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The Ecological Effects of Wood Fuel Extraction on the Gazetted Forests within Koibatek Zone, Mau Forests Complex, Kenya

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Abstract:

Despite the importance of woodfuel in Kenya's economic development, the ecological effects of its extraction on forests (particularly gazetted forests) remain unclear. Studies contradict each other on effects of woodfuel extraction on forests with some indicating that it leads to loss of biodiversity and forest degradation while others stating that woodfuel extraction is a forest cleaning activity and a part of good forest management. Little has been done to establish the area of forests lost due to woodfuel extraction as well as changes in distribution of preferred tree species from gazetted forests in Kenya. The objective of this paper was to establish the ecological effects of woodfuel extraction on the gazetted forests within Koibatek Zone, Mau Forests Complex-Kenya. Cross-sectional descriptive research design was adopted with all the 8 gazetted blocks within the Zone purposely selected. Stratified random sampling was used to select 384 woodfuel extractors and 8 FGDs were conducted each comprising of 10 participants. World Bank (2009) was used to convert volumes of woodfuel to equivalent forest cover required/consumed in gazetted forests from 2006-2014. Forest cover change for 2006-2014 was examined by analyzing satellite images acquired from the United States Geological Survey Global Visualization viewer. The estimated volume of woodfuel from gazetted forests between 2006 and 2014 was 260,746.1m³ out of which 113,289.59m³ was firewood and 147,456m³ was charcoal. The forest cover lost due to woodfuel was equivalent mature trees contained in 3902.6ha of closed-canopy forests. This is equivalent to 7.6% of closed forests of the gazetted blocks within Koibatek Forests Zone. About 13 tree species were preferred for woodfuel; 8 indigenous species and 5 exotic species. Indigenous trees preferred had reduced as indicated by 89% of extractors while distribution of exotic species remained constant as reported by 68% of extractors

Keywords: Ecological effects, wood fuel extraction, gazette, and closed-canopy cover

1. Background

A number of anthropogenic activities have led to destruction and general decrease of forests with increased woodfuel usage being identified as one of the biggest threat (Agarwala, 2006). Martinez-Alier (1995) established that demand for woodfuel destroys forests located near villages and towns in many countries of the world. For instance, in the arid regions of Asia, Africa and Latin America (i.e. the coast of Peru, the Sertões in Brazil, Central America or the highlands of Andes), the main reason for deforestation is the use of woodfuel by the poor communities. FAO (2000) indicated that the annual rate of deforestation in Africa ranges between 0.75% in Angola and 2.2% in Malawi. Soussan (1998) stated that forest depletion has often been attributed to over reliance on woodfuel enhanced by factors such as local proximity and access, land tenure, and local management regimes. Abd'razack (2013) on its part stated that the ecological effects of woodfuel extraction in Africa include: loss of indigenous biodiversity, depletion of ecosystems and desertification of some regions. FAO (2006) established that over-reliance of woodfuel in rural areas has caused changes in forest ecosystems in various ways such as changes in distribution plant species, tree physiology and stability. This manifests itself in stand-level effects, as well as in major disruptions or disasters caused by more dramatic weather events. Therefore, protection and management of forests should assure that the ecological effects can be foreseen, managed and reduced to the greatest possible levels, in consideration of the long ecological cycle of forests. However, it is not clear from the studies how factors such as lumbering, animal grazing or weather events play out in destruction or depletion of global forests.

According to Abd'razack (2013), wood fuel extraction alone cannot be blamed for deforestation in developing countries of Africa; there are other factors such as timber logging and export to other nations particularly developed nations. UN ECOSOC (2017) added that there exist other drivers of deforestation that include: illegal or unsustainable logging, unmanaged forest fires, pollution, disease, pests, invasive alien species, land fragmentation and the impact of climate change, including severe weather events. Leach and Mearns (1998) also agrees by stating deforestation cannot be stopped even if the use of woodfuel is completely stopped. It is evident from studies that woodfuel extraction from forests is not solely responsible for reduction of forest cover and loss of biodiversity. Arnold et al (2003) also indicated that there

exists some localized deforestation in most countries of the world, but depletion of forest cover on a large scale has not been found to be attributable to demand for firewood. This is because firewood is more often gathered from the roadside and trees outside forests, rather than from natural forests. The argument has been supported, in part, by ESMAP (2012) which stated that woodfuel harvesting is no longer considered the primary source of global deforestation, as it was in the 1970s. Currently, most deforestation results from clearing of land for farming to meet the food requirements of the rising population. Woodfuel supply to the dispersed rural populations is rarely an environmental threat nor is it globally unsustainable. A great portion of rural energy supply comes from trees outside forests, dead branches and logs, and agricultural residues. However, the studies did not isolate the ecological effects of woodfuel extraction on forests.

