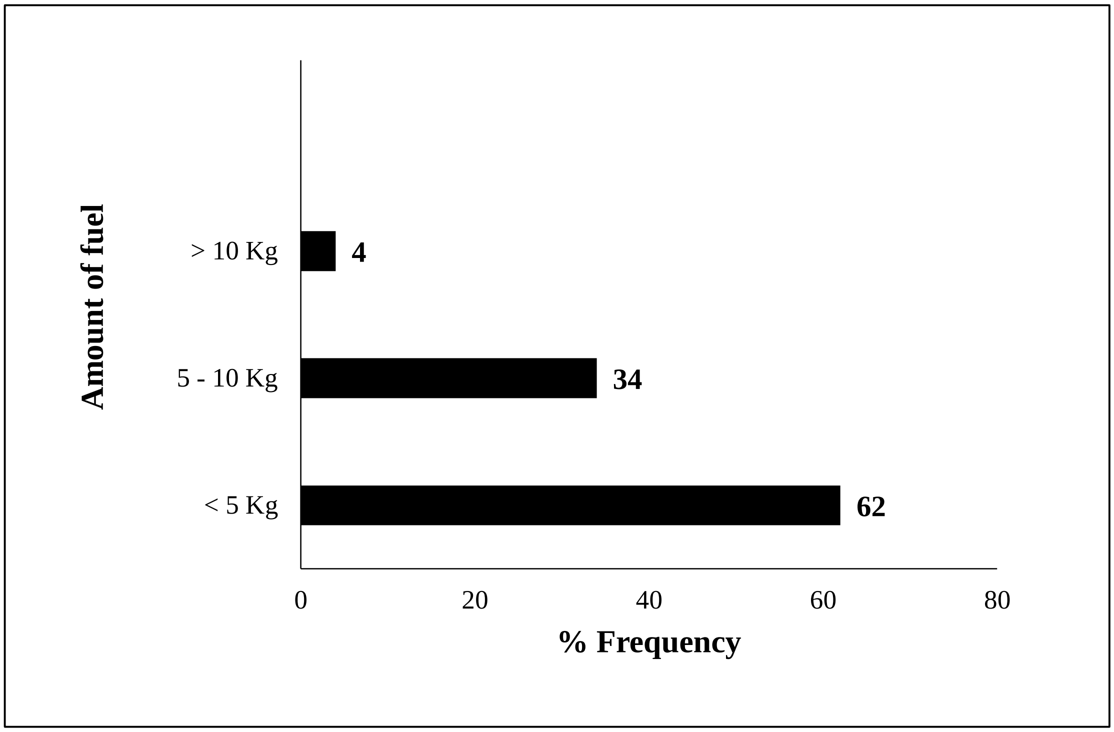

Figure 4.15: Amount of Fuel Used to Prepare One Meal

Fifty eight percent of the respondents belonged to households of less than five persons, and only 4% to households with over ten persons (Figure 4.16).

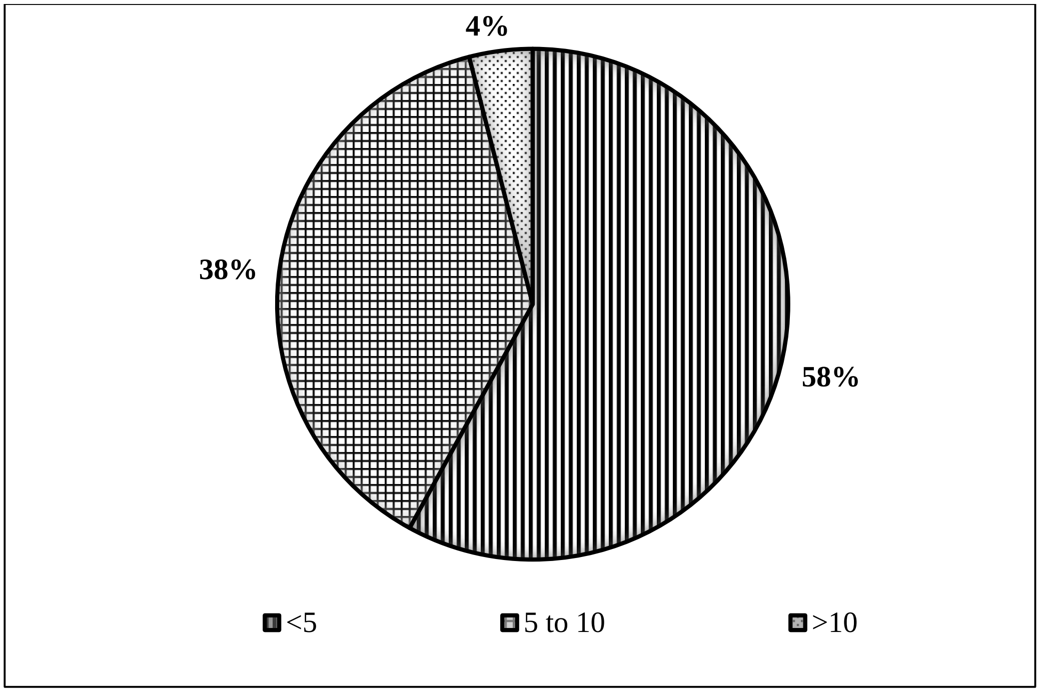

Figure 4.16: Size of Household

Though statistics from ROK (2009a) showed that the average household size of Likia was seven persons a study carried out by (Bett *et al.*, 2009) gave the average household size for Njoro as five persons. This findings of the study were partly attributed to the fact that most households comprised of older citizens and their grandchildren while the younger persons were away from home in search of employment, similar to the findings of (Kuria, 2011) in a study carried out on the adoption of energy efficient stoves in Nakuru County. In the cited study, most of the younger members of the community moved out of the rural to urban centres in search of employment or business opportunities. The number of members in a household for whom food was jointly prepared directly influenced amount of wood fuel used in the study area.

4.3 The Lighting Duration of Stoves

The waste paper briquettes in the wood ceramic stove took the longest time to light of 27 minutes while maize stover in both the wood ceramic and the ceramic stove took the shortest time to light (1minute). Charcoal dust briquettes in the three stone stove also took long to light (21 minutes) and charcoal briquettes in the wood ceramic stove twenty minutes (Figure 4.17).

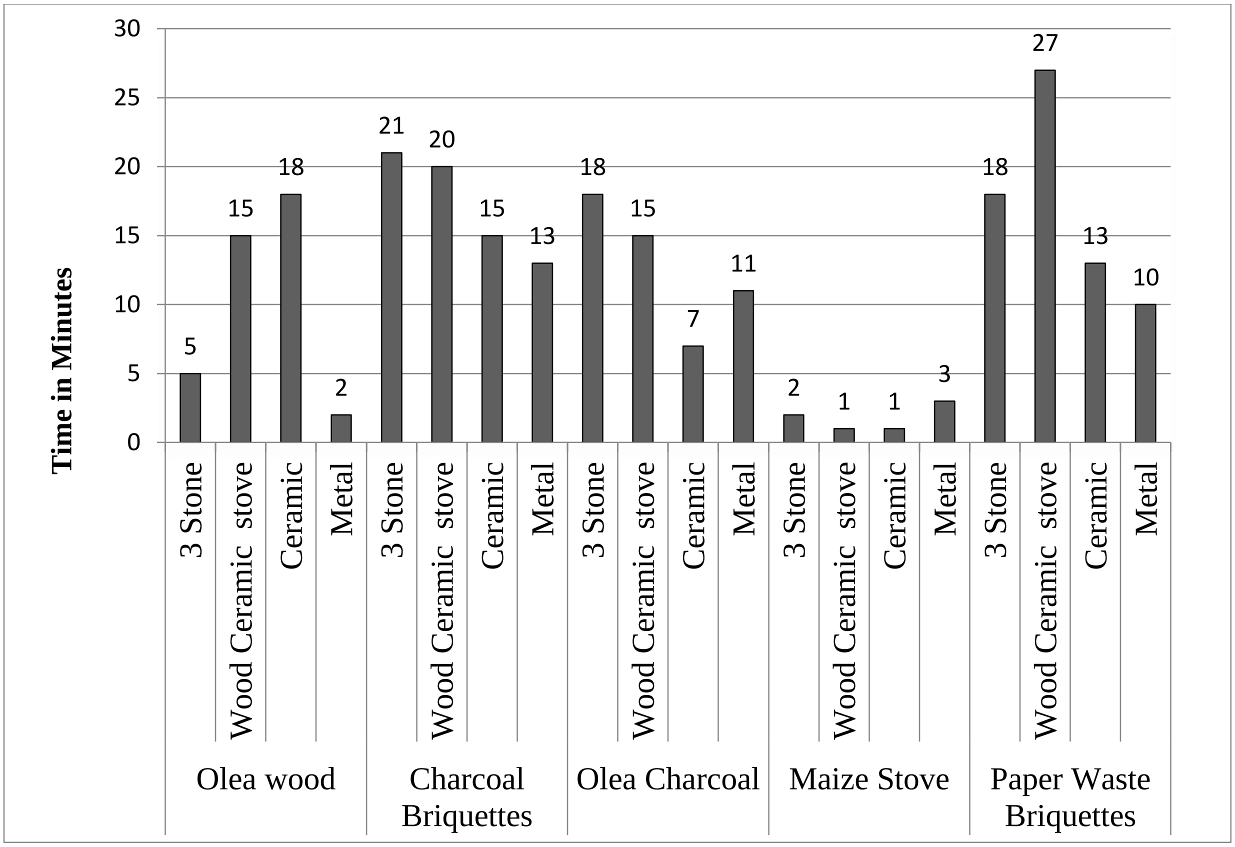

Figure 4.17 Lighting Duration of Cooking Stoves

Olea africana firewood in the ceramic stove, *Olea africana* charcoal in the three stone stove and the waste paper briquettes in the three stone stoves all took 18 minutes to light. Charcoal dust briquettes in the three stone stove also took long to light (21 minutes) and charcoal briquettes in the wood ceramic stove twenty minutes.

