Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.5, No.24, 2015

www.iiste.org

Wood fuel Utilization Patterns and Cooking Devices Efficiency Analysis for Likia Residents, Njoro Kenya

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The research is financed by Corresponding author (As partial fulfilment for the award of M.Sc. in Natural Resource Management of Egerton University Kenya)

Abstract

Over 2.6 billion people of the world's population prepare their food and heat their homes with coal and the traditional biomass fuel. Wood fuel continues to be used as a major source of energy without a replacement program and is partly the cause of wide spread deforestation at an alarming rate of about 13 million hectares per year. Crucial to slowing the loss of the vegetation is promoting alternative sources of energy and/or using fuel efficient devices. This study examined the efficiency of cooking devices and the wood fuel consumption patterns among the rural population sampled from Kenya in Likia village near Njoro, so as to determine the more efficient cooking device and corresponding wood fuel. Initially, a survey was carried out capturing baseline data on the wood fuel utilization patterns and Split Plot in Randomized Complete Block Experimental Design used to select an efficient heating device where heating devices were a sub plot factor and the sources of energy as main plot factor to study the efficiencies of the devices. The results showed that wood fuel was the major source of cooking energy among the study population, and there were significant differences in the efficiencies of the devices due to the fuel type, the devices and interaction between the fuel and the devices. Among the recommendations made include the need to promote on-farm forestry specifically for wood fuel and timber production; effective management of natural forests, creating awareness about the key ecological services provided by forest ecosystems and delayed possible deforestation; promotion of energy saving stoves, the improvement of biomass briquette burning properties alongside the design of stoves for briquette use. Ultimately these results are expected to contribute to the slowing down of deforestation of the Mau Forest which is major water catchment for East Africa with overflow benefits to the Sudan and Egypt and promote sustainable uses of forest resources.

Keywords: Wood fuel, Cooking devices, Efficiency

1.0 Introduction

Six million hectares of primary forests are lost every year due to deforestation and modification through selective logging and other human interventions, among which are wood fuel needs especially in developing countries (UNEP, 2007).

Globally wood fuel accounts for 6 % of the Total Primary Energy Supply (FAO, 2014). In the developing countries wood fuel accounts for the largest share of household energy primarily for cooking and space heating (Sepp *et al*., 2014). In Kenya biomass energy provides 68% of the national energy requirement (Muchiri, 2008; Gathui and Mugo, 2010) and is expected to remain the main source of energy for the foreseeable future. According to (Republic of Kenya, 2007; Muchiri, 2008; Gathui and Mugo, 2010), it is estimated that about 80 % of Kenya's population lives in the rural areas characterized by limited access to affordable and convenient energy sources which is argued to be amongst the greatest impediments to social and economic development of the rural populations. Fuel wood is the most common type of energy in rural setups, while charcoal is considered an urban fuel. 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 (Republic of Kenya, 2003).

Harvesting of wood as fuel is associated with increasing levels of deforestation (Muchiri, 2008; Bett *et al*., 2009; Mbuthi, 2009; Gathui and Mugo, 2010; FAO, 2011; Sepp e*t al*., 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; Sepp e*t al*., 2014).

In Likia, land that was originally under forest cover has been converted to settlement and subsistence agriculture the major form of land use. Current wood fuel consumption patterns coupled with the indifference of the second generation of settlers to plant trees has precipitated a wood fuel shortage crisis. Other sources of energy are either beyond the means of this rural population or are totally unavailable. The increasing population and demand for wood fuel have led to increasing vegetation depletion with the potential to escalate the degradation of land. 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). Due to need for sustainability in wood fuel use, this study analyzed the wood fuel utilization patterns and the efficiency of heating/cooking devices used in the study area.

1.1 Objectives

The objective of this research was to enhance the sustainable environmental management by the conservation of the wood fuel energy resource, through the assessment of the efficiency of cooking devices and the wood fuel utilization patterns in the study area.

1.2 Hypothesis

H_a: There is significant difference in the efficiency of the cooking devices

2 Materials and Methods

Likia is located in Mau Narok ward of Njoro Sub County (See Figure 8). GPS of Likia location is 0^0 25, 07'51" S; 2618m a.s.l - 0^0 33, 04'47" S; 2693m a.s.l and 35^0 48'50" E; 2527m a.s.l - 35^0 55' 4" E; 2536m a.s.l.

2.1 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*).

The 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 is 10^0 C to 40^0 C.

2.2 Socio-economic Profile

Administratively Likia location is in Mau Narok Ward within Njoro Sub County. According to the (MOA 2009), the population of Likia location 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 by larger acreages with livestock production activities also being prominent. The average farm holding is 2 hectares (MOA 2009). Declining productivity of agricultural resources, unreliability of rainfall and shortage of land due to population increase is reducing 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 in diverse ways and varying magnitude. 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.