Nellie and Githiomi (2009) stated that continued loss of forests and associated resources in Kenya have caused far reaching negative effects on the country's economy and welfare of citizens. According to Forest Society of Kenya (2010), extraction of woodfuel from fragile areas of Kenya has caused severe deforestation, biodiversity loss and reduction of food opportunities from natural vegetation. Therefore, supply of wood to meet household energy needs should be properly taken into account in forest planning and policy formulation. ESMAP (2012) pointed out that, concentrated industrial or urban demand for woodfuel in a situation of weak regulations can contribute to degradation of forests located around major centers of consumption. This arises because small rural industries (such as brick making), urban businesses (such as bakeries and restaurants), and traders of woodfuel for the urban household market are largely unregulated. Such woodfuel consumers tend to source wood at the lowest possible price, with little concern for supply-side sustainability. Du Plessis (1994) reported that woodfuel harvesters first collect all available dry wood on forest floor, and then proceed to break dead branches off live trees. When all available dead wood has been collected, the harvesters turn to cutting down live trees and branches. Therefore, woodfuel extraction eventually has ecological effects on forests. In spite of these, information on the linkage between the quantity of woodfuel extracted and forest cover lost and or distribution of tree species is missing for forests in Kenya.

Gevorkiantz and Olsen (1955) provided a conversion table of wood to the number of standing trees as shown in Table 1. For instance, one cord of firewood is made from one tree with a diameter of 22 inches (at the height of 4.5 feet) or 50 trees each having a diameter of 5 inches.

Tree Diameter (in inches) of 4.5 feet in Height	Number of Trees to make a Cord of firewood	Number of Cords per Tree
5	50	0.02
6	20	0.05
7	12	0.08
8	8	0.12
9	6	0.17
10	5	0.21
11	4	0.25
12	3.5	0.30
14	2.5	0.40
16	2	0.50
18	1.5	0.65
22	1	1.00

*Table 1: Table for Converting Number of Trees into Cords of Firewood
Gevorkiantz and Olsen (1955)*

Patmos (2005) stated that the table can be used to keep a running tally of the number of many trees to cut for the required number of wood stacks rather than waiting until the wood is all stacked (Table 4). However, the conversion table did not provide the average diameters of trees either within a natural forest or forest plantations making it difficult to be applied on forests whose information on the average Diameter at Breast Height (DBH) of its trees is unknown. World Bank (2009) stated that, the total annual charcoal consumption in Tanzania is estimated at 2650 tonnes per day produced from 82,192 m³ of wood using traditional kilns. This daily wood requirement is equivalent to that contained in 342.5 ha of forest. Although World Bank (2009) did not provide formulae for converting the amounts of charcoal (in tonnes) consumed into area of forest cover required for charcoal production, the statistics are applicable in converting the volumes of woodfuel to the equivalent area of forests cover lost during extraction.

The paper focused on Mau Forests Complex (MFC) which according to ENSDA (2005) has been the most degraded amongst Kenyan forests and its cover has receded drastically over time. MFC covers an area of 400,000 ha and forms the largest forest block in Kenya and the largest single block of closed-canopy forest in East Africa (KFS, 2014). Mau Forests Complex which is made up of 22 blocks of gazetted forests, eight of which lies within Koibatek Forests Zone in Baringo County, Kenya. According to KFS-Koibatek (2011), the gazetted forests of Koibatek Forests Zone are the most vulnerable to degradation within Mau Forest Complex due to high demand for woodfuel and other forest products such as timber and grass. The area of gazetted forests of Koibatek Forests Zone is 51,007.7 ha; 27,996.5 ha being natural forests and 19,416.3 ha forests plantations (KFS-Koibatek, 2011).

1.1. Statement of the Problem

Despite the importance of woodfuel in Kenya's economic development, the information on its ecological effects on forests (particularly government forests) is scarce. Studies contradict each other on the effects of woodfuel extraction on forests with some studies indicating that woodfuel extractions leads to loss of biodiversity and forest degradation while other studies have indicated that woodfuel extraction is a forest cleaning activity and a part of good forest management. However, little has been done to establish the area of forests lost due to woodfuel extraction and changes in distribution of preferred tree species from gazetted forests in Kenya. Therefore, the purpose of the paper was to establish the area of closed canopy forests lost due to woodfuel and changes in distribution of preferred tree species for wood fuel in the gazetted forests.

1.2. Objectives

The main objective of the paper was to establish the ecological effects of woodfuel extraction on the Gazetted Forests within Koibatek Zone, Mau Forests Complex, Kenya. It specifically sought to: establish the volume of wood fuel extracted from gazetted forests between 2006 and 2014 and convert it to the equivalent area of closed canopy cover of forest lost. In addition, the paper examined the effects of woodfuel extraction on distribution of preferred trees species.

1.3. Justification

The findings are useful to policy makers and managers in the forest sector providing information on the effects of wood energy on forest reserves. This will guide policy formulation and preparation of management plans for sustainable forest management through planned utilization of forest products. The findings will also guide future researches on utilization of products within gazetted and private forests.