Maize stover was readily available to most residents from their farms and easy to light which probably explained why the rural population in the study area frequently used it as fuel. Most of the maize stover fuel acted like kindling for the fire thus easily burned away (Ravado, 2016). Maize stover had a very low density, was easily dried and thus when lit burned quickly. The major disadvantage with the use of maize stover was the large quantities required to achieve a cooking task as compared to other fuel sources. Also the continued use of maize stover as fuel accentuated the mining of nutrients from the soil for the very same farmers who could not afford fertilizer leading to subsequent low yields and the perpetuation of the continued cycle of poverty among this rural population. Maize stover removal from the farms removes valuable soil nutrients eventually leading to a degraded soil (Camberato, 2015). Maize stover removal for fuel was not recommended for the residents of Likia.

Olea africana charcoal in three stone stoves and the wood ceramic stove took longer to light simply because these two stove designs are specifically for firewood rather than charcoal. The three stone stove and the wood ceramic stove by design limited air movement through the fuel mass to heat it and thus raise the fuel temperature to combustion temperature (Ravado, 2016). With the metal stove and the ceramic stove, the lighting duration was shortest because the stoves were specifically designed for use with charcoal and offered sufficient draught into the stove to enhance the fuel lighting and burning. The two stoves had grates for the placement of fuel off the base of the combustion chamber allowing air draught into the stove a basic requirement for burning as indicated by (Dutt & Geller, 1997; Bryden *et al.,* 2004; Bailis *et al.,* 2007). The lighting duration of *Olea africana* wood was shortest with the metal stove two minutes and five minutes for the three stone stoves. These two stoves provided ample draught into the stove that ensured faster lighting. Wood ceramic stove and ceramic stove have insulated inner walls that delayed the accumulation of heat that would have enhanced the drying of the adjacent fuel mass and its lighting by that already alight, thus delayed the lighting of the fuel mass in the stove.

Of all fuel types tested, both types of briquettes took a longer time to light. For the charcoal dust briquettes the longest time being that with the wood ceramic stove. The major reason was lack of adequate good air movement into the fire and placement of the fuel on the base of the combustion chamber with no air flow below the fuel to facilitate burning. The three stone stove also took long to light but being open, air was let in from three sides hence had better performance than the wood ceramic stove. The state of inadequate air supply and the absence of kindling (Ravado, 2016) contributed to the long lighting duration. Waste paper briquettes proved most difficult to light in the wood ceramic stove which took 27 minutes the longest time of all fuel/stove combinations. The briquettes showed that an ample supply of air was required to allow them light and burn. There was again in this case a need for kindling to start of the fire. Like in charcoal briquettes, the ceramic and metal stoves were easier to light, followed by the three Stone stove and wood ceramic stove last with waste paper briquettes. According to O’Connell (2007) and GVEP (2010), the use of biomass briquettes as fuel could offer alternative and more sustainable sources of biomass energy. This however was not the case in the study area as the performance of briquettes (time of lighting) was not impressive. Briquettes produced should be easy to light as a positive attribute encouraging their use (GVEP, 2010).

4.4 The Heat Gained During Water Heating

The changes in temperature were recorded as basic data from which heat gained was computed. The *Olea africana* firewood/ceramic stove combination consistently displayed the highest temperature change recorded during the heating process (69^0C), regardless of the combustion stage during which the readings were taken. The waste paper briquettes/Wood ceramic stove combination displayed the lowest temperature change (14^0C) during all four combustion stages. Generally temperature changes recorded were higher for the second and third pans for most of the fuel/stove combinations e.g. (the case of *Olea africana* charcoal/ceramic stove 66^0 C and 67^0C) (*Olea africana* fire wood/wood ceramic stove 37^0C and 41^0C) for second pan and third pans respectively) However the maize stover /ceramic stove and the charcoal dust briquettes./ceramic stove combinations the temperature changes were highest at the fourth stages of combustion i.e. 57^0C and 43^0C respectively (Appendix 4). The maize stover/metal stove and the waste briquette/ceramic stove combinations were unique in that the highest temperatures recorded were in the first stage of combustion (Table 4.1). The four pans represented the stages of combustion of the fuel from the time the fuel was lit to the time the fire died out as described by Dutt & Geller (1997) and (Bailis *et al.* (2007) as shown in (Table 4.1)

Table 4.1: Change in temperature during water heating

FUEL TYPE	STOVE	Change in Temperature ^{0}C			
		First Pan	Sec Pan	Third Pan	Fourth pan
***Olea africana* charcoal**	Wood ceramic stove	12	17	23	20
	Metal	68	68	68	67
	Ceramic	55	66	67	57
	Three stones	20	27	28	24
Waste paper Briquette	Wood ceramic stove	14	14	14	14
	Metal	28	26	22	19
	Ceramic	40	31	28	24
	Three stones	17	18	14	15
Charcoal dust briquettes	Wood ceramic stove	15	24	29	28
	Metal	50	63	60	54
	Ceramic	31	36	42	43
	Three stones	12	24	24	24
***Olea africana* firewood**	Wood ceramic stove	27	37	41	25
	Metal	69	69	62	62
	Ceramic	69	69	69	69
	Three stones (CONTROL)	62	56	59	49
Maize stover	wood ceramic stove	63	67	67	63
	metal	66	56	46	37
	ceramic	49	39	39	57
	three stones	36	40	34	32

From the changes in temperature heat gain for each replicate was computed (Table 4.2).

Table 4.2: Computed Heat Gains

FUEL SOURCES	STOVES	HEAT GAINED(KJ)			
		I	**II**	**III**	**IV**
***Olea africana* charcoal**	Three stone stove	113.05	117.24	100.49	83.74
	Wood ceramic stove	87.93	100.49	75.37	50.24
	Ceramic stove	276.34	280.53	238.66	230.29
	Metal stove	284.72	284.72	280.53	284.72
Waste paper briquettes	Three stone stove	75.37	71.18	62.81	71.18
	Wood ceramic stove	58.62	58.62	58.62	58.62
	Ceramic stove	167.48	129.80	100.49	167.48
	Metal stove	96.30	92.11	79.55	117.24
Charcoal dust briquettes	Three stone stove	57.72	115.44	115.44	115,44
	Wood ceramic stove	72.15	117.04	121.42	100.49
	Ceramic stove	150.73	175.85	180.04	129.80
	Metal stove	267.97	255.41	230.29	213.54
***Olea africana* wood fuel**	Three stone stove (**control**)	259.59	234.47	247.03	205.16
	Wood ceramic stove	113.05	154.92	171.67	104.68
	Ceramic stove	288.90	288.90	288.90	288.90
	Metal stove	288.90	288.90	259.59	259.59
Maize stover	Three stone stove	167.48	142.36	138.17	154.92
	Wood ceramic stove	280.53	276.34	267.97	267.97
	Ceramic stove	159.11	163.29	242.85	209.35
	Metal stove	234.47	192.60	159.11	280.53

The heat gained during heating of water computed from the temperature changes showed that the highest heat gain was 288.90 kJ for the *Olea africana*/ceramic stove combination. On the other hand, the lowest computed value for heat gained with the waste paper briquette/ wood ceramic stove combination was 58.62kJ (Table 4.2).

The mean heat gained by the use of waste paper briquettes was generally lower than for the other four fuels with a range of 82.69 kJ. Maize stover generated values of mean heat gained with a range of 122.47 kJ among the different stoves, against a range of 140.79kJ and 82.69 kJ for the charcoal dust and the waste paper briquettes respectively.

Olea africana charcoal on the other hand had the highest range of all the five fuels i.e. 205.16 kJ (Figure 4.18). According to Bryden *et al.* (2004) and Bailis *et al.* (2007), the enhanced performance of stoves required adequate air movement into the fire, insulation around the fire to help it burn hotter and keeping the fuel off the base of the stove using a grate which the ceramic stove and the metal stove adequately provided.

From the mean heat gain values and the standard deviation for each woodfuel/stove combination (Figure 4.18) was generated.

