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# The Effect of Land Use on Carbon Stocks and Implications for Climate Variability on the Slopes of Mount Elgon, Eastern Uganda

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## Abstract

We investigated the impact of land use change on carbon stocks and its implications to climate variability in Mountain environments. Remotely sensed biophysical data was used to determine the extent of land use change over the last two decades. Land uses were stratified thus; forest under restoration, woodlots/plantations, agricultural land, regenerating forest and intact forest. Carbon in above and below ground biomass was measured using the allometric equations, whilst soil samples were analyzed for total carbon by the dry combustion method. The differences in carbon stocks in various land uses were analyzed using Analysis of variance (ANOVA). Top soil layers (0-10cm) were found to store more carbon than the deeper ones. Furthermore, intact forest stored more soil organic carbon (> 45t/ha) compared to other land uses with the least in land under agriculture (about 1.5 t/ha). The decimation of land uses with high carbon stocks was noted to reduce the potential of Mt. Elgon as a carbon sink. This therefore calls for the scaling out and up of forest restoration programmes in and

around mountain environments, whose success will depend on the active participation of all stakeholders including, Uganda Wildlife Authority (UWA), local communities, politicians and leaders.

**Keywords:** Land use change; Carbon stocks; climate variability; Mt. Elgon; Eastern Uganda

## 1. Introduction

Forests, tree plantations and soils are major sinks of atmospheric carbon (Schimel *et al.*, 2001; FAO, 2006; Saugier and Pontailler, 2006; IPCC, 2007), whose influence in the global carbon cycle is now widely recognized (Basu, 2009; Bonan, 2008; González *et al.,* 2008, Barasa and Kakembo, 2013). According to Land Use, Land Use Change and Forestry (LULUCF), sustainable management, tree planting and forest restoration increase forest carbon stocks, on the other hand deforestation, degradation and poor forest management will lead to reduced carbon stocks. Global forest resources (GFRA) 2010 key findings state that globally, carbon stocks in forest biomass decreased by an estimated 0.5 Gt annually during the period 2005–2010, mainly because of a reduction in the forest area (FAO, 2006).

Tropical forests in their natural condition contain more aboveground C (Carbon) per unit area than any other land cover type Saatchi, et al. (2011). According to Kurniatun *et al.,* (2001), when forests are cut to create open vegetation, a large amount of atmospheric carbon is released thereby altering terrestrial carbon stocks. It is believed that Land Use, Land Use Change and Forestry (LULUCF) contribute 10–20% of total greenhouse gas emissions (Houghton, 2005; van der Werf *et al*., 2009; Dolman *et al*. 2010, Kurniatun *et al* 2001, IPCC, 2006). However, for developing countries, only one category of the various land use/cover changes is eligible as mitigation action i.e. afforestation/reforestation. Forest restoration activities contribute to up to 25% reduction of atmospheric $CO_2$ through sinks and help with adaptations and sustainable development (Reyer et al., 2009).

Human destruction of forests especially in the tropical and subtropical mountain environments he become a concern and the associated consequences on soil and water quality, biodiversity, global climatic and livelihood systems (Turner et al., 1995; Laurence, 1999; Noss, 2001; Armenteras et al., 2003: Mugagga et al., 2012). Annual humid tropical forest cover losses are estimated at 5.8 ± 1.4 million hectares (Frédéric et al., 2002; Hansen et al., 2008) with corresponding global carbon emissions ranging between +0.5 to +3.0 GtC yr-1 (Houghton, 2003b; Frédéric et al., 2004).

There is urgent need to assess the likely impact of anthropogenic activities on local and regional climate. While some progress has been made, more comprehensive studies are needed. It is estimated that 50-80% of the total earth's system’s carbon stock is found in the top 1.5 m below the ground (Walker and Desanker, 2004; Ryan *et al.,* 2011). However, deforestation and rapid population growth rates have led to reduced fallow periods and widespread degradation on the slopes of Mount Elgon (Muwanga *et al*., 2001; Breugelmans, 2003; Bamutaze, 2004; Glade and Crozier, 2004; Kitutu et al., 2004; Knapen et al., 2006; Buyinza and Nabalegwa, 2008: Kitutu et al., 2009; Mugagga et al., 2010; Barasa and Kakembo, 2013). It is noteworthy that mountain ecosystems are particularly sensitive to anthropogenic impacts and the loss of vegetation cover inevitably alters mountain hydrology and has implications for local and regional climate variability (Beniston, 2003; IPCC, 2007a,b; Mugagga et al., 2011).