1.4. Study Area

The area of study was Koibatek Forests Zone which lies on Eastern part Mau Forests Complex between longitudes 35°35' and 35°15' and Latitudes 0°11' South and 0° 15' North. The Zone's gazetted forests cover an area of 510.08 km² or 51,007.7ha which is approximately 20.12% covers of Eastern Mau having an area of 2,535 km² or 253,500 ha (IUCN, 2008). According to KFS-Koibatek Zone (2011), the Zone comprises of eight (8) gazetted forest blocks namely: Chemorgok, Chemususu, Narasha, Sabatia, Esageri, Maji Mazuri, Kiptuget and Koibatek forests. The main vegetation of the gazetted forest blocks constitutes natural forest, grassland vegetation, and industrial plantation. Figure 1 shows the location of Koibatek Forests Zone in Map of Kenya and also indicates the boundaries of the eight gazetted forest blocks within the Zone.

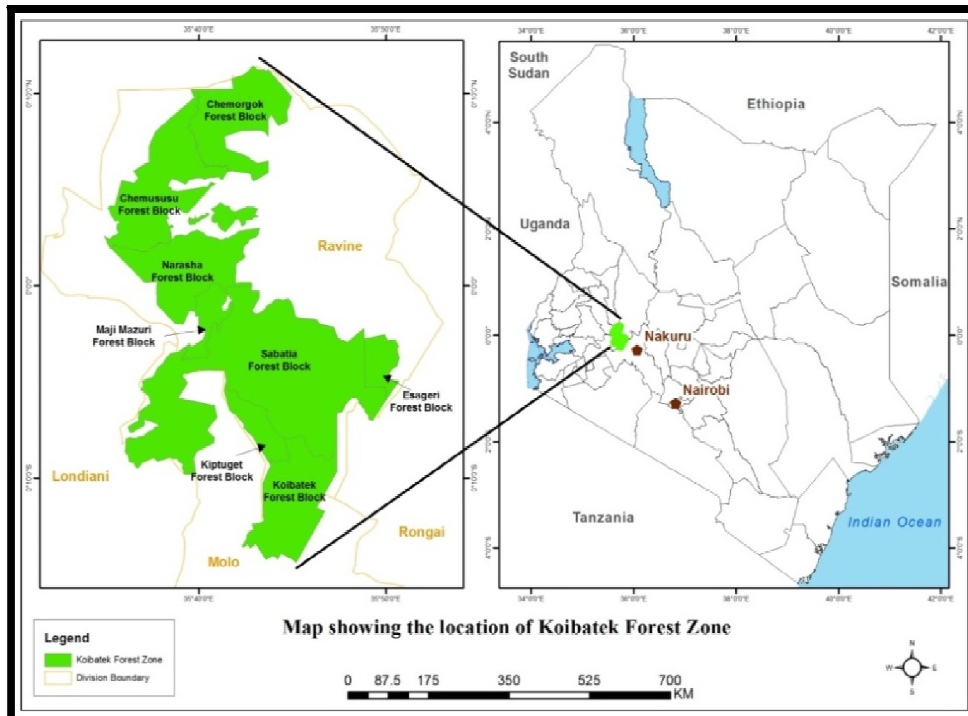


Figure 1: The Eight Gazette Forest Blocks within Koibatek Forests Zone
Source: Kenya Forest Service (KFS), 2015

2. Methodology

A cross-sectional descriptive research design was adopted. Firstly, all the eight (8) gazetted forest blocks within Koibatek Forests Zone were selected. The target population was 7,154 registered Community Forest Association (CFA) members which reflected the population of adjacent forest community of the gazetted forests within the Zone. Kothari (2004) formula was applied to derive a sample of 384 members who were interviewed by administration of questionnaires. 8 Focused Group Discussions (FGD) were conducted each comprising of 10 participants in accordance

with Escalada and Heong (2010) that stated that the optimum number of participants in a FGD should be 8 to 10. Volume of firewood extracted was estimated by examining the licensing profiles between 2006 and 2014 while volume of charcoal was estimated by establishing the number of producers; the number of bags produced within the period. World Bank (2009) was then used to convert the volume of woodfuel to equivalent forest cover required for the woodfuel extracted. Forest cover change over the period of between 2006 and 2014 was examined by acquiring and analyzing satellite images acquired from the United States Geological Survey (USGS) Global Visualization viewer website (www.glovis.usgs.gov). The satellite images acquired were for 2006, 2010 and 2014 in line with commencements of implementation of both Forest Act, 2005 and Energy Act, 2006; year 2010 due to the promulgation of Constitution of Kenya (2010) and, the year 2014 because of establishment of Kenya's Forest Policy, 2014.