Likia is served by the main Nakuru Mau Narok Road(C57), that links 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 centers.

The main sources of energy used were found to be wood fuel for cooking and kerosene for lighting. Electricity use is limited to residents in the township area based on affordability.

2.3 Research design, Survey

Response was obtained from 100 residents of Likia. The sampling design used was Stratified Random Sampling. Respondents were selected randomly from four strata representing the four major villages of Likia, (Top life, Dam Kiahiti and Taifa villages). Top life village was almost urban with the Likia town centre within it; Taifa village was considered periurban further away from the town centre but with households within farms. Dam village was further away, on the left hand side of the C 57 (Njoro Mau Narok main road) and completely consisting of households that were farm families, while Kiahiti was far in the interior of Likia, on the left hand side of C 57(Figure 1). According to (GOK 2009), the population of Likia was 4750 persons, with an average household size of seven persons giving 678 households (respondent population for this study). The sample was assumed genuinely random, with an error margin of 9% and at 95% confidence level a sample size of 100 households was obtained (Online sample size calculator software (Creative Research Systems, 2014)). Twenty five households were randomly selected from each of the four villages (strata) considering that in each of the households food was cooked regularly. Each household (respondent) was required to respond to a series of 24 relevant structural questions.

2.3.1 Research design, Experiment

Split Plot in Randomized Complete Block Design was used. The fuel types (*Olea* charcoal and firewood, paper waste briquettes, charcoal dust briquettes and maize stover) were considered the main plot factor while the sub plot factor were the cooking devices (three stone stove, ceramic stove, wood ceramic stove and the metal stove), replicated four times.

2.3.2 Procedure

In the experimental procedure, 1 kg sample of known wood fuel was collected and weighed for each of the cooking devices; 1 liter of water in a cooking pan were weighed. Using one type of fuel cooking device was lit. Initial temperature of the water was recorded, 1 liter of water was heated and temperature was first recorded after 5 minutes, then at an interval of one minute until the tenth minute was reached. The pan was then removed from the fire and immediately another pan of water placed on the same fire and temperatures recorded to the tenth minute. The procedure was repeated until the changes in temperature were notably too low indicating that the heat locked up in the fuel as having been transferred to the cooking pot. This was repeated by the same cooking device for all wood fuel type and data recorded.

2.3.3 Efficiency of the Cooking Device

The formula stated below was used to compute the mean efficiencies from the temperature readings taken for each device/fuel type combination.

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

Where; ε_1 = the efficiency during one complete cooking cycle ((Dutt and Geller, 1997; Bailis *et al.,* 2007).

For each item i, M_{pi} = mass of cooking pot; M_{mi} = mass of cooking media, and M_{fi} mass of food. C_{pi} =specific heat of pot, C_{mi} = specific heat of cooking media, and C_{fi} = the specific heat of food. T_a = the initial temperature of the pots, cooking media and foods (normally the ambient temperature) and T_{ci} = the final cooking temperature of item i. K_{fi} = 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 while M_r and E_r are the weight and calorific value of any wood fuel recovered upon completion of cooking. For each experiment, the type of cooking pot used was aluminum pot of specific heat (C_{pi}) = 0.92 KJ/Kg ^{0}C, the specific heat for cooking medium {water (C_{mi})} = 4.18 KJ/Kg ^{0}C, the food item used was water, mass of cooking medium used (M_{mi}) = 1Kg and mass of cooking pot (M_{pi}) = 0.5 Kg.

2.4 Data Collection and Analysis

Amount (kg) of wood fuel used was recorded for each device. Temperature readings (^{0}C) first reading after 5 minutes then at 1 minute intervals for up to 10 minutes during heating of water for each energy source. The questionnaire was analyzed using The Statistical Package for Social Sciences (SPSS). An ANOVA at $\alpha = 0.05$ was conducted to test the H_o then LSD to test the significance of the differences in efficiencies attributable to fuel type, devices used and interaction between the fuel type and the devices.

3 Results and Discussion

3.1 Wood fuel Utilization Patterns

3.1.1 Form of Energy Used

All the respondents interviewed used wood fuel as source of energy for cooking with 90 % of the respondents using it in the form of firewood (Figure 2).Kerosene was the major source of supplementary energy used mainly for lighting the homes in the evenings. Though there were high rates of charcoal conversion activities within the area most of the charcoal was sold rather than used for cooking. Firewood was the most affordable form of energy available to the residents of Likia. This generally implied a continuous supply required hence the substantial conversion of vegetation to wood fuel energy. Wood fuel use 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*., 2007) generally and by (Bett *et al*., 2009) in a study carried out in Njoro district.