Biophysical changes arising from climate variability and changes in carbon stocks will inevitably increase stress on socio-ecological systems on the slopes of mountain Elgon. Household asset portfolios are bound to fluctuate depending on their sensitivity to increasing stress. Adaptation strategies in such environments should therefore be anchored on a clear assessment of carbon stocks and how they are impacted by land use changes.

Understanding of the possible effects of past and present day land use cover change on soil organic carbon and land degradation is not only scientifically important, it is also a prerequisite for the development of a sustainable land use policy on the slopes of Mount Elgon that will anchor adaptation to climate change strategies in mountain environments (Mugagga et al., 2011). The purpose of the study was to carry out a comprehensive analysis of land use/cover change, its impact on soil organic carbon and implications for climate variability on the slopes of Mt. Elgon, Eastern Uganda.

## 2. Methods

### *2.1 Study Area*

The study was carried out on the slopes of Mt. Elgon from the Uganda side. Mt. Elgon is a trans-boundary massif that is shared between Uganda and Kenya, 100km northeast of Lake Victoria. Mt. Elgon is a non-active volcano built up from lava debris rising to a height of about 4320m above sea level (Hitimana et al., 2004). The slopes receive a bimodal pattern of rainfall with the wettest period occurring from April to October. The mean annual rainfall ranges from 1500mm on the eastern and northern slopes to 2000mm in the southern and the western slopes. The mean maximum and minimum temperatures are $23^0$C and $15^0$C respectively (Mugagga et al., 2012).

Many rivers flow from Mt. Elgon’s upper slopes, providing drinking and irrigation water for thousands of communities on Mt. Elgon and below into the increasingly arid plains. The adjacent low lying areas are heavily cultivated by the communities with crop growing (coffee, bananas, cereals, cassava etc), livestock grazing (cattle, goats, pigs etc), medicine, fire and wood extraction from the forest, and small scale businesses being the main sources of household income. Movement in the area is difficult due to the hilly terrain and the roads, which become extremely slippery after light drizzles (Onapa et al., 2001).

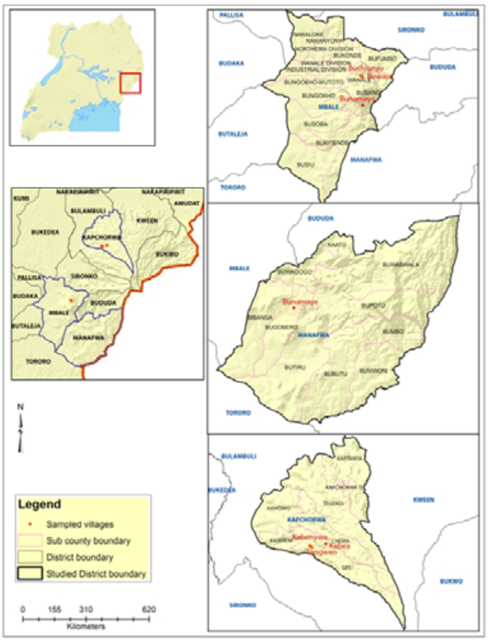

Figure 1. Study sites within the Sampled Districts on the slopes of Mt. Elgon, Eastern Uganda

Owing to the ruggedness and steepness of the terrain around Mt. Elgon, accessibility was key in selecting the sites within the study Districts thus; Mbale, (Bushiunyo and Bumayoga villages) and Kapchorwa (Kabea and Kabenywa villages).