Olea africana firewood with the ceramic stove produced a high amount of mean heat consistently during combustion i.e. 288.90kJ (Figure 4:18) recorded across all the replicates.
The performance of maize stover as fuel was best with the wood ceramic stove with 273.20 kJ of heat gained and 216.68kJ gained with the metal stove and a range of 122.47kJ among the stoves.

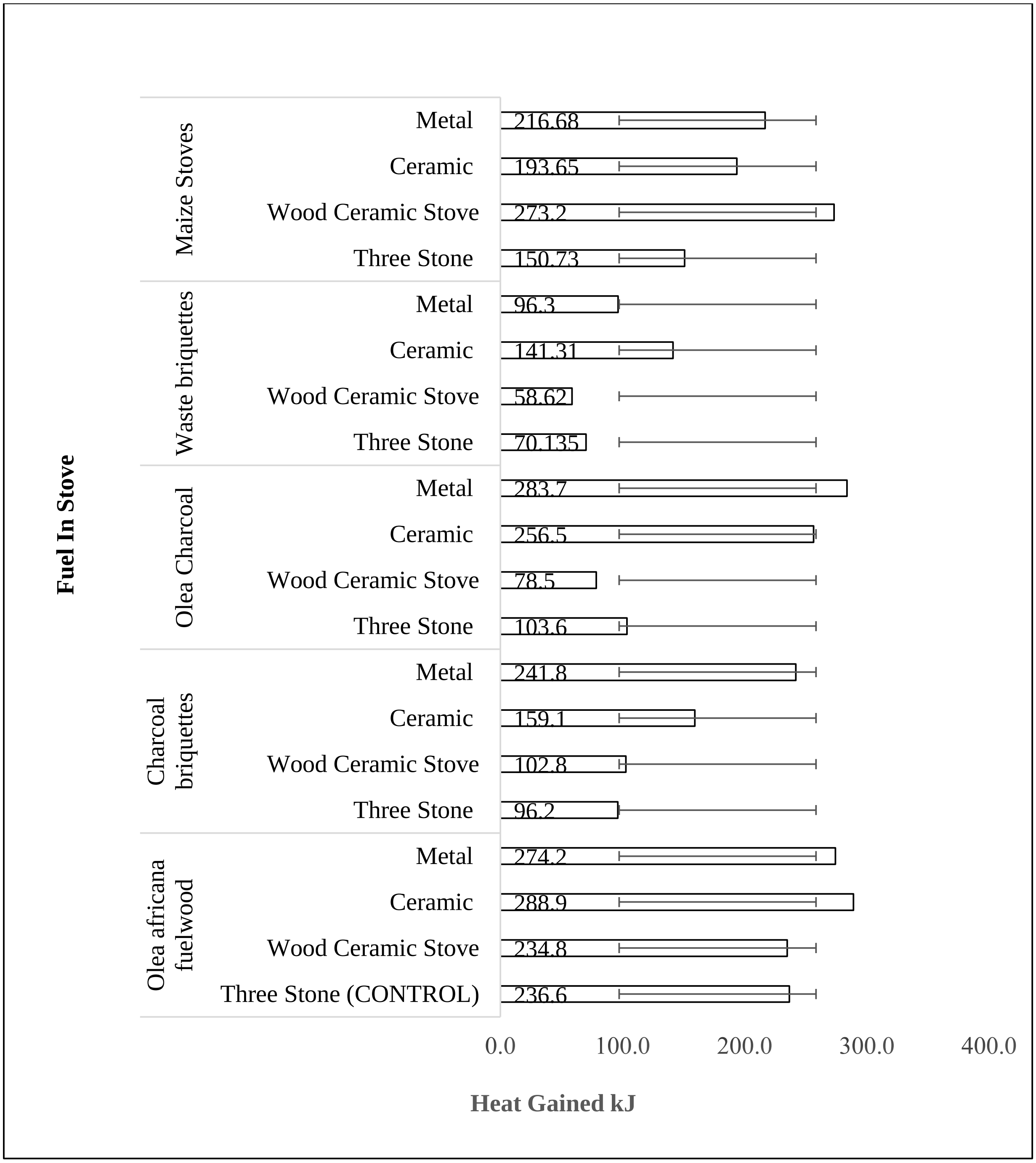

Figure 4.18: Mean heat gained (kJ) and Standard Deviation

When treated to an ANOVA at α = 0.05, the null hypothesis (H_{o_1}) was rejected (Appendix 3)From the comparison of means using LSD there were significant differences in the mean heat gained due to the fuel, and the interaction between the fuel and stove, but not due to all the stoves.

Tests (LSD) for Heat Gained

α = 0.05; Error Df = 57; Error Mean Square = 598.0936; Critical Value of t = 2.00247

Table 4.3 Fuel Means for Heat Gained

Fuel	Mean
Olea africana wood[a]	233.947
Maize stover wood[b]	208.566
Olea africana charcoal[c]	180.566
Charcoal dust briquettes[d]	151.173
Waste paper briquettes[e]	91.069

Means with the same letter are not significantly different

(α = 0.05; Error Df = 57; Error MS= 598.0936; Critical Value of t = 2.00247; LSD = 15.486)

Table 4.4 Stove Means for Heat Gained

Stove	Mean
Metal stove [a]	222.54
Ceramic stove [a]	207.89
Three stone stove [b]	132.00
Wood ceramic stove [b]	129.84

Means with the same letter are not significantly different.

From these results there was significant difference in the heat gained by the different fuel/stove combinations used due to type of fuel used. There was significant difference in the heat gained between the metal stove and the three stone stove; the metal stove and the wood ceramic stove; the ceramic and the three stone stove; the ceramic and the wood ceramic stove. However there was no significant difference in the heat gained due to the use of either the metal stove or the ceramic stove and there was no significant difference in the heat gained due to the use of either the wood ceramic stove or the three stone stove. There was significant interaction between the fuel type and stove on the heat gained.

The *Olea africana* wood/ceramic stove combination gave the largest amount of heat gained 288.90kJ and ± 0.00 SD among the replicates (Figure 4.18).The *Olea africana* fire wood/three stone stove combination which was the control, performed fairly well with heat gained of 236.56KJ and ± 23.317kJ SD among the replicates, which was lower than the heat gained by *Olea africana* fuel wood/ceramic stove combination., closely followed by the *Olea africana* charcoal/metal stove with a mean heat gain of 283.67 kJ and ± 2.10 SD. Thus this implied that the type of wood fuel selected was important as it partly determined the heat gained during cooking (McCarty *et al.*, 2010).

The use of waste paper briquettes consistently gave low heat gain and could not be said to compete well with other fuel types. According to Legacy Foundation, (2003), three dried waste paper briquettes were expected to burn for a time period of 3 hours sufficient to prepare a long cooking meal which could not be expected from the briquette performance during the experiments. These particular briquettes took a longer time for the combustion process to take hold compared with the other fuels, had lower levels of heat gained during the experiments and produced a considerable amount of smoke. Briquettes tend to burn longer but produce less intense heat and specifically waste paper briquettes which required to be carbonized to reduce the smoke produced to acceptable levels (GVEP, 2010).The worst briquette performance was with the waste paper briquette in wood ceramic stove with only 58.62 kJ of heat gained. This was attributed to poor draught into the stove and thus low combustion efficiency and a lot of smoke produced (Bryden *et al.*, 2004). The wood ceramic stove was expected to conserve energy but because the briquettes required adequate draught into the stove to burn cleanly thereby reducing smoke and harmful emissions (Bailis *et al.*, 2007), this stove proved incompatible for use with waste paper briquettes.

The performance of the charcoal dust briquettes was comparatively better than the waste paper briquettes with the highest mean heat gained of 241.80 kJ with the metal stove as compared with 141. 31 kJ for the waste paper briquettes with the ceramic stove, and was associated with the production of less smoke. Charcoal dust briquettes are credited as having a long burning time, reduced amount of smoke, not easily extinguishable and can be used as a supplement or alternative to charcoal and firewood, thus reduce some pressure off forestry resources (GVEP, 2010). However from the results of this study for heat gained, charcoal and firewood of the *Olea africana* species still remain the superior fuel sources in terms of heat gained.

Other factors that affected the heat output of stoves included the size of the stove, the size of the firebox and the amount of woodfuel required (www.stoveonline, 2016). Test conditions can only be comparable if exactly the same. An example is how open the stove vents were during the tests, therefore the point of the test was to give an idea of how the stove was likely to perform therefore allow comparison of the different stoves. The values obtained from tests showed that a particular output was achievable and the efficiency at this heat output.

4.5 The Trends of Heating

From graphs of trends of heating for the various stoves with the different types of fuel and correlation coefficient r computed, there was a positive correlation between the times of cooking and the temperature change regardless of the stove and fuel used in all cases.

The trends of heating for all stoves with the maize stover fuel showed a positive and significant correlation in all cases (Figure 4.19). However the computed correlation coefficient (r) was highest for the three stone stove (r = 0.998) and lowest with the ceramic stove (r= 0.987).