3. Results

3.1. Forest Canopy Equivalent for Woodfuel Extracted Between 2006 and 2014

3.1.1. Volume of Firewood Extracted between 2006 and 2014

Forest Block	Annual Volume of Firewood (M ³) Between 2006 and 2014									Total
	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Chemorkok	813.57	664.1	365.8	255.6	405.8	442.6	426.7	323.2	484.4	4,181.8
Chemususu	276.7	521.4	180.8	147.5	400.3	1972.1	2703.8	2363.3	2245.0	10,810.9
Narasha	3307.9	2132.2	517.2	2627.46	1763.0	2209.7	1196.21	788.4	711.1	15,253.2
Maji-Mazuri	3061.2	3625.5	1828.1	2631.9	1602.2	1315.1	3200.9	3560.0	1899.5	22,724.4
Sabatia	721.4	366.3	332.7	1190.6	465.5	177.5	466.6	99.2	329.2	4,149.0
Esageri	2970.7	3277.2	1429.0	604.5	1555.1	1757.9	2802.6	866.5	1623.2	16,886.7
Koibatek	1493.6	2888.9	1588.0	2613.7	6186.1	2277.4	8357.3	3814.7	2287.3	31,507.0
Kituget	1159.3	1363.7	300.6	653.9	548.7	622.9	1579.5	902.2	646.3	7,777.1
Total	13804.4	14839.3	6542.2	10725.2	12926.7	10775.2	20733.6	12,717.5	10,226	113,290.1

Table 2: Estimated Volume of Firewood Extracted from Gazette Forests of Koibatek Zone from 2006 to 2014

Source: KFS, Koibatek (2015)

Table 2 indicated the total estimated volume of firewood extracted from the eight gazette forest blocks from 2006 to 2014 was 113,290.1m³. Volumes within each of the blocks from the highest to the lowest were: Koibatek block (31,507 m³), Maji-Mazuri (22,724.4m³), Esageri (16,886.7m³), Narasha (15,253.2m³), Chemususu (10,810.9m³), Kiptuget (7,777.1m³), Chemorgok (4,181.8m³) and Sabatia (4,149.0m³). Within the 9 year period, the highest annual volume of firewood extracted was 20,733.6 m³ in 2012 while the lowest annual volume was 6,542.2 m³ in 2008.

3.1.2. Estimated Volume of Charcoal between 2006 and 2014

Extraction Activity	% of the Number of Bags Produced at a Time				Total
	0-1	1-5	6-10	11-15	
Firewood and Charcoal	6.3	72.9	4.2	0.0	83.3
Charcoal only	0.0	2.1	12.5	2.1	16.7
Total	6.3	75.0	16.7	2.1	100

Table 3: Table: Percentage of Number of Bags of Charcoal per a Production Event

Source: Field Survey, 2015

Table 3 shows that 83.3% of charcoal producers did the activity together with firewood collection while 16.7% were exclusively charcoal producers within gazette forests of Koibatek Zone. 75% of the charcoal producers made 1-5 bags of charcoal per event while 16.7% produced 6-10 bags of charcoal. Charcoal producers who made less than 1 bag of charcoal per event were 6.3% and those who produced 11-15 bags were 2%. Therefore, it was noted that, though charcoal production were illegal within gazette forests (KFS Koibatek, 2015), most charcoal producers entered the gazette forests as firewood collectors only to secretly undertake charcoal burning illegally.

The amount of charcoal produced at any one time by the 48 charcoal producers interviewed within Koibatek Zone was found to be approximately 186.0 bags at a time (Table 4).

Number Of Bags At A Time	Frequency (F)	Mid-Points (X)	Fx
0-1	3	0.5	1.5
1-5	36	3	108
6-10	8	8	64
11-15	1	13	13
	$\sum F=48$		$\sum Fx=186.5$

Table 4: Number of Bags of Charcoal Produced at a Time from Koibatek Forests Zone

Source: Field Survey, 2015

On average, charcoal produced at any one time by one charcoal producer within Koibatek Forests Zone is approximately 3.9 bags (Equation 1).

Average number of bags at a time = $(\sum fx)/(\sum f) = (186.5)/48 = 3.9$ bags of charcoal

Equation 1: Per Capita Charcoal produced

Given that approximately 895 charcoal producers operates within the entire Koibatek Forests Zone, then, the amount of charcoal produced at a time is 3,480 bags as shown by Table 6. The cohort of 1-5 bags cumulatively accounted for approximately 2,013 bags, cohort of 6-10 bags totaled to 1,192 bags, cohort of 11-15 bags totaled to 247 bags and cohort of 0-1 bag totaled to 28 bags.

No. Of Bags		Charcoal Producers		Total No. of Bags of Charcoal
Cohort	Average	% Of 895	No. Of Producers	
0-1	0.5	6.3	56	28
1-5	3	75	671	2,013
6-10	8	16.7	149	1,192
11-15	13	2	19	247
Total	-	100	895	3,480

Table 5: Bags of Charcoal Produced Per Event within Koibatek Forests Zone

Source: Field Survey, 2015

Table 6 shows that the proportion of charcoal producers who did the activity once a month were 35.4%; 2 times were 47.9%; 3 times were 12.5% and 4 times were 4.2%. Within the cohorts of producing less than 1 bag of charcoal at a time; 33.3% did production twice a month, 33.3% (3 times) and another 33.3% (4 times). Of those who produced 1-5 bags of charcoal; 25% did the activity once a month, 62.5% (2 times) and 12.5% (3 times) while 100% of producers who produced between 11-15 bags did the activity only once per month (Table 6). Therefore, majority of the producers did charcoal production either twice a month (47.9%) or once a month (35.4%) within gazette forests of Koibatek Forest Zone.