### *2.2 Data Collection*

### 2.2.1 Estimating Land Use Change

Stratified sampling was used because of its classical and accuracy benefits, when compared to a random sampling approach. The land use strata adopted were the intact forest, agriculture regenerating/restoration forests and the woodlots/plantations. A combination of prior knowledge about the study area and land use/cover maps covering Mt. Elgon created by the National Biomass Study (2003) were used as a reference in the classification and description of land use/cover types. Land use /cover changes were determined by way of two sets of Land sat Imagery TM/ETM+ of 1995 and 2013 (30m) acquired during the dry season. The images were pre-processed by gap filling using ENVI software version 4.7 to reduce on the number of strips, resulting in about 22% of the pixels per scene not being scanned (Chen et al., 2011). The 1995 year was selected as a base year to determine the changes in land use/cover which occurred after gazetting the mountain into Mt. Elgon National Park in 1992.

The ortho-rectified and cloud free images were downloaded from the http://glovis.usgs.gov/ website. The image acquisition path is 170 and row 059 (PCS WGS 1984 UTM zone 36N). A 7, 4 and 2 band combination was adopted by the study. The images were filtered with 3 x 3 majority filter prior to classification to replace each pixel value with a new value (McDonnell, 1981; Cleve *et al.,* 2008).The images were subjected to supervised classification procedure with maximum likelihood algorithm. A supervised maximum likelihood methodology was adopted because each land use/cover class had a Gaussian distribution (Dewan & Yamaguchi, 2009). A total 129 points were collected during the ground-thruthing exercise for image accuracy classification in 2013. The standard error matrix was adopted for accuracy assessment. The drivers of changes in land use and land cover were assessed from the group focus discussions.

### 2.2.1 Estimation of Aboveground Woody Carbon Stocks

In each homogenous land use, sampling plots of 50 m X 50 m were randomly selected. Trees were identified using both the scientific and local names. The height and diameter of all trees greater than 1.3 m were measured. Tree height was measured using a Suunto clinometer and the diameter at breast height (DBH) was estimated from a tape measure as the tree circumference value at breast height divided by pie or diameter calipers. Samples were then collected slightly above the DBH for carbon content determination.

### 2.2.2 Estimation of Soil Organic Carbon and Litter

For each selected site, composite soil samples were collected at three soil depths, 0-10 cm 10-20, and 20-30 cm, using an auger. Total soil C at 0-30 cm depth was calculated from values of C concentrations from single depths using the Nelson and Sommers' methods (1975). Three replications were selected at three soil depths, 0-10 cm, 10-20cm and 20-30 cm, using an auger randomly in each land use type. The soil samples from the three points were then mixed to represent one sample for a replicate.

Litter was also collected from the selected sites in each plot of 50 by 50m, and taken to the lab for analysis.

### *2.3 Data Analysis*

Data was entered in Microsoft Excel for coding. Carbon stocks from the Above Ground Biomass (AGB) and Below Ground Biomass (BGB) were calculated using allometric equations. Carbon stored in the roots was calculated from the default values for the shoot/root ratio (SR-ratio) of 4:1 for humid tropical forest on normal upland soils (Saatchi *et. al.*, 2011).

The DBH was converted to AGB using allometric equations as per the forest stands empirical regressions as follows (Chave *et.al,* 2005):

$$AGB= \rho*\exp(-0.667+1.784*\ln(D)+0.207(\ln(D))^\wedge 2-0.0281(\ln(D))^\wedge 3)$$

Where:

$\rho$ = wood specific gravity = oven–dry wood over green volume (g/cm$^3$). The mean $\rho$ for tropical forests Africa is estimated to be 0.5 g/cm$^3$.

D = tree diameter at breast height (1.3 m)

The AGB was converted into shoot carbon estimates by multiplying by 0.5 on the assumption that on average the dry carbon mass is 50% of dry wood mass. To get the shoot + roots carbon, shoot carbon were multiplied by 1.25 on the assumption of shoot: root ratio of 1:4 (Chave et.al, 2005).

The difference in carbon stocks between different land uses was analyzed using a one-way

ANOVA in Minitab statistical software (Release 13.32). A linear regression analysis was used to estimate the rate of carbon stock change in different land use changes.

The soil organic matter samples were analyzed in the soil laboratory following the standard soil laboratory analysis procedures as described by Nelson and Sommers (1975) and Okalebo et al., (2002). The data collected from the soil samples was categorized according to land use/cover for comparisons by an application of two way NOVA (p<5) using Genstat software to separate the means.