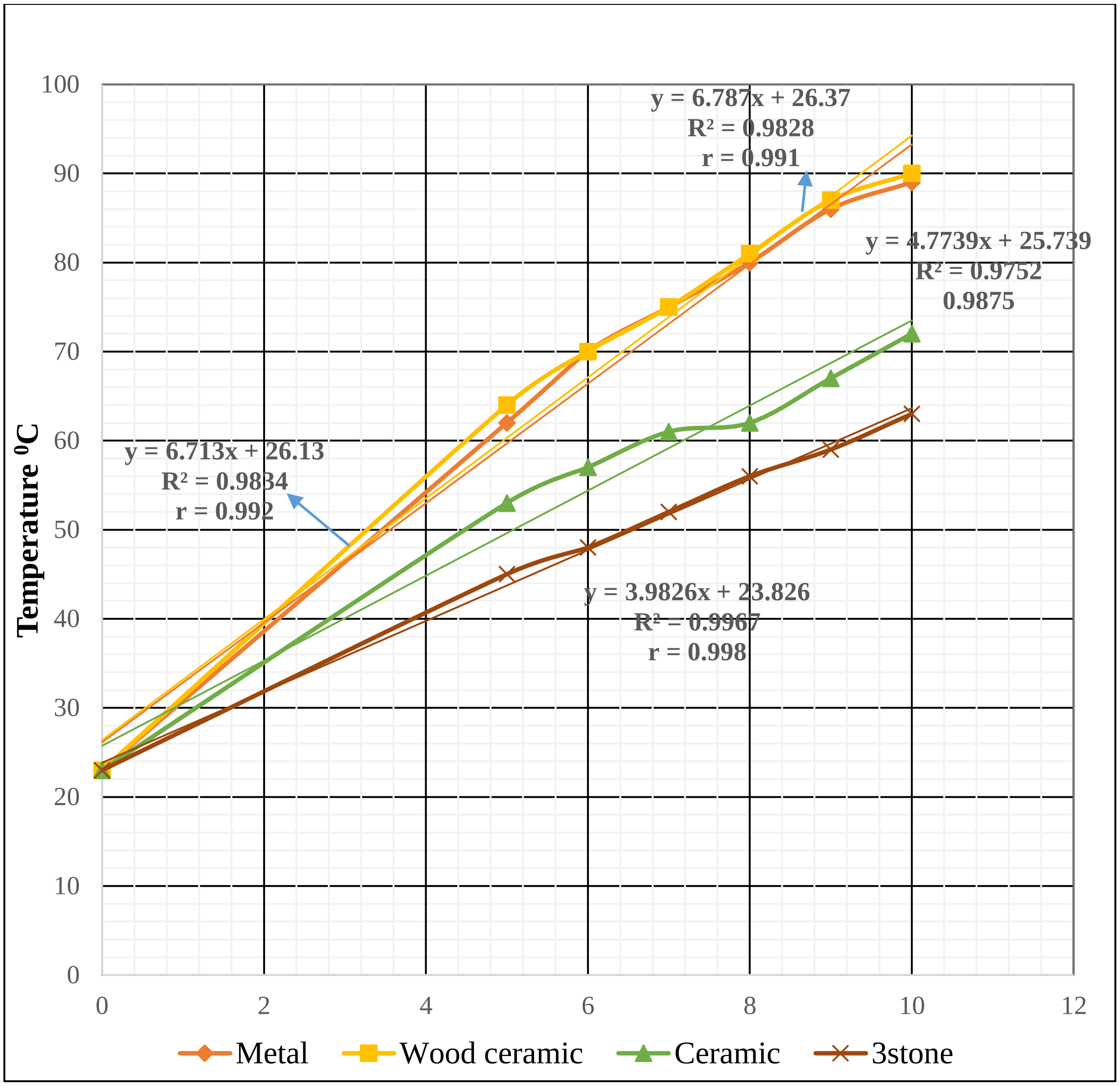

Figure 4.19: Trend of Heating for Maize Stover Fuel

With the maize stover fuel, none of the cooking stoves were able to raise the temperature of the water to the local boiling point (91^{0}C) within 10 minutes. The highest temperature reached was 90^{0}C with the wood ceramic stove.

The heating trend for all stoves with the *Olea africana* charcoal showed a significant and positive correlation between temperature and time. The computed coefficient of correlation was highest with the three stone stove (r = 0.999) and lowest with the metal stove (r = 0.945) as shown (Figure 4.20).

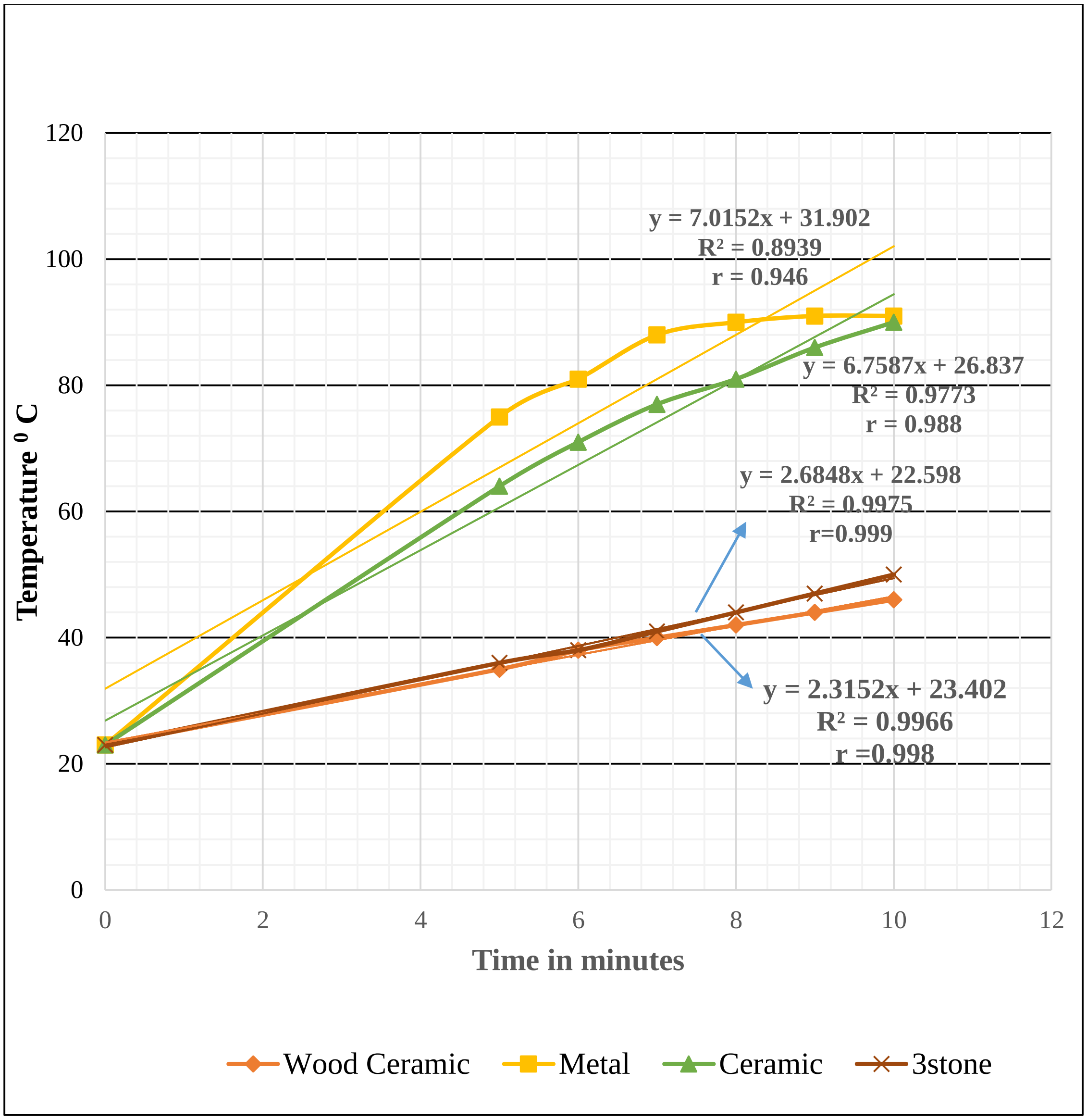

Figure 4.20: Trend of Heating for *Olea africana* Charcoal

The metal stove and the ceramic stove managed to raise the temperature of the water to local boiling point (91^0C) within ten minutes.

The heating trend for all stoves with charcoal briquettes showed a positive and significant correlation between the temperature and time. The correlation coefficient was highest with the Ceramic charcoal stove (r = 0.998) and lowest with the three stone stove (r = 0.973) as shown in (Figure 4.21).