Bags Charcoal Per Event	% Within The Times Per Month				Total
	1	2	3	4	
0-0.99	-	33.3%	33.3%	33.3%	100.0%
1-5	38.9%	47.2%	11.1%	2.8%	100.0%
6-10	25.0%	62.5%	12.5%	-	100.0%
11-15	100.0%	-	-	-	100.0%
Total	35.4%	47.9%	12.5%	4.2%	100.0%

Table 6: Percent of Charcoal Producers on Monthly Frequency of Charcoal Production

Source: Field Survey, 2015

Table 7 shows that the monthly charcoal production within gazette forests of Koibatek Zone was about 6,144 bags. Most of these charcoal (3408.8 bags) was produced by producers who undertook the activity twice a month while the least (262.5 bags) were produced in four events per month. Production events of between 1-5 bags per event cumulatively accounted for 3,579 bags of charcoal per month while events that produced 6-10 bags accounted for 2,235 bags per month. Therefore, the study established that it was easy to produce more charcoal within gazette forests by undertaking two events per month with each event producing between 1-5 bags.

Cohorts of Bags of Charcoal	BAGS of Charcoal Per Month				Total
	1	2	3	4	
0.1-0.99	0	18.5	27.7	37.0	83
1-5	783	1900.3	670.3	225.5	3,579
6-10	298	1490.0	447.0	0	2,235
11-15	247	0	0	0	247
TOTAL	1,328	3,408.8	1,145	262.5	6,144

Table 7: Approximate Number of Bags of Charcoal Produced per Month

Source: Field Survey, 2015

According to Ndegwa (2010), the average weights of charcoal packed in a standard bag is 40kg. Therefore, the estimated weight of the 6,144 bags of charcoal produced within the gazette forest blocks within Koibatek Forests Zone per month was 245,760 kg. Assuming that the volume of charcoal produced remained constant in the entire period of 108 months between January 2006 and December, 2014); then the total weight of charcoal produced within gazette forests was approximately 26,542,080 Kgs. The study converted the weights (kg) into volume (m^3) by utilizing Openshaw (1978) which stated that $1m^3$ of charcoal from preferred tropical hardwoods weighs 180kg. Therefore, the estimated volume of 26,542,080 kgs (or 26,542.08 tonnes) of charcoal was $147,456 m^3$.

The results show that larger volume of charcoal ($147,456 m^3$) was produced compared to that of firewood ($113,290.1m^3$) within gazette forests of Koibatek Forest Zones between 2006 and 2014. The results conforms to the findings of MoE (2002) that reported that charcoal production from Kenyan forests stood at 16,506,498 tonnes which was more than firewood whose volumes were 15,111,180 tonnes. Hillring (2006) in justifying why charcoal was more than firewood stated that most of the wood extracted for woodfuel is processed to charcoal so as to make transportation more efficient and increase the energy value.

3.1.3. Forest Canopy Equivalent for Woodfuel Extracted between 2006 and 2014

According to World Bank (2009), $82,192 m^3$ of wood required to produce charcoal or for firewood is equivalent to wood contained by a closed canopy of mature trees contained in 342.5 hectares of a forest. Therefore, $113,290.1m^3$ of firewood was extracted from gazette forests of Koibatek Zone between 2006 and 2014 translated to an approximated 472.1 ha of the gazette forests as deduced from World Bank (2009). Given that the total area of the gazette forests within Koibatek Zone was 51,007.7 hectares, 0.9% of the forests were consumed by firewood extraction between 2006 and 2014. The equivalent gazette forests area required for firewood extracted within each of the eight gazette forests blocks was: Koibatek block (131.3 ha), Maji Mazuri (94.7 ha), Esageri (70.4 ha), Narasha (63.6 ha), Chemususu (45.0 ha), Kiptuget (32.4 ha), Chemorgok (17.4 ha) and Sabatia (17.3 ha). Table 33 shows the equivalent percentage area the gazette forests blocks for firewood extracted between 2006 and 2014

Gazetted Forest Blocks	Total Gazetted Forest(Ha)	Forest Equivalent Of Firewood (2006-2014)	
		Area in Ha	% of the forest block
Chemorgok	5,851.5	17.4	0.3
Chemususu	11,304.8	45.0	0.4
Narasha	6,159.4	63.6	1.0
Maji Mazuri	6,065.0	94.7	1.6
Sabatia	4,108.0	17.3	0.4
Esageri	7,797.5	70.4	0.9
Kiptuget	850.0	32.4	3.8
Koibatek block	8,871.5	131.3	1.5
Total	51,007.7	472.1	0.9

Table 8: Area and Percent of Forests Equivalent of Firewood Extracted Between 2006 and 2014
Modified From KFS(2011)

Table 8 shows that Kiptuget forest block was the most affected by firewood extraction with 3.8% of its area equated to firewood extracted from 2006 to 2014 followed by Maji Mazuri block (1.6%) and Koibatek block (1.5%). The least affected was Chemorgok block with only 0.3% of its area equated to the firewood extracted. The findings strengthen the argument by FAO (2006) that nearly a quarter of the tropical rainforest biome has been removed by humans due to woodfuel extraction and lumbering.