## 3. Results

### 3.1 Extent of Land Use Change between 1995 and 2013 around Mt. Elgon

Analysis of land use change between 1995 and 2013 revealed indicative change within the four land use types (intact forest, agriculture regenerating and restoration forest (recovery forest) as presented below;

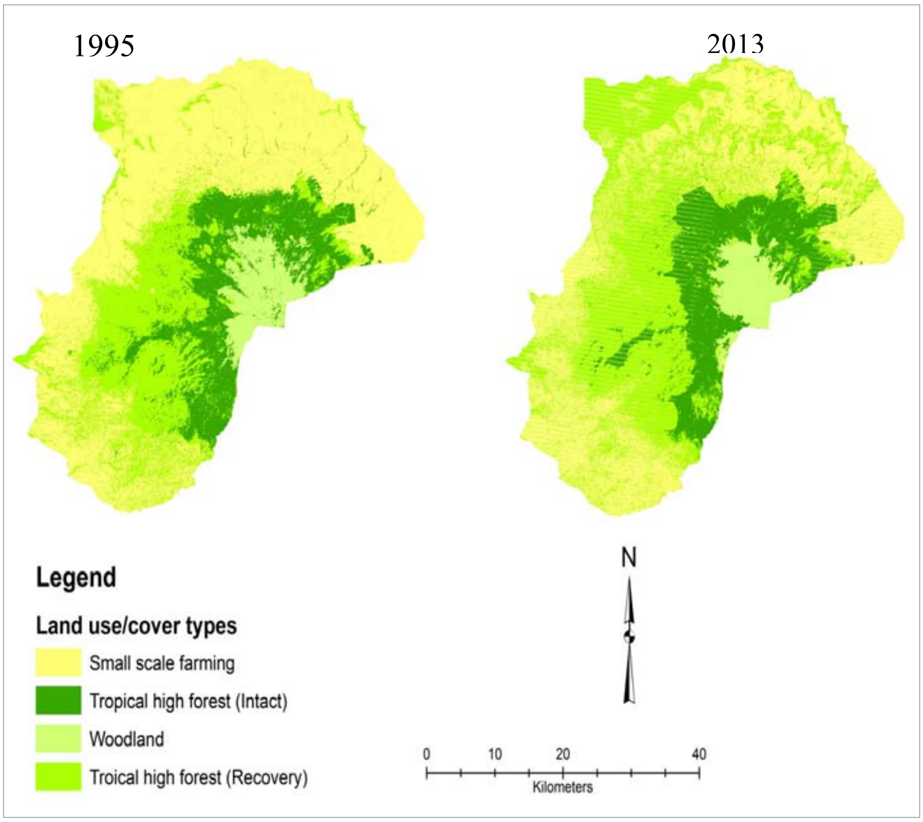

Figure 2. Land use/cover change maps between 1995 and 2013

Small scale farming/agriculture land reduced from 2083sq.km to 1623.6sq.km, tropical/intact forest declined from 692.2sq.km to 675.9sq.km; whilst forest under recovery increased from 1173.7sq.km to 1708.6sq.km and woodland/plantation reduced from 250.1sq.km to 189.6sq.km.

Table 1. The extent of land use change between 1995 and 2013

| **land use/cover type** | **1995** | | **2013** | | **Change** | |
|---|---|---|---|---|---|---|
| | **sq.km** | **%** | **sq.km** | **%** | **sq.km** | **%** |
| Agriculture | 2083.6 | 49.6 | 1623.6 | 38.68 | -460 | 42.92 |
| Tropical high forest (Intact) | 692.2 | 16.5 | 675.9 | 16.10 | -16.3 | 1.52 |
| Tropical high forest (Recovery and regeneration) | 1173.7 | 27.9 | 1708.6 | 40.70 | 534.9 | 49.91 |
| Woodland/plantation | 250.1 | 6.0 | 189.6 | 4.52 | -60.5 | 5.65 |

### *3.2 Average Carbon Stocks in Different Land Uses*

Diameters at Breast Height (DBH) in each of the plots were converted to mean DBH per land use/cover. By using the AGB allometric equation and the shoot: root ratio estimates of humid tropical forests on normal soils of 4:1[40], the DBH was used to calculate the carbon and the average carbon stock was found to be 17.960 t/ha for restoration, 45.220t/ha for woodlots/plantation, 1.523 t/ha for Agriculture, 36.193t/ha for Regenerating, 121.612t/ha for Intact forest. The impact of land use change on soil carbon was found to be significant (p= 0.00791) in the top layers of the soil (0-10cm) and not significant (p=0.70968 and 0.73103) in the deeper layers (10-20; 20-30cm respectively).