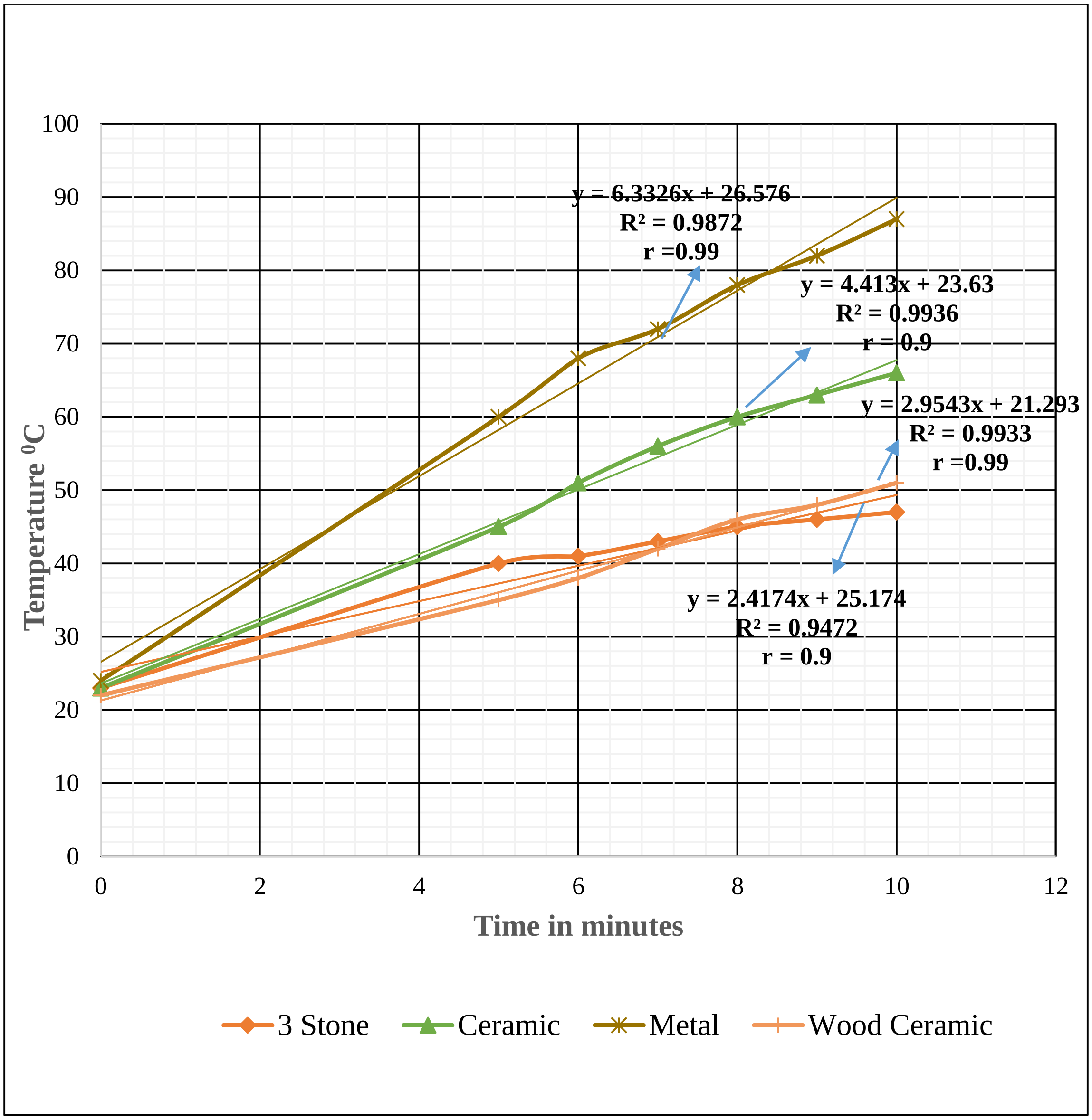

Figure 4.21: Trend of Heating for Charcoal Briquette

None of the cooking stoves using the charcoal dust briquettes managed to raise the temperature of the water to local boiling temperature (91^0C) within 10 minutes.

The trend of heating for waste paper briquettes with all stoves showed a positive and significant correlation between temperature and time. The coefficient of correlation was highest with the three stone stove(r = 0.999) and lowest (r = 0.991) with the metal stove (Figure 4.22).

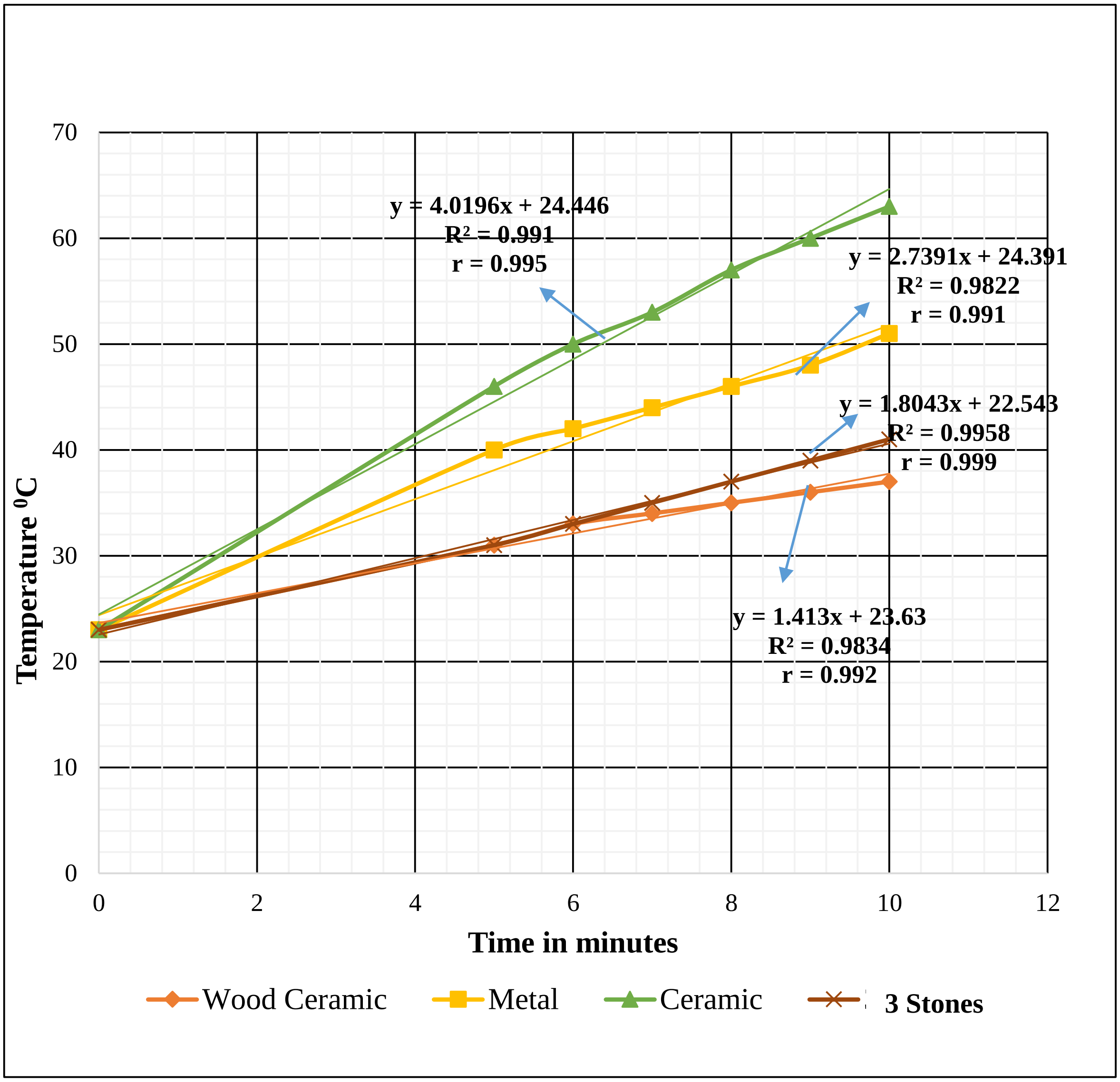

Figure 4.22: Trend of Heating for Waste paper Briquettes

The highest temperature reached was with the metal stove (51^0C). *Olea africana* firewood showed a positive and significant correlation between time and temperature in the heating trends for all stoves. The coefficient of correlation was highest with the three stone stove and the Ceramic Charcoal stove (both r = 0.994) and lowest with the Wood ceramic stove (r = 0.981) as shown in (Figure 4.23).