On the other hand, the estimated $147,456 m^3$ of charcoal produced within Koibatek forests Zone between 2006 and 2014 using traditional kilns whose efficiency was 20% (World Bank,2009 and KFS (2009) meant that $823,247m^3$ of wood was consumed in the charcoal burning activities. The wood consumed was equivalent to mature trees contained that contained in 3,430.5 hectares of closed canopy forests. Therefore, the area of closed canopy of forests required by charcoal production equates to approximately 6.7% of the total gazette forests of Koibatek Forests Zone.

3.1.4. Forest Cover Change Linked To Woodfuel Extraction between 2006 and 2014

The paper established that the total area of gazette forests closed canopy cover lost due to woodfuel i.e. firewood and charcoal extraction between 2006 and 2014 was 3,902.6 hectares. The area was equivalent to 7.6% of the gazette forests area of total 51,007.7 hectares. However, according to FAO (2000) forests are capable of regenerating naturally or through intervention by man in establishing forests plantation. Thus, the ideal 7.6% loss due to wood fuel in gazette forests cover over a period of 9 years is difficult to be accounted for in change detections maps of forests. The cumulative changes in closed canopy forests and non-forest such as grasslands, water cover and agricultural land cover within the gazette forests of Koibatek Zone detected within the two periods of 2006-2010 and 2010-2014 is indicated in Table 9.

	Change in 1st Period (2006-2010)		Change in 2nd Period (2010-2014)	
	Area (ha)	%	Area(ha)	%
Land Cover	4032.63	5.65	-1635	-2.20
Closed Forests	4032.63	5.65	-1635	-2.20
Open lands, grasslands and water	-4032.63	-11.36	1635	4.94

Table 9: Forest Cover Change within Gazetted Koibatek Forests Zone

Source: Field Survey, 2015

Table 9 shows that there was a significant increase of 5.65% (4032.63 ha) in cover of closed forests between 2006 and 2010. This meant that 11.36% of non-forest decreased that period. However, in the period between 2010 and 2014, there was a decrease of the forest cover by 2.2% (1635ha) indicating an increase of 4.94% in the total area of non-forest. Therefore, in the period between 2006 and 2010, there was afforestation or regeneration of 5.65% and in the period between 2010 and 2014 there was deforestation of 2.2%. An analysis of firewood extraction alone within the two periods i.e. 2006-2010 and 2010-2014 reveals that, woodfuel extraction played a role in the decline in cover of gazette forests of Koibatek Forests Zone. For instance, in the period between 2010 and 2014 (the period where deforestation by 2.2% occurred) total volume of woodfuel extraction was 67,378.8 m³ (Table 10) which was an increase from 58,837.5m³ for the previous period of between 2006 and 2010 (Table 11).

Forest Block	Volume of Firewood (M ³) from 2006- 2010					
	2006	2007	2008	2009	2010	TOTAL
Chemorkok	813.57	664.09	365.75	255.56	405.83	2,504.8
Chemususu	276.7	521.39	180.77	147.46	400.3	1,526.62
Narasha	3307.92	2132.2	517.23	2627.46	1762.96	10,347.8
Maji Mazuri	3061.21	3625.44	1828.12	2631.86	1602.23	12,748.9
Sabatia	721.42	366.3	332.66	1190.56	465.54	3,076.48
Esageri	2970.69	3277.22	1429.02	604.46	1555.12	9,836.51
Koibatek block	1493.61	2888.88	1588.03	2613.7	6186.07	14,770.3
Kituget	1159.34	1363.73	300.58	653.86	548.65	4,026.16
Total	13,804.46	14,839.25	6,542.16	10,724.92	12,926.70	58,837.5

Table 10: Annual Volume of Firewood Extracted between 2006 and 2010

Source: Field, 2015

Forest Block	Volume of Firewood (M ³) from 2010-2014					
	2010	2011	2012	2013	2014	TOTAL
Chemorkok	405.83	442.56	426.69	323.21	484.37	2,082.66
Chemususu	400.3	1972.08	2703.75	2363.26	2245	9,684.39
Narasha	1762.96	2209.66	1196.21	788.38	711.09	6,668.30
Maji Mazuri	1602.23	1315.08	3200.94	3560	1899.51	11,577.8
Sabatia	465.54	177.47	466.6	99.17	329.2	1,537.98
Esageri	1555.12	1757.88	2802.59	866.48	1623.24	8,605.31
Koibatek block	6186.07	2277.42	8357.33	3814.66	2287.33	22,922.8
Kituget	548.65	622.92	1579.45	902.23	646.34	4,299.59
Total	12,926.7	10,775.07	20,733.56	12,717.39	10,226.08	67,378.8