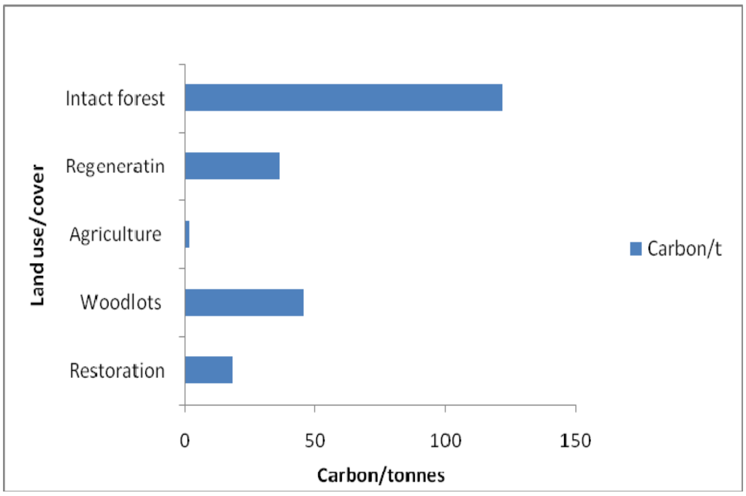

Figure 3. Carbon per land use/cover

### *3.3 Soil Organic Carbon in Different Land Uses*

Soil carbon was high in the intact forest, followed by woodlots, and lowest in restoration and agriculture as shown below.

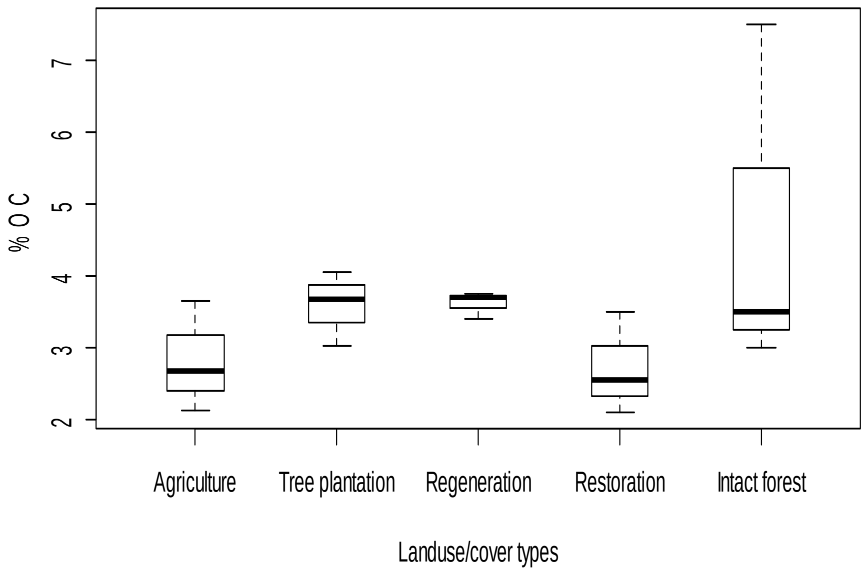

Figure 4. Soil organic carbon in different land uses/covers

### *3.4 Soil carbon in different soil depths*

Analysis revealed that Soil carbon was high in the top soils (0-10), followed by 10-20cm and lowest in soil depth of 20-30cm.