3.1.2 Time Spent Fetching Wood fuel and Amount Fetched in One Fetching

The time spent fetching wood fuel ranged from three hours to a whole day was influenced by the distance to collection points and transport back to the homesteads (Figure 3). 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 and 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 3). For those who fetched fuel less than10 kgs, fetching had to be done more often.

3.1.3 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). Thus a lot of time was spent which affected the completion of other chores scheduled for the day, consistent with the findings of (Muchiri, 2008) which observed that 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. Women were also largely responsible for food production and a lot of time spent in collection and gathering of wood fuel did not auger well for ensuring food security.

Eighty five percent of the respondents' wood fuel was fetched dry either obtained from the forest or purchased directly from vendors while 6 % of the respondents obtained their wood fuel neither wet nor dry (Figure 4.). Among this group were respondents that used charcoal for cooking and those that used other forms of energy such as LPG or kerosene. For respondents who fetched their wood fuel when not dry, it was mostly harvested from their own farms from felling or pruning of trees and 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. This situation was similar to that reported by (Gathui and Mugo, 2010) in a study on Biomass Energy use in Kenya whereby the principal users of wood fuel made little or no effort to ensure sustainability in its availability.

3.1.4 Mode of Acquisition and Responsibility for Fetching

Sixty nine percent of the respondents purchased wood fuel (Figure 5). 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 period of one month. The wood fuel collected from the forest was available as a result of thinning and pruning carried out as regular management activities of the various plantation forest blocks. Twenty four percent of the respondents obtained wood fuel from their farms (Figure 5). These were farmers who had embraced agro forestry and planted trees alongside their other enterprises to ensure a sustainable supply of wood fuel. Six percent of this population illegally obtained wood fuel free from the forest. This 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.

Fetching of wood fuel was mostly done by adult females for 71 % of the respondents and 16% by adult males (Figure 5), consistent with the findings of (KWDP, 2005) and (Muchiri, 2008) 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 situation was again in agreement with a status report on the progress towards achievement of MDGs and specifically MDG 3 which stated women on average spend roughly twice as much more time than men on unpaid domestic and care work principal among which was fetching wood fuel, a situation that MDG 3 had failed to address, (UN, 2013).

3.1.5 Cost of Fetching Fuel and Means of Transporting Fuel to Homesteads

Seventy nine percent of the respondents incurred a cost of KES. 50 to 150 per fetching of wood fuel (Figure 6), more than half of this cost was attributed to transport of the wood fuel. This 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.

Seventy three percent of the residents preferred to carry the wood fuel home on their backs, while 20 % 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 (Figure 5)

3.1.6 Types of Known Devi and Other Functions of Stoves

Seventy one percent of the respondents were familiar with the three stone stove, and 1% familiar with the sawdust stove (Figure 7). The traditional three stone stove was the most popular (71 %) with the residents of Likia, mainly based on the initial cost of obtaining other stoves, and partly due to the fact that issues of wood fuel shortage in the past did not seem as pressing. In a study on wood fuel use carried out in three districts in Central Kenya by (Gathiomi *et al*, .2011), 71 percent of the population used three stone fires with 44% of the cases attributable to the cost of improved stoves which was similar to the case of Likia.

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 but was used to boil water. 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 on completion of cooking task was, which was purely wastage of fuel. (Figure 7).

3.1.7 Most Preferred Stove and Reasons for Preference

Seventy two percent of the respondents preferred the Wood Ceramic Stove, (Figure 7). The saw dust stove was among the least preferred stoves.

The major reason that was given for the most preferred stove was the conservation of energy by 75% of the respondents (Figure 8).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) in a study in Njoro.

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 consistent with the findings of (FAO, 2014) 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). Seven percent of the respondents chose the Kenya ceramic stove as most preferred because of reduced smoke emitted (Figure 8). This was consistent with the findings of (McMullan *et al*., 1990) that charcoal(the form of wood fuel used with the ceramic stove) when burned at temperatures of less than 600^0 C, had less toxic carbon monoxide and nitrogen oxides generated, also confirmed by (Placket and White, 1981; Adegbulugbe and Bello, 2010).

3.1.8 Location of Stove and Number of Cooking Devices Used

For 95 % of the respondents, cooking stoves were indoors. (Figure 9). The choice of stove location was due to reduced draft 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 draft (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 device was found among 59 % of the respondents (Figure 9). The lack of access to information on alternative devices and cost of the devices were the major reasons given for not adopting improved and energy saving cooking devices. 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 devices among the study population was 70%.