Table 11: Annual Volume of Firewood Extracted between 2010 and 2014

Source: Field Survey, 2015

The results indicate an increase of 8,541.3m³ in firewood extracted in 2010-2014 period where deforestation of 2.2% occurred compared to that of 2006-2010 period. This shows that part of the deforestation which occurred in the period is attributable to the increased in volume of firewood extracted.

3.2. Effects of Woodfuel on Distribution of Preferred Trees Species

3.2.1. Preferred Trees Species for Woodfuel

Table 13 shows the common exotic tree species preferred for both charcoal and firewood within the gazette plantations forests of Koibatek Forests Zone.

Scientific Names	Common/ Local Name	% of The Total Respondents
<i>Cupressus lusitanica</i>	cypress	74.7
<i>Pinus radiata</i>	Pine	56.0
<i>Grevillea robusta</i>	Silky oak	33.9
<i>Eucalyptus grandis</i>	Blue gum	24.2
<i>Casuarina cunninghamiana</i>	Casuarina	14.8

Table 12: Exotic Trees Species Preferred for Firewood and Charcoal
Source: Field Survey, 2015

The exotic tree species extracted for firewood and charcoal were: *Cupressus lusitanica* as reported by 74.7% of the total respondents, *Pinus radiata* (56%), *Grevillea robusta* (33.9%), *Eucalyptus grandis* (24.2%) and *Casuarina cunninghamiana* (14.8%) (Table 13). Therefore, *Cupressus lusitanica* (cypress) and *Pinus radiata* (pine) tree species were the most preferred exotic tree species extracted while *Casuarina cunninghamiana* was the least preferred species of the reported tree species. The results of the study concur with KEFRI (2014) which reported that the major uses of tree species such as *Cupressus lusitanica*, *Eucalyptus* spp, *Pinus radiata* and *Grevillea robusta* is timber or poles, firewood and charcoal.

Table 14 on the other hand shows eight (8) indigenous tree species within gazette forest blocks of Koibatek Forests Zone preferred for firewood and charcoal. The most preferred tree species was *Tarchonanthus camphoratus* known locally in tugen language as *lelechwet* reported by (81.3%) of the respondents and *maregeiwet* (Kipsigis language) reported 61.2% of the respondents. Other indigenous tree species used for firewood and charcoal were: *Thalictrum rhynchocarpum* (33.9%), *Podocarpus falcatus* (31.3%), *Olea africana* (24.0%), *Juniperus procera* (20.8%), *Acacia polyacantha* (10.4%), and *Croton megalocarpus* (7.8%).

Scientific Names	Common Name	% of The Total Respondents
<i>Tarchonanthus camphoratus</i>	lelechwet (tugen)	81.3
	Maregeiwet (Kipsigis)	61.2
<i>Thalictrum rhynchocarpum</i>	Chebositewo or Sitewet (tugen)	33.9
<i>Podocarpus falcatus</i>	Yellow wood	31.3
<i>Olea africana</i>	Wild olive-emitit	24.0
<i>Juniperus procera</i>	E.A cedar, Mtarakwa	20.8
<i>Acacia polyacantha</i>	Falcons-claw acacia	10.4
<i>Croton megalocarpus</i>	Otonwo (tugen)	7.8

Table 13: Indigenous Tree Species Preferred for Firewood and Charcoal
Field Survey, 2015

FGDs (2015) revealed to the study that most of the licencees with MFLs preferred indigenous tree species to exotic species. FAO (2003) agrees with the results as it stated that, although practically all tree species could be used for firewood, there is a group of tree species that is generally preferred because they usually burn without excessive smoke and unpleasant odours. Among the indigenous species, the most widely used tree species in the different countries is *Acacia* spp while exotic tree species that are being grown for firewood include *Eucalyptus* spp., *C. cunninghamiana* and *Acacia mearnsii*. Pines and cypresses although often used in areas of high wood deficit are not preferred species.

3.2.2. Level of Extraction of Preferred Trees Species for Woodfuel

Table 12 shows the level of extraction of both indigenous and exotic tree species by charcoal producers and firewood extractors within gazette forests of Koibatek Forests Zone.