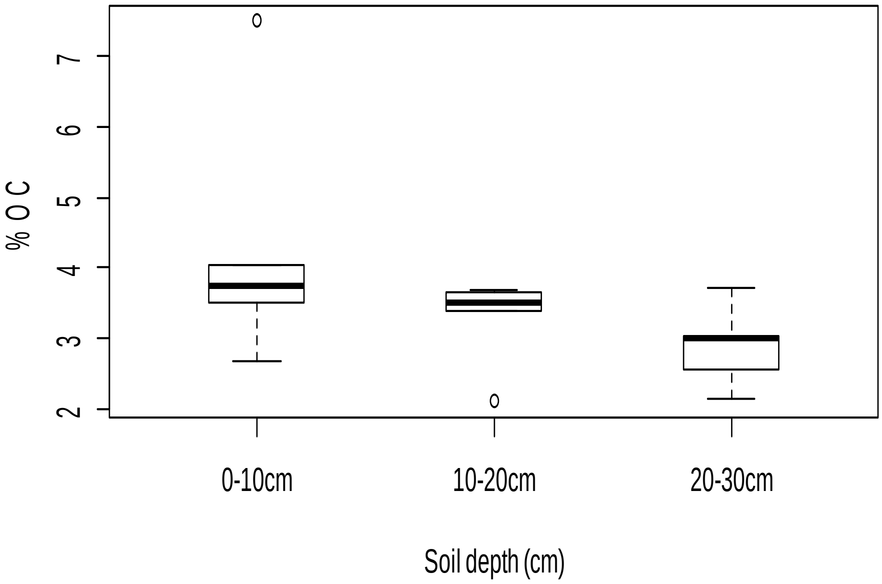

Figure 5. Soil carbon in different soil depths

### *3.5 Carbon from Litter*

As presented in the Figure below, carbon was high in regeneration, followed by restoration, intact forest, tree plantation and least in agriculture litter.

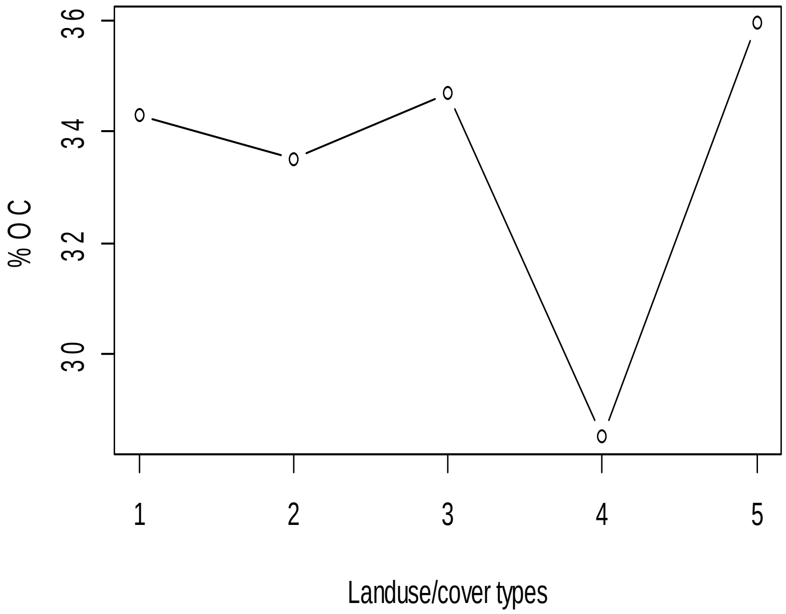

Figure 6. Carbon from litter in different land uses/covers

Legend: 1=Intact forest, 2=Tree plantation, 3=Restoration, 4=Agriculture, 5=Regeneration).

### *3.6 Impact of Land Use/Cover and Depth on Soil Carbon Stocks*

Intact forest registered the highest carbon stocks, while, agricultural land presented the lowest amounts. However, there was no statistical difference in carbon stocks amongst the different land uses ($p = 0.09$).

## 4. Discussion

### *4.1 Extent of Land Use Change*

Land use/cover changes are largely induced by land degradation resulting from increasing population pressure in search of settlement areas and farming areas (Kikula, 1990; Joseph et al., 2010). The largest land use conversion in East Africa over the last 50 years has been the expansion of agriculture. Similar studies by Mugagga et al. (2012) and Barasa and Kakembo, (2013), revealed progressive conversion of forests and woodlands to agriculture over the last forty years. The increase in regenerating/ restoration forests as found out in the present study could be attributed to the 1995 Uganda Wildlife Authority forest restoration programme , which enabled collaborative management and active participation of all stake holders in the management of Mt Elgon Forest. Within this programme, Mt. Elgon National Park was demarcated into six management zones (Wilderness zone, Integrated Resource Use zone, Tourism Zone, Administration zone, Recovery zone and Boundary zone) each being allocated specified activities, facilities and management regimes (UWA, 2011). The implication of this zoning on the observed land use changes is elucidated in the next sections.