3.1.9 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 4 % used more than 10 kg (Figure 10). The small amount of wood fuel used was attributed to two main factors, first was the reduced availability of wood fuel 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 (Muchiri, 2008; Gathui and Mugo, 2010). The constrained availability of wood fuel sometimes compromised the nutritional status of communities and 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 had also been noted by (Bett *et al.,* 2009). (FAO, 2014) and (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.

Fifty eight percent of the respondents belonged to households of less than five persons, and only 4 % to households with over ten persons (Figure 10). This was despite the census statistics of (GOK, 2009) that showed that the average household size of Likia was seven persons. However 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 devices in Nakuru county. In the cited study, most of the younger members of the community moved out of the rural areas 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.

Conclusion

The computed mean efficiencies of the various fuel/device combinations showed that the *Olea* wood fuel/Ceramic Charcoal 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 (Table 1). The control combination *Olea africana* wood fuel/three stone stove 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 device 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. The performance of the waste paper briquettes was the worst of all five fuels giving low efficiencies regardless of cooking device 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.

When treated to an ANOVA at $\alpha = 0.05$ the H_o was rejected. Least significant difference (lsd) was used to test for the significance of differences in efficiencies due to the fuel, the devices and the interaction between the fuel and the device (Table 2, Table 3 and Table 4).

These results showed that there was significant difference in the mean efficiencies due to the cooking devices used, and due to the fuel type used. There was also significant difference in the mean efficiencies due to the interaction of the fuel type and devices. The *Olea africana* firewood ceramic stove combination had the highest mean efficiency (69.00%) with a standard deviation of 0.00 among the replicates. The waste paper briquettes had the lowest mean efficiency (14 %) with a standard deviation of 0.00% among the replicates. The *Olea africana* firewood/ceramic stove combination performed much better with a mean efficiency of 69.00 % and a standard deviation of 0 .00% among replicates , as compared with the control *Olea africana* firewood/three stone stove with a mean efficiency of 56.50% and a *SD* of 5.57%.

From the experiments done, the efficiency of cooking devices is dependent on the type of wood fuel used, the type of device, and the interaction between the device and wood fuel. Even though the study partly aimed at recommending the most efficient cooking device, 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 devices, also noted by (GVEP, 2010) in a study on the use of briquettes in Kenya.

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 draft into the stove) for the briquettes to burn which the wood ceramic stove did not provide by design. The wood ceramic stove was sealed on three sides, limiting air inflow to facilitate burning, 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. These 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; Bailis *et al*., 2007) allowing adequate draft 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 which could have also contributed to the low efficiency recorded during the experiments S

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 draft 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).

Olea africana charcoal / metal stove combination recorded the second highest efficiency of 67.75 % and standard deviation 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 (MacMullan *et al.,* 1990; Adegbulugbe and Bello, 2010) 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.

The continued conversion of vegetation to wood fuel energy had impacted negatively on the environment as continued removal of vegetation cover left 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. The wood fuel utilization patterns of Likia involved the use of wood fuel by over 90% of the population, with firewood as the most popular and available form of wood fuel. 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 land degradation. Few of the residents of the study area had adopted the use of improved cooking devices.

The use of improved cooking devices was expected to improve the efficiency of energy conversion from that locked up in the fuel to that usefully employed during cooking demonstrated by the trends of heat dispersion, the time required to raise the temperature of water to the local boiling temperature and the significant positive correlation between the choice of fuel/device combination.

The significant difference in the efficiencies shown by the ANOVA at 95% level of confidence was due to the interaction of the fuel and devices, the type of fuel wood used, and the cooking device used. Thus the type of fuel used and the type of device selected greatly influenced the efficiency of the cooking devices.

The metal stove and the Kenya ceramic stove were found to be the most efficient devices 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.

From the results obtained from this study, the improved efficiency of cooking devices 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 also showed that even when a particular device fuel combination enhanced the efficiency of heat transfer its acceptability and thus use depended on the preference of the user among other factors. Other factors include the initial purchase price of the cooking devices the ease with which the fire is lit; the suitability of the device 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.

Recommendations

From the results of this study, the following recommendations were made:-`

1. The promotion of structured management of production of charcoal and fuel wood by small scale farmers as a source of income. This would increase the acreage of woody vegetation on the farms specifically for wood fuel production and maintain good level of soil cover.
2. The promotion of sustainable management of natural forests guided by approved management plans supplying wood fuel as by product. This in conjunction with active Community Forest Associations would ensure more sustainable use of wood fuel while allowing the forests to perform their ecological functions and delay possible deforestation.
3. The promotion of the expanded manufacture and ease of availability of improved stoves and the continued advocacy for their use would enhance both the thermal efficiency and the fuel use efficiency during cooking.
4. The promotion of alternative biomass energy sources such as briquettes alongside the design and development of specific stoves for briquette use.