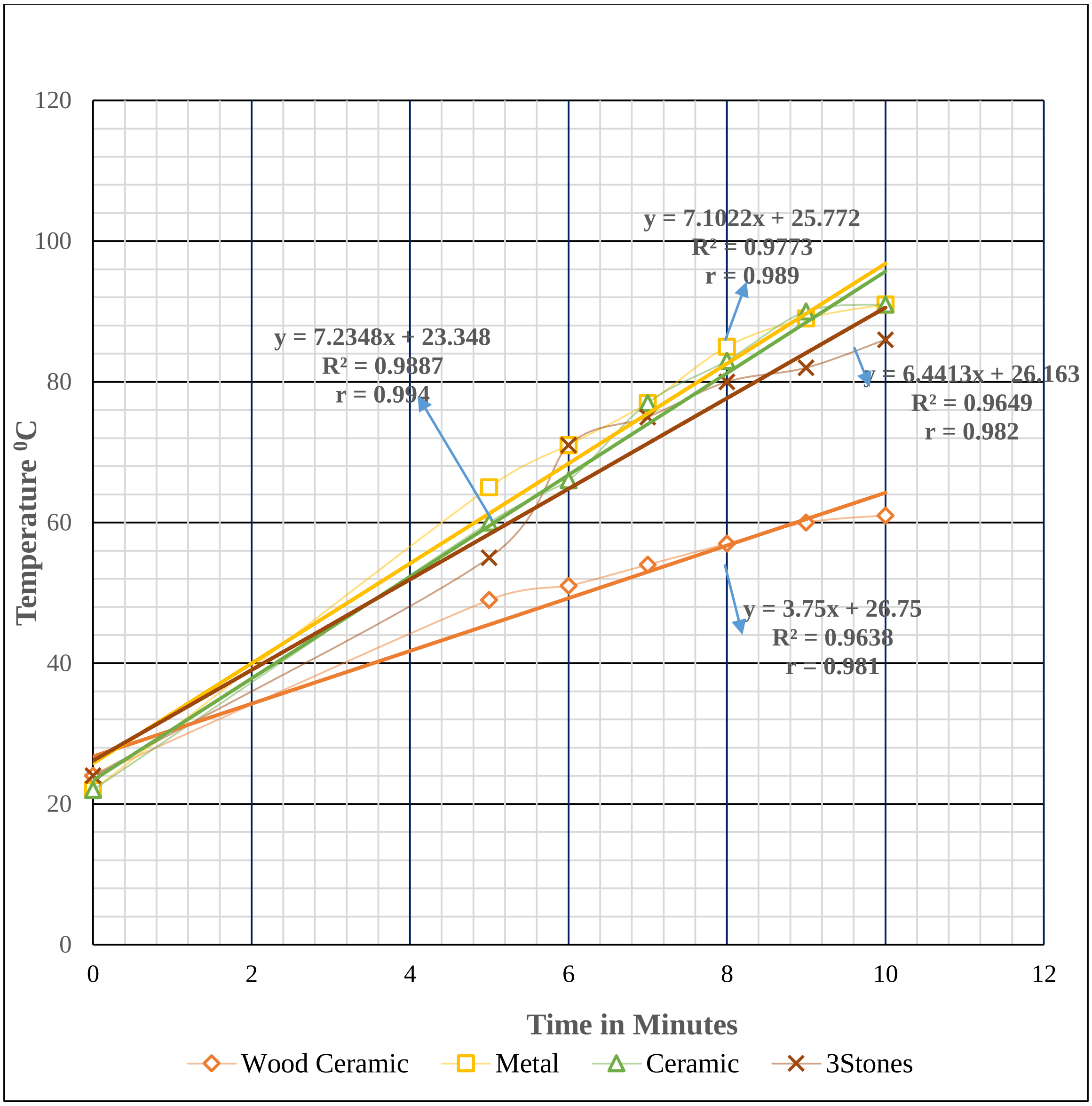

Figure 4.23 Trend of Heating for *Olea africana* firewood

Of all the four stoves only the metal stove and the ceramic stove using the *Olea africana* firewood were able to raise the temperature of the water to local boiling point (91^{0}C) within the ten minute period.

From the values of r (coefficient of correlation) computed for each fuel stove combination, the Hypothesis (H_o: There is no significant correlation between the temperature change and time for the various stove/fuel combinations ($H_{a:}$ ρ= 0) was tested at α = 0.05 and values of t_{cal} for each fuel/stove combination was tabulated alongside the significance of correlation (Table 4.5).

Table 4.5 Significance of Correlation

FUEL SOURCES	STOVES	r^2	r	t_{cal}	Significance
Olea africana wood fuel	Three Stone Stove(CONTROL)	0.99	0.995	22.249	**
	Wood ceramic stove	0.964	0.982	7.383	*
	Ceramic stove	0.991	0.995	23.452	**
	Metal Stove	0.977	0.988	14.567	*
Charcoal briquettes	Three Stone Stove	0.992	0.996	24.9	**
	Wood ceramic stove	0.991	0.995	23.452	**
	Ceramic stove	0.997	0.998	40.743	**
	Metal Stove	0.987	0.993	40.539	**
Olea africana Charcoal	Three Stone Stove	0.842	0.918	5.164	*
	Wood ceramic stove	0.816	0.903	4.707	*
	Ceramic stove	0.997	0.998	40.743	*
	Metal Stove	0.816	0.903	4.707	*
Waste Paper Briquettes	Three Stone Stove	0.995	0.997	31.528	**
	Wood ceramic stove	0.983	0.991	16.996	*
	Ceramic stove	0.991	0.995	21.243	**
	Metal Stove	0.981	0.99	16.06	*
Maize stover	Three Stone Stove	0.996	0.997	35.249	**
	Wood ceramic stove	0.982	0.991	16.517	*
	Ceramic stove	0.947	0.973	9.451	*
	Metal Stove	0.99	0.995	21.243	**

*= significant; **= very significant

Since $t_{cal} > t_{tab}$ i.e. >2.571; (Ho_2) was rejected. Thus there was significant correlation between the time of heating and the temperature change regardless of the energy source or cooking stove used. The time to boil a specific amount of water was one of the stove performance measures. In this experiment a task of heating 1 litre of water by the stove /fuel combinations showed that the *Olea africana* fuel wood/metal stove; the *Olea africana* fuel wood/ceramic stove; the *Olea africana* charcoal/ metal stove; the *Olea africana* charcoal /ceramic stove were able to raise the water temperature to the local boiling temperature (91^0C) within ten minutes.

For the trend lines drawn for each experiment and r computed, there was positive and significant correlation between the temperature change and time regardless of the cooking stoves and the fuel source used. For all four cooking stoves, the most suitable phase of combustion to make comparisons of stove performance and heating trend was the second pan of water. The highest temperatures reached were by the second pan in almost all cases except for maize stover which quickly lit and reached 90^0C at 2272m a.s.l during the first phase of combustion. This confirmed the results of Foley *et al.* (1984) that at different stages of combustion, different results were likely to be obtained hence the need for taking the test data at the same phase for each experiment. The second phase of combustion was chosen in this case taking into consideration the likelihood that the fuel would be well lit then and combustion process taken hold (Foley *et al.*, 1984; Bryden *et al.*, 2004; Bailis *et al.*, 2007). However from the computed heat gained due to temperature change for each test, not all stoves showed highest temperature gain during the second phase of combustion. This was most likely influenced by the choice of fuel (Bryden *et al.*, 2004), that some fuels when used yielded performances that departed from the optimum expected from the stove use and the fuel's pattern of progression during the combustion process, The wood ceramic stove and the ceramic charcoal stove displayed similar characteristics due to their insulating liner that conserved heat even when combustion was dying out hence portraying greater progression in heat transmission to the cooking pot at a later phase of combustion.

In tests done on the performance of cooking (www.stoveonline, 2016) the time to boil water was shortest with wood ceramic stove, followed by the three stone, the ceramic stove then the metal stove. In this study, the type of fuel used was also important in determining how fast water could be boiled, for instance the waste paper briquettes only managed to raise the water temperature from the room temperature 23^0C to 51^0C within ten minutes unlike *Olea africana* which raised the water temperature from 23^0C to 91^0C (Local boiling point).

4.6 The Efficiency of Cooking Stoves

The computed mean efficiencies of the various fuel/stove combinations showed that the *Olea africana* wood fuel/ceramic stove combination had the highest efficiency at 69. 00% ± *SD* of 0.00, while the waste paper briquettes/wood ceramic stove had the lowest efficiency at 14 .00% ± *SD* 0.00 (Figure 4.24).