#### 4.1.1 Intact Forest

The reduction of land under intact forest could be attributed to encroachment in search of fertile lands for cultivation since virgin forest land is usually perceived to be very fertile. However, it tends to lose its fertility in a few years, prompting further clearing of more forest (Ronell 1995). The intact forest is normally encroached by local communities because of poverty, diversification of livelihoods, need for land for cultivation, and settlement (Buyinza et al., 2008; Majaliwa et al., 2010; Mugagga et al., 2010). The impact of settlement pressures on forest cover around Mt. Elgon contributes to increased forest degradation. Rural poverty and the continued search for better income on short-term basis is a major driver for forest conversion (Majaliwa et al., 2010). Human survival is entirely dependent on direct consumption of environmental amenities; in particular forest products like food, medicine and firewood, and this accelerates deforestation. For forest adjacent communities, forest products contribute about 20% to household incomes (FAO 2010). In Africa, it is believed that 3.4 million hectares of intact forest are being lost annually. The main causes of this are logging, clearance for agriculture and wood fuel collection (FAO 2010). The deforestation in Mt Elgon began in the 1960s (Kitutu 2004) and since then most of the local forests outside the National Park, including all forests below 2000M elevation have been cleared and converted to agricultural land (Mugagga et al., 2011).

### 4.1.2 Regenerating and Restoration Forests

Enrichment planting of the former degraded, logged forests was being done to restore the natural forests that had been encroached on hence the increase of land under regeneration/restoration over the last two decades. The regenerating forests were heavily protected by the Park Authorities from further encroachment and degradation. Regeneration zones were created by the Park Authorities to protect the forests that were formally degraded and were now in the stages of regeneration (UWA 2010). The Park Authorities carry out sensitization meetings in the communities around Mt. Elgon on benefits of forest restoration. Studies have estimated that a minimum of 60 years is required for recovery to pre-logging conditions (Plumptre, 1996; Fashing et al., 2004). The intensity of disturbance is thought to be an important factor in determining the speed and specific pathway of forest recovery following disturbance (Chazdon, 2003). Some scholars such as (Claessens et al., 2007), have suggested reforestation with deep-rooted trees as an innovative strategy to effectively reduce the landslide hazard on certain landscape positions. This recommendation contributed to the increase in the restoration and regenerating land covers. Between 1993 and 2006 the Uganda Wildlife Authority was supported by the FACE Foundation, with finance from the Dutch Electricity companies, to re-establish forest growth through enrichment planting with indigenous trees in some 8,500 ha of the encroached forest inside the National Park.

### 4.1.3 Agriculture

According to the study agriculture land decreased by 42.92% between 1995 and 2013 which contradicts with studies done by Mugagga et al. (2012) in the same area; which revealed that between 1960 and 1995 land under agriculture had increased by 3.4%. Between 1995 and 2006, 2093 ha of National Park forest was lost to illegal expansion of agricultural fields on steep slopes at steady rate. The decrease in agricultural land was attributed to the increased sensitization of communities to embrace AgroForestry as a way of reducing poverty and protecting their soils from landslides (Claessens et al., 2007). Agriculture land which was previously acquired by encroaching on the protected forest / park was left to regenerate after the park authorities evicted the encroachers and started restoration programmes of the degraded forests and woodlots (UWA 2011). In 1996 the then Ministry of Water, Land and Environment in collaboration with UWA implemented The Mt. Elgon Conservation Development Project (ECDP) in response to threats to the Mt. Elgon ecosystem through agricultural encroachment and illegal resource exploitation (Hinchely et al., 2000). This involved restoring degraded lands due to agriculture/cultivation by planting trees in these areas and leaving others to regenerate naturally. Handling this problem required a combination of approaches including improved management of production forests, strengthening protected areas and restoring native forests using indigenous species.