Recommendation for further research

The Kitchen performance efficiency test be used to enhance the data obtained in the comparison of the performance of these cooking devices alongside the different fuel types in actual kitchen conditions rather than controlled conditions.

Acknowledgements

The authors wish to extend their gratitude to all those who made it possible to write and publish this study, Rose. Nyagwoka, William. Karoki and Petterson. Muriethi (colleagues in the State Department of Agriculture Njoro Sub County) who participated actively in the administration of the questionnaire, E. Mideva who was key in recording data during the experiments; and the people of Likia location who willingly gave information required of them during this study. This study was sponsored and financed by the main author as partial fulfilment for the award of MSc in Natural Resource Management of Egerton University.

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Table 1. The mean efficiencies and standard deviations

Level of FUEL	Level of DEVICE	EFFICIENCIES %	
		Mean	SD
Charcoal briquettes	Ceramic stove	38.00	5.60
Charcoal briquettes	Wood ceramic stove	24.00	6.38
Charcoal briquettes	Metal stove	56.00	5.85
Charcoal briquettes	Three stone stove	21.00	6.00
Maize stover	Ceramic stove	46.00	8.72
Maize stover	Wood ceramic stove	65.00	2.31
Maize stover	Metal stove	51.25	12.53
Maize stover	Three stone stove	35.50	3.42
Olea africana wood	Ceramic stove	69.00	0.00
Olea africana wood	Wood ceramic stove	58.00	4.24
Olea africana wood	Metal stove	65.50	4.04
Olea africana wood (CONTROL)	Three stone stove	56.50	5.57
Olea africana charcoal	Ceramic stove	61.25	6.13
Olea africana charcoal	Wood ceramic stove	18.00	4.69
Olea africana charcoal	Metal stove	67.75	0.50
Olea africana charcoal	Three stone stove	24.75	3.59
Waste paper briquettes	Ceramic stove	30.75	6.80
Waste paper briquettes	Wood ceramic stove	14.00	0.00
Waste paper briquettes	Metal stove	23.75	4.03
Waste paper briquettes	Three stone stove	16.00	1.83

Table 2 ANOVA table for efficiencies

Source of Variation	D.F	Sum of squares	Mean square	F_{Value}	Pr > F
Model	22	29087.38	1322.15	44.80	<.0001
Blocks(REP)	3	106.14	35,3791735.38	1.20	0.3185
Fuel	4	15228.93	3807.23	129.01	< .0001
Devices	3	6698.54	2232.85	75.66	< .0001
Fuel* Device	12	7053.78	587.81	19.92	<.0001
Error	57	1682.11	29.51		
Total	79	30769.49			

ANOVA at α =

(α = 0.05; Error Df = 57; Error Mean Square = 29.51; Critical value of t = 2.00; lsd = 3.44