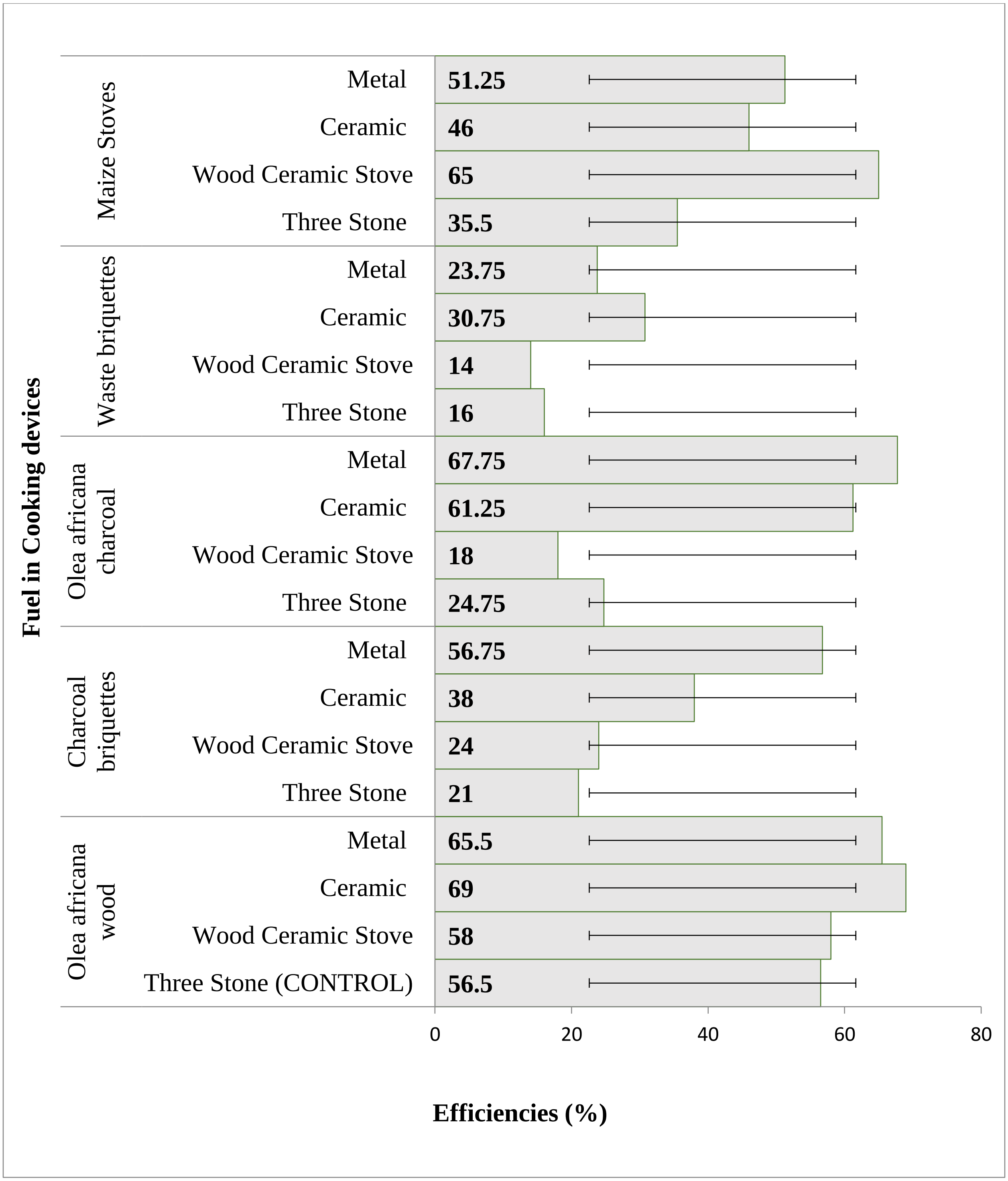

Figure 4.24: Mean Efficiencies of Stoves and Standard Deviation

The control combination *Olea africana* wood fuel/three stone stove (Control) had a mean efficiency of 56.50% ± 5.57 *SD* among replicates and was certainly not the most efficient. The performance of the waste paper briquettes was the worst of all five fuels giving low efficiencies regardless of cooking stove used, with the highest computed mean efficiency of 30.75% ± 6.80 *SD* and lowest at 14% ± 0.00 *SD*. However the charcoal dust briquettes had higher efficiencies than the waste paper briquettes managing to give an efficiency of 56.00% ± 5.85 *SD* with the metal stove as its highest mean efficiency as compared to the waste paper briquettes that had a highest mean efficiency of 30. 75%.± 6.80 *SD* among the replicates (Figure 4:24)**.**

When treated to an ANOVA at $\alpha = 0.05$ the, Ho_3 was rejected (Appendix 4). Means were separated using LSD, and there were significant differences in efficiencies due to the fuel, the stoves and the interaction between the fuel and the stove (Table 4.6) and (Table 4.7).

R-Square = 0.95; Coefficient of Variation = 12.89; Root MSE = 5.43; EFFICIENCY Mean= 42.14
t Tests (LSD) for Efficiency (Type I comparison wise error rate, not experiment wise error rate.)
(α = 0.05; Error Df = 57; Error Mean Square = 29.51; Critical value of t = 2.00; LSD = 3.44).

Table 4.6: Stove Means for Efficiency

STOVE	Mean
Metal stove [a]	53.00
Ceramic Charcoal stove [b]	49.00
Wood ceramic stove [c]	35.80
Three stone stove [d]	30.75

Means with the same letter are not significantly different

(α = 0.05; Error DF = 57; Error mean Square = 29.51; Critical Value of t = 2.00; LSD= 3.85)

Table 4:7 Fuel Means for Efficiency

FUEL	**Mean**
Olea africana wood[a]	62.25
Maize stover[b]	49.44
Olea africana charcoal[c]	42.94
Charcoal dust briquettes[d]	34.94
Waste paper briquettes[e]	21.13

Means with the same letter are not significantly different.

These results showed that there was significant difference in the mean efficiencies due to the cooking stoves used, and due to the fuel type used and also due to the interaction of the fuel type and stoves. From the experiments done, the efficiency of cooking stoves is dependent on the type of wood fuel used, the type of stove, and the interaction between the stove and wood fuel. Even though the study partly aimed at recommending the most efficient cooking stove, it was apparent that the type of wood fuel chosen also contributed to the efficiency of heat transfer efficiency from the burning wood fuel to the cooking pan. It was also clear that not all cooking fuel types were compatible with all cooking stoves, as illustrated by the *Olea africana* charcoal /wood ceramic stove(efficiency 18%), waste paper briquettes/three stone (efficiency 16%), waste paper briquette/ wood ceramic stove (efficiency 14%) ,also noted by GVEP, (2010) in a study on the use of briquettes in Kenya.

The efficiencies of both briquette types were lower than the other fuels with the charcoal dust briquettes having a range of 35% and the waste paper briquettes a range of 16.75%. The mean efficiency for waste briquettes in the wood ceramic stove was lowest (14% ± *SD* 0.00), while the mean efficiency of waste briquettes with ceramic stove was highest (30.75% ± *SD* 6.80).This was attributed to the need for adequate air supply (high draught into the stove) for the briquettes to burn which the wood ceramic stove did not provide by design but the ceramic stove provided. The wood ceramic stove was sealed on three sides, limiting air inflow to facilitate burning .This stove was designed such that wood fuel was placed on the base of the combustion chamber again limiting air flow which the waste paper briquettes adequately required to burn clean. Waste paper briquettes were described as requiring carbonization (partial pyrolysis) to enable them burn and reduce the amount of smoke produced (GVEP, 2010). According to Bryden *et al.*, (2004) and Bailis *et al.*, (2007), allowing adequate draught into the fire improves the combustion efficiency but may result in poor fuel use efficiency. The waste paper briquettes like other briquettes had the properties of lower heat production but long burning time (O'Connell, 2007) which could have also contributed to the low efficiency recorded during the experiments.
The efficiencies of the charcoal dust briquettes were higher than those of the waste paper briquettes though not according to the expected from studies carried out on briquette use. According to Azeus (2012), the briquette making process includes the carbonization of the briquettes in a furnace at temperatures 160^0C to 200^0C to improve their burning properties. For the charcoal briquettes used

in this study their processing methods were unknown as they were purchased and their performance as differed from the expected could be attributed to their processing.

The performance of the *Olea africana* firewood /ceramic stove combination was attributed to two factors. First *Olea africana* wood fuel had desirable attributes that made it a highly desired wood fuel tree species (quick lighting, high calorific value, long burning time (Ayensu, 1989). Second was the design of the ceramic stove which allowed adequate draught into the stove, had insulating wall that conserved energy causing the fire to burn hotter thus contributing to the high efficiency recorded during the experiments (Bryden *et al.,* 2004; Bailis *et al*., 2007).

Olea africana charcoal / metal stove combination recorded the second highest efficiency of 67.75 % and SD of ± 0.50 among the replicates. Although the charcoal was from the same species as the fuel wood used (*Olea africana*), the efficiencies reached during the experiments were lower than those of the fuel wood. This was in disagreement with other studies eg (MacMullan *et al.,* 1990; Adegbulugbe & Bello, 2010; Jamnadass *et al.,* 2014) that the charcoal which is a product of the pyrolysis of the wood would have a higher energy density than the wood thus show greater efficiency.

The efficiency recorded for the control combination *Olea africana* firewood/three stone stove was 56% with a standard deviation of 5.57% and certainly not the most efficient combination but the most commonly used. Among the reasons advanced by the residents of the study area for the use of the three stone stove were the low initial cost, the warmth radiated in the kitchen, the large fire that could easily be obtained and the faster cooking. This is in agreement with (Defoort, 2016) that a three stone fire is not necessarily an inefficient cooking method and could be controlled to compare well with improved stoves.

From the results obtained from this study, the improved efficiency of cooking stoves and more sustainable use of wood fuel cannot be obtained from modification of one factor alone, but several variables which in combination enhance the cooking efficiency. This study has also shown that even when a particular stove fuel combination enhances the efficiency of heat transfer its acceptability and thus use depends on the preference of the user among other factors. Other factors include the initial purchase price of the cooking stoves the ease with which the fire is lit; the suitability of the stove for a specific fuel and the ease of the availability of the fuel. Also the stove user’s method of lighting, loading of fuel into the stove’s combustion chamber, venting of the stove were likely to affect the efficiency of the stove and therefore yield completely different results depending on the stove user.