Sections Of Gazette Forests	% Responses On Species Preferred For Firewood		% Response On Species Preferred For Charcoal Burning	
	Indigenous	Exotic	Indigenous	Exotic
Natural	42.3	5.3	34.8	4.3
Plantations	9.3	43.1	4.3	56.5
Total	51.6	48.4	39.1	60.9

Table 14: Responses on the Preferred Tree Species for Firewood and Charcoal
Source: Field Survey, 2015

Table 12 shows that 51.6% of woodfuel extractors preferred firewood from indigenous tree species of which 42.3% from natural forests and 9.3% from plantation forests. 48.4% of the extractors preferred firewood from exotic tree species of which 43.1% was sourced from plantations and 5.1% sourced from natural forests. On the other hand, 39.1% of charcoal producers preferred indigenous species while 60.9% preferred exotic species. Therefore, more firewood extractors preferred indigenous tree species compared to exotic tree species while charcoal producers preferred exotic

tree species compared to indigenous tree species. Personal communications by Forest Officers (2016) supported the findings by stating that, though Monthly Fuel Licenses had no restrictions on the sections of the forest from which firewood was collected, most woodfuel extractors preferred indigenous species. According to the FGD participants, indigenous tree species provided good quality woodfuel and produced less smoke during burning. In addition, tree species such as *Olea Africana* and *Tarchonanthus camphoratus* had the capability to burn efficiently even when wet (high moisture content).

Figure 2 shows that 66% of woodfuel extractors reported that the preferred tree species for woodfuel were not the dominant species within the gazette forests while 34% of the extractors reported that the species were the dominant species. Therefore, woodfuel extraction leads to reduction in the number of tree species preferred for wood fuel within gazette forests since were not the dominant species of the forests.

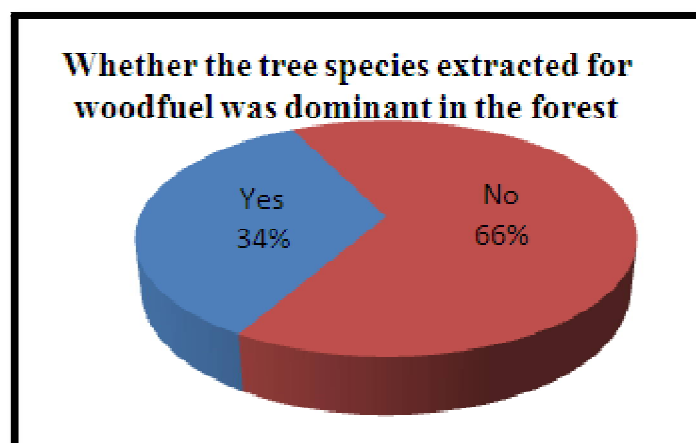


Figure 2: Tree Species Dominance within the Gazette Forests

Source: Field Survey, 2015

Species of trees	% responses on change in distribution due to woodfuel extraction from 2006-2014			
	Increased	Decreased	No Change	Total
Indigenous	7	89	4	100
Exotic	9	23	68	100
Mean	8	56	36	100

Table 15: Changes in Distribution of Preferred Tree Species between 2006 and 2014

Source: Field Survey, 2015

Table 15 indicates that between 2006 and 2014, 56% of woodfuel extractors indicated that distribution of preferred tree species for woodfuel decreased, 36% reported that there were no changes and 8% indicated that trees species had increased. It was also noted that indigenous tree species within gazette forests decreased due to woodfuel extraction as indicated by 89% of woodfuel extractors. For exotic species, 68% of the total woodfuel extractors reported a no change in their distribution within gazette forests. According to Cardoso et al (2015) most indigenous tree species are preferred because they have high calorific value and low moisture contents compared to most exotic species. Cardoso et al (2015) also agrees with findings that distribution of exotic species did not change since it stated that exotic species are fast growing species planted for various purposes such as shelter, shade, fodder, and fence posts, ornamental and for firewood. FAO (2003) in supporting preference of exotic species for woodfuel reported that pines and cypresses are often used in areas of high wood deficit, however, are not preferred species.

4. Conclusions

The paper concludes that woodfuel extraction within a period of 9 years between 2006 and 2014 was equivalent to 7.6% loss in forest cover of gazette forests. Charcoal production accounted for 6.7% of the loss in forest cover while firewood extraction accounts for 0.9% loss in forest cover. The higher loss of forest cover associated with charcoal burning was mainly caused by the use of traditional kilns whose efficiency 20%. The cumulative deforestation caused by firewood and charcoal results from the reduction in distribution of approximately 13 tree species mostly preferred for firewood and charcoal extraction. Five (5) of the tree species preferred for woodfuel were exotic species within plantation forests while 8 are indigenous species within natural forests.

5. Recommendations

The potential wood equivalent from standing tree stands within both natural and plantations forests should be calculated or measured. This will ensure monitoring of level of exploitation based on extraction permits issued by management authorities. Additionally, the preferred tree species for wood fuel gazette forests should be protected and or sustainable extraction plans such as temporal closures and ban of cutting of standing trees for woodfuel be developed and implemented. Accurate forest inventory of the existing tree species should also be kept and monitoring of the trends on

distribution of these species be done regularly. Tree species that endangered by woodfuel extraction must be identified and protected.

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