Table 3 Device means for efficiencies

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

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

Table 4 Fuel means for efficiencies

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

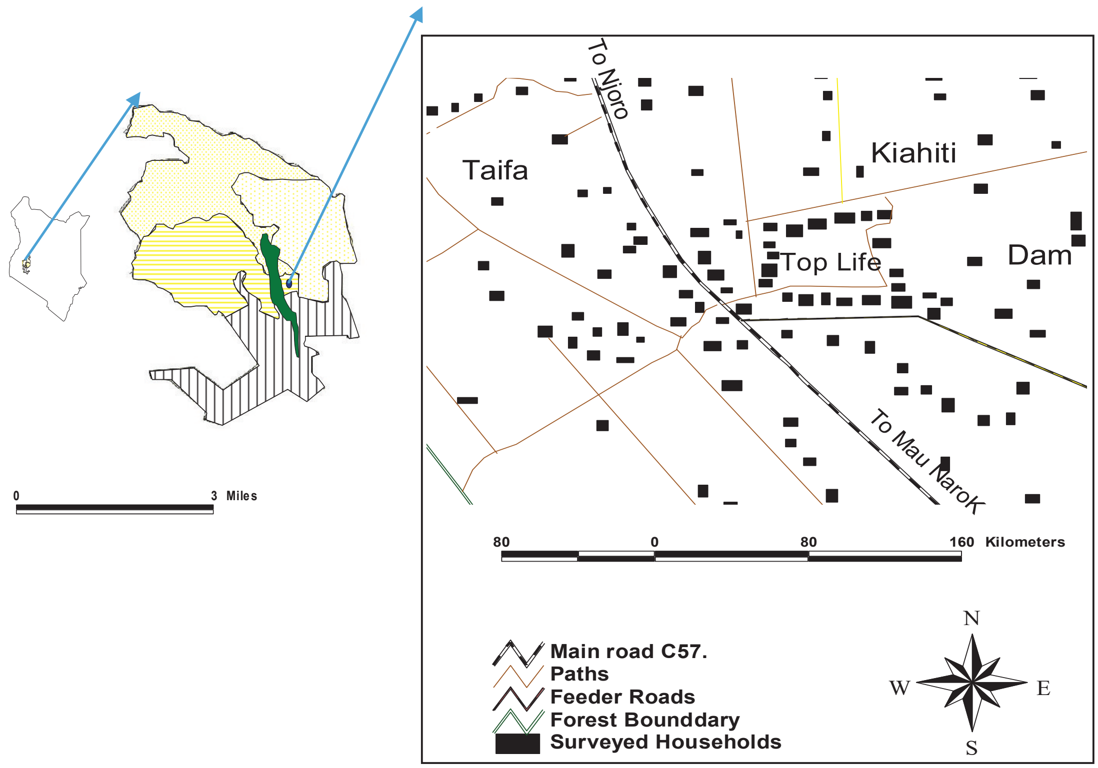

Figure 1: Location of Study Area (Njoro Sub County and Likia Location)