CHAPTER FIVE

5.0 CONCLUSSIONS AND RECOMMENDATIONS

5.1 Sumary of the Chapter

This chapter states the conclusions made from this study in relation to the four specific objectives, followed by recommendations based on conservation and further research.

5.2 Conclusions

From this study, the following conclusions were made. One, the residents of Likia use wood fuel as major source of energy for cooking. The continued conversion of vegetation to wood fuel energy has impacted negatively on the environment as continued removal of vegetation cover leaves the land susceptible to soil erosion and ultimately land degradation. This is in view of the fact that biomass conversion for energy remains and will in the foreseeable future remain the only affordable form of energy for the population of Likia. Wood fuel utilization in Likia involved the use of wood fuel by over 90% of the population, with firewood as the most popular and available form. Charcoal use was limited to fewer households that could afford to purchase it. This study also found that despite the heavy reliance of this population on wood fuel, there was a severe demand /supply imbalance prompting the residents to use crop residues as fuel. The constant removal of vegetation without a sustainable replacement plan was accelerating the transition towards deforestation. Few of the residents of the study area had adopted the use of improved cooking stoves.

Two, the type of fuel used had an effect on the heat gained. This implied that the metal stove and the ceramic stove could generate equal amounts of heat likewise the wood ceramic stove and the three stone stove but choice of fuel used determined the heat gained. The Lighting duration of fuel in cooking stoves was an important reason as to why a particular fuel type was not preferred an example being the time required to light briquettes coupled with the slow trend of heat dispersion that was not a characteristic that encouraged their use.

Three, there was a positive correlation between temperature gain and time during cooking. However some fuel/stoves were unable to achieving a specified cooking task within a given time.

The time within which a particular cooking stove could achieve a specific cooking task was an important indicator of the stove's performance. In this study, the wood ceramic stove took the shortest time to boil one litre of water.

Four, the type of fuel and the type of stove used had an effect on the thermal efficiency during cooking. The metal stove and the Kenya Ceramic stove were found to be the most efficient stoves in the transfer of heat from the fuel to the cooking pot while *Olea africana* wood fuel (both firewood and charcoal) were found to be the best forms of fuel wood which in combination with metal stove and ceramic stove enhanced heat gained and thermal efficiency during cooking.

5.3 Recommendations

5.3.1 Recommendation for Management and Conservation of Mau Forest

- Need for the promotion of agroforestry systems in Likia to increase the availability of wood fuel and thus ease pressure on the adjacent Mau Forest.
- The promotion of manufacture and ease of availability of improved and efficient cooking stoves to reduce the demand for woodfuel.
- The promotion of alternative energy sources such as biomass briquettes alongside the design and development of specific stoves for briquette use.
- The need for consideration of provision for some subsidy for residents to invest in alternative sources of energy such as solar energy thus reducing reliance on the Mau Forest for woodfuel as an energy source.

5.3.2 Recommendation for Further Research

Similar study be conducted using the Kitchen Performance Test (KPT) to compare with the results from this study.

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APPENDICES

Appendix 1: Table for Data Collection Burning Experiment

Mass of fuel used Kg		**1 kg**
Volume of water heated (*l)		1 litre
Stove Lighting Duration		7 min
Initial water temperature(^{0} C)		23
FIRST PAN	0 min	23
Temp of heating water	after 5 min	52
^{0} C	After 6min	58
	After 7 min	62
	After 8 min	66
	After 9min	72
	After 10 min	78
SECOND PAN	0 min	23
Temp of heating water	after 5 min	60
^{0} C	After 6min	64
	After 7 min	75
	After 8 min	79
	After 9min	85
	After 10 min	89
THIRD PAN	0 min	23
Temp of heating water	after 5 min	64
^{0} C	After 6min	71
	After 7 min	77
	After 8 min	81
	After 9min	86
	After 10 min	90
FOURTH PAN	0 min	23
Temp of heating water	after 5 min	54
^{0} C	After 6min	60
	After 7 min	66
	After 8 min	71
	After 9min	75
	After 10 min	80

Appendix 2: Changes in Temperature during the Heating of Water

FUEL TYPE	STOVE	CHANGE IN TEMPERATURE ^0C			
		First	Sec	Third	Fourth
***Olea africana* charcoal**	Wood ceramic stove	12	17	23	20
	metal	68	68	68	67
	ceramic	55	66	67	57
	Three stones	20	27	28	24
Waste paper briquette	Wood ceramic stove	14	14	14	14
	metal	28	26	22	19
	ceramic	40	31	28	24
	Three stones	17	18	14	15
Charcoal dust briquettes	Wood ceramic stove	15	24	29	28
	metal	50	63	60	54
	ceramic	31	36	42	43
	Three stones	12	24	24	24
***Olea africana* firewood**	Wood ceramic stove	27	37	41	25
	metal	69	69	62	62
	ceramic	69	69	69	69
	Three stones	62	56	59	49
Maize stover	Wood ceramic stove	63	67	67	63
	metal	66	56	46	37
	ceramic	49	39	39	57
	Three stones	36	40	34	32

Appendix 3: ANOVA for heat gain

Source of	D.F	Sum of	Mean	F value	Pr > f
Model	22	484516.76	22023.49	36.82	<.0001
Reps	3	764.49	254.83	0.43	0.7351
Fuel	4	195612.88	48903.22	81.77	<.0001
Stove	3	144309.75	48103.25	80.43	<.0001
Fuel*stove	12	143829.64	11985.80	20.04	<.0001
Error	57	34091.33	598.09		
Corrected	79	518608.09			

Appendix 4: ANOVA for Efficiencies

Source of Variation	D.F	Sum of squares	Mean square	F_{Value}	Pr > F
Model	22	29087.4	1322.15	44.8	<.0001
Blocks(REP)	3	106.14	353,791,735.38	1.2	0.3185
Fuel	4	15228.9	3807.23	129.01	< .0001
Stoves	3	6698.54	2232.85	75.66	< .0001
Fuel* Stove	12	7053.78	587.81	19.92	<.0001
Error	57	1682.11	29.51		
Total	79	30769.5			

Appendix 5: Calorific values

Fuel	Calorific Value KJ/KG
Olea africana firewood	17,400
Olea africana charcoal	29,600
Charcoal dust briquettes	7,213
Waste paper briquettes	4,841
Maize stover	18,570

Appendix 6: Questionnaire

Introduction

I am Florence Mukesia Wanjala a student from Egerton University Njoro, pursuing MSc studies in Natural Resource Management. The purpose of this questionnaire is to obtain information on woodfuel utilization for academic purpose only with an interest in promoting the conservation of the Mau forest and sustainable use of woodfuel.

Please allow me to ask you questions concerning wood fuel, it will not last long
Wood fuel use parameters
1. Code name?
1. Resident1 2.resident2 3.resident3 4.resident4 5.resident5 6.resident6 7.resident7 8.resident8……………………………..
2. What is your source of energy for cooking?

Electricity	Wood fuel	Petroleum based fuel	Biogas	Other(specify)

3. If biomass, in which form?

Firewood	Charcoal	Briquettes	Sawdust	Biogas	Biofuels

4. If petroleum based, in which form?

Kerosene	1. Liquefied Petroleum Gas

5. How much time is spent in gathering firewood?

Whole day	Half day	¼ day	Other

6. How long does the one days' fetching last?

One day	More than four days	Two–four days

7. What amount is fetched in one day (kg)

< 5kg	5-10kg	>10 kg

8 Is the wood fetched dry?

Yes	No	Other

9. Who fetches fuel energy?

Adult male	Adult female	Male child	Female child	Other(specify)

10. What is the mode of acquisition?

Buy	Free from forest	Own farm	Other

11. What is the cost of fuel/kg?

>50	50- 100	100 -150	>150

12. What is the means of transport to the home?

Motor	Draught animal	Bicycle	Human

13. Who provides the means of transport?

Self	Hired

14. How far is the fuel fetched?

<1km	1-3 km	3-5 km	>5km

15. What is the cost of transport (KES)?

<50	50 -100	100-150	>150		
16 What are your most preferred types of species for wood fuel?					
Olea africana	Eucalyptus	Cypress	Grevillea	Other	
17. What is your reason for the most preferred species of tree?					
Availability	High density	Low smoke	Fast lighting	Burning time	Costs
18. What type of cooking devices do you know?					
Three stone	Maendeleo	Kenya ceramic stove	Metal stove	Sawdust stove	Other
19. What other functions do the stove(s) serve besides cooking?					
Boiling drinking water	Space warming	Drying food for preservation	Other		
20. What is your most preferred cooking device?					
Three stone	Maendeleo	Kenya ceramic	Metal	Saw dust	Other
21. Why is cooking device in (18) preferred?					
Conserves fuel	Radiates more heat	Emits less smoke	Low cost	Other reason	
22. Where is the stove located?					
Inside	Outside in the open	Outside behind a shield			
23. How many cooking Stoves do you use?					
1	2	3	4	Others	
24. Approximately how much wood fuel do you require to prepare one meal?					
1<5kg	25-10kg	Over 10kg			
25 Size of household (no of persons)					
< 5	5 -10	>10			