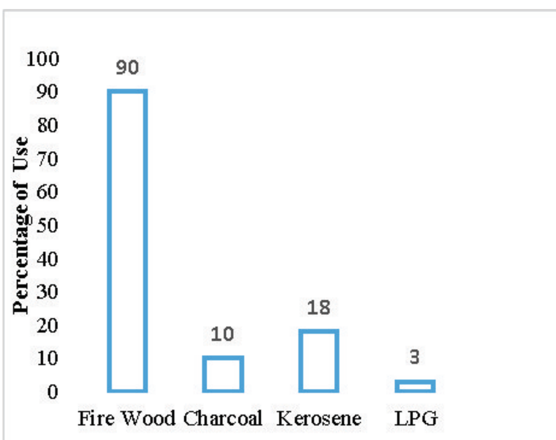

Figure 2. Form of energy used

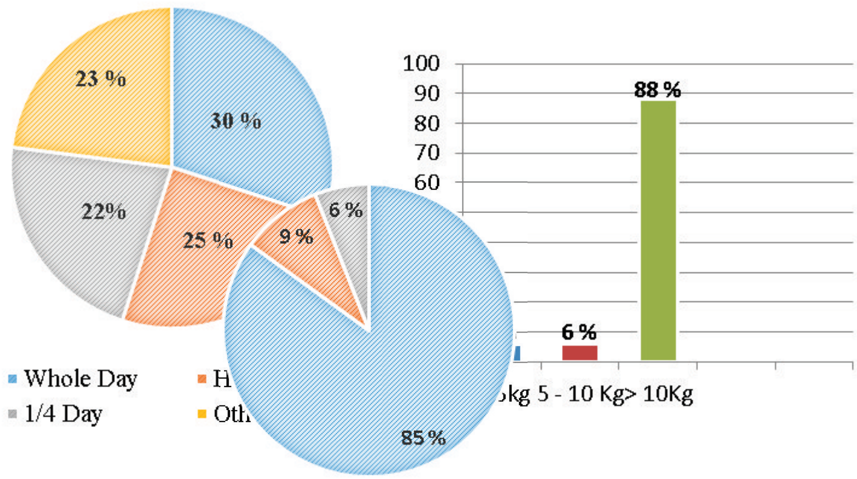

Figure 3: Time for fetching wood fuel and amount (kgs) fetched

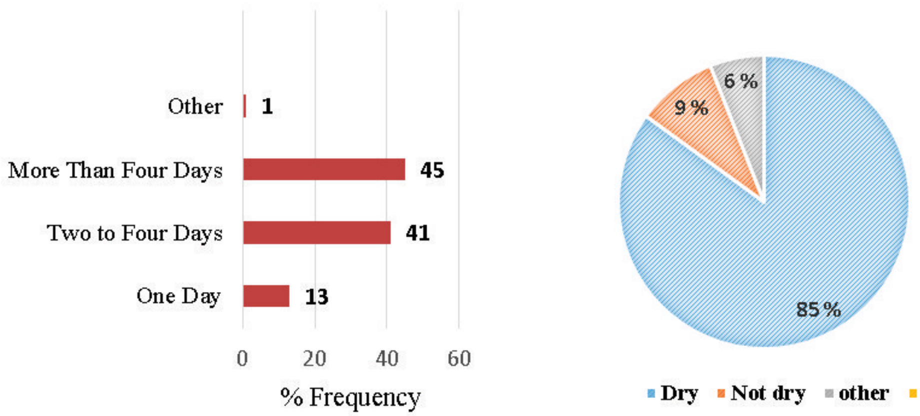

Figure 4: Time fuel lasts and the state of fuel when fetched

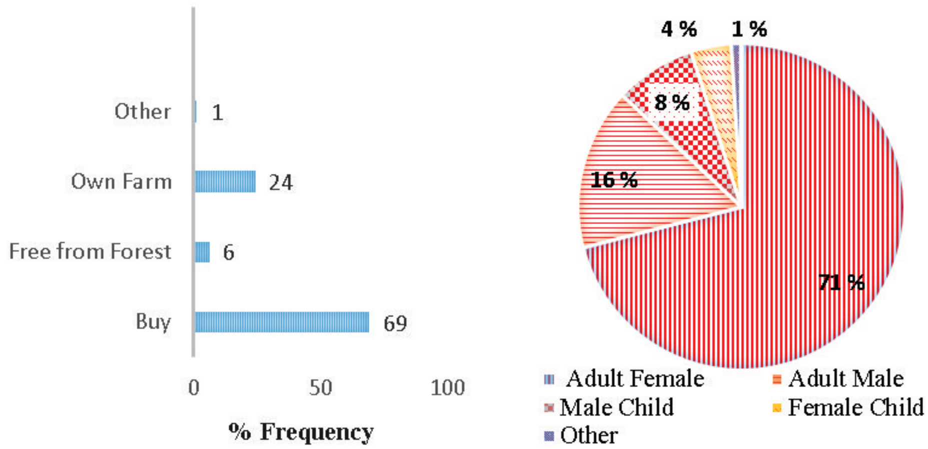

Figure 5: Mode of acquisition of fuel and the responsibility of fetching

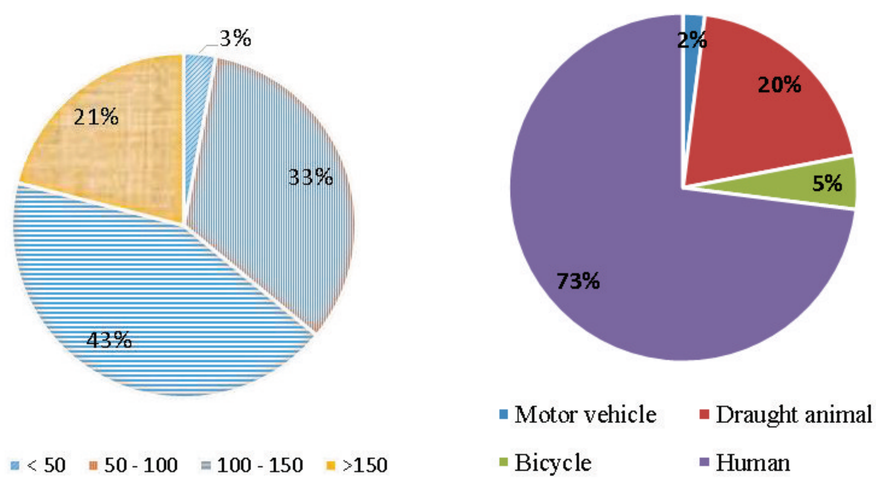

Figure 6: Cost of fetching fuel and means of transport home

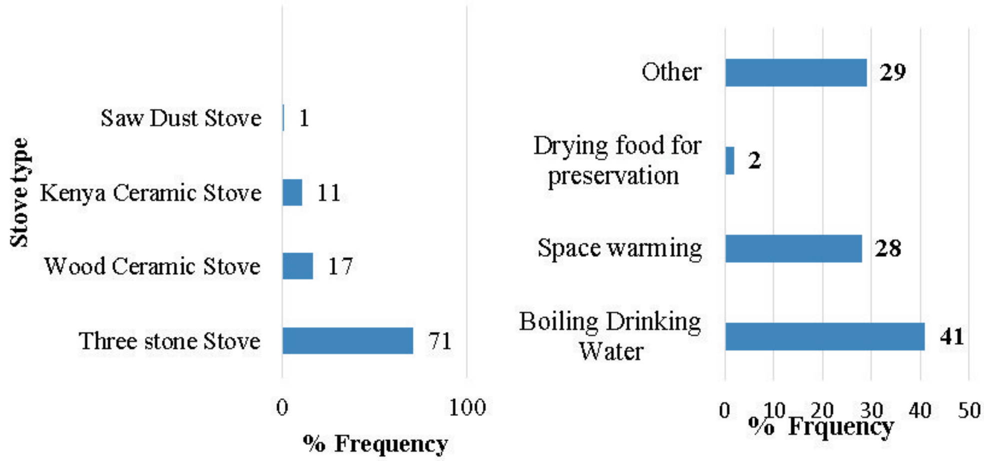

Figure 7: Types of known devices and other functions of devices

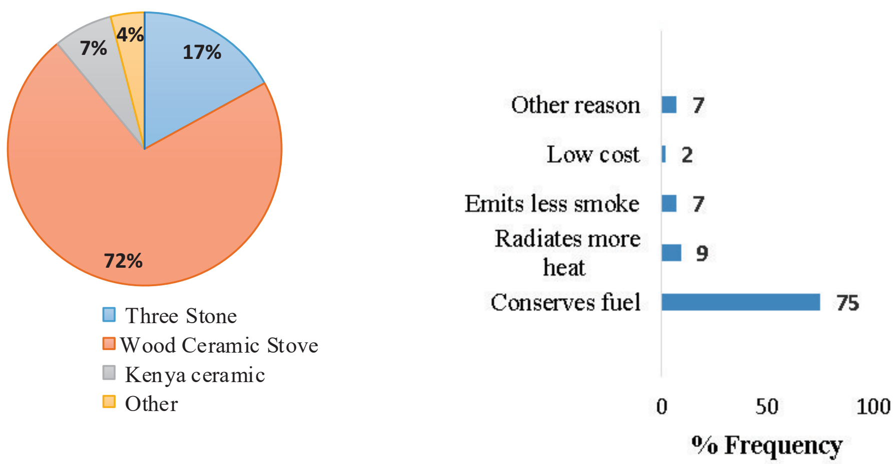

Figure 8: Most preferred stove and reason for preference

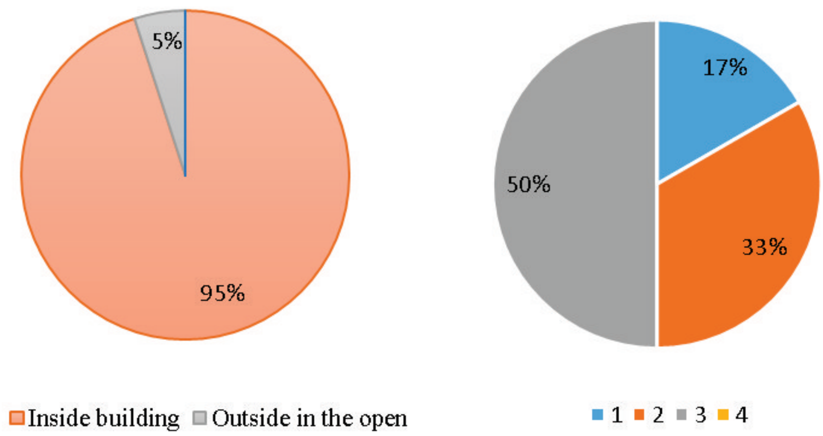

Figure 9: Location of Stove and number of devices used

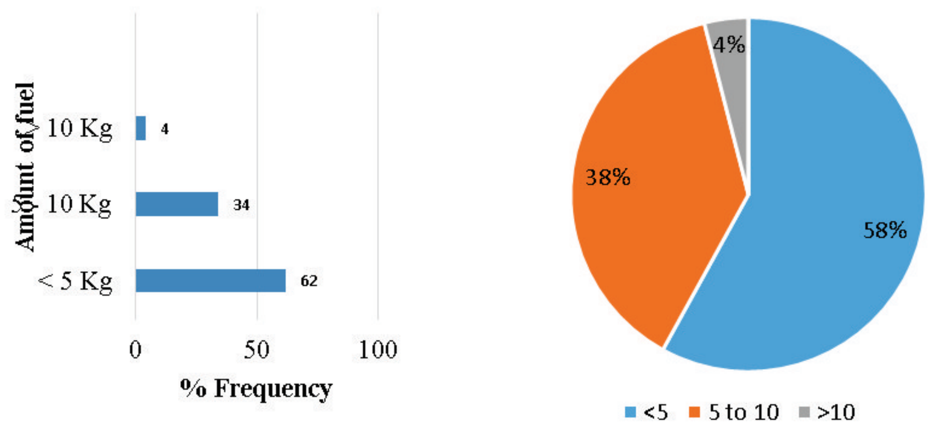

Figure 10: Amount (kgs) of fuel used to prepare a meal and size of household