#### 4.1.4 Woodlots/Plantations

Land under woodlots/plantations decreased due to the search for new lands for cultivation and settlements. Virgin lands like woodlands are usually perceived to be very fertile though it tends to lose its fertility in a few years, prompting further clearing of more forest (Ronell, 1995). The increasing population around Mt. Elgon exerts pressure on the free woodlots for more land for settlement, grazing and cultivation (UBOS, 2001). Studies reveal heavy encroachment on park environment by the communities for agriculture (Muwanga et al., 2001; Breugelmans, 2003; Bamutaze., 2004; Glade and Crozier, 2004; Kitutu *et al*., 2004; Knapen et al., 2006; Buyinza and Nabalegwa, 2008: Kitutu et al., 2009; Mugagga et al., 2010; Mugagga et al., 2012). The Park Authorities face challenges of limited resources, rugged terrain, and limited staff to control encroachment by communities (Hinchely et al., 2000; Majaliwa, 2010; Mugagga et al., 2012). Political interference is also the major challenge in controlling encroachment on the National Park (Mugagga et al., 2010). The tree plantations which were intended to serve as alternative sources for forest products that were formerly got from natural forest (Hinchely et al., 2000) are often harvested within a short period thereby compromising expansion.

### *4.2 Carbon Stocks in the Different Land Uses*

Carbon stocks were highest in intact forest and least in agriculture. This could be attributed to the number of trees, tree species, size of trees and other disturbances (Struhsaker 1997; Babaasa et al., 2004; Bonell, 2011). Agricultural plots had very few small scattered trees, whilst plantations had very many trees though composed of one species compared to intact forest that was comprised of several species. Some trees species are fast growing compared to others and attain different sizes at maturity e.g. *Ficus exasperate* (Chapman et al., 2004). Intact forest had a greater number of tree species with largest DBH and most of these were not found in regenerating and restoration forest. The species in intact forest included; *Milicia excelsa, Cordia africana, Ficus exasperate* and *Olea welwitschii.*

#### 4.2.1 Carbon in Woodlots/Plantations

The management purpose of the forest plantation determines the amount of carbon stocks in the trees (Kabogozza, 2011). For example, plantations may be established for timber, shelter belts, orchards, or fuel wood, and the carbon stocks in biomass consequently vary. Whether plantations are established on non forest lands or on recently cleared forests also affect the net changes in biomass and soil carbon (Kabogozza, 2011). From the results it was found that the establishment of plantations on forest lands generally decreased soil carbon stocks. In another review, it was revealed that plantations established on agricultural lands (both croplands and pastures) lost soil carbon during the first 5–10 years but gained it over periods longer than 30 years. The changes in soil carbon were generally small relative to the gains in biomass (Paul et al., 2002).

### 4.2.2 Carbon in Regenerating and Restoration Forests

Heavy logging or disturbance of an intact forest leaves it degraded requiring restoration measures to allow the forest to regenerate and recover from the disturbance effects (Chapman, 1997). The rate of carbon loss due to disturbance is highly uncertain, largely because the areal extent of disturbance is difficult to measure (Asner et al., 2003). In other cases the soils may gain carbon or show no discernable change (Smith and Johnson, 2003). The forests under regeneration and restoration stored less carbon compared to intact forests. Accordingly, a heavily disturbed forest takes a period 60 years to restore all the carbon lost and fully recover (Fashing et al., 2004). The ecology of the regenerating forest plays an important role in its response to recovery and effects on carbon stocks (Picett et al, 1987; Chazdon, 2003). For example the species distribution and variety in the regenerating forest will determine the tree composition at recovery and hence the carbon it stores.

### 4.2.3 Organic Carbon from Litter and Soil

Organic carbon was found to be higher in the intact forest and least in agricultural land. The high organic matter in the regeneration and restoration land uses could be attributed to the higher temperatures associated with the younger vegetation as a result of a less dense canopy. Similar studies observed that the breakdown of fresh litter can be quite rapid in temperate and cool climates to a few months in the tropics and that litter decomposition rates can be slow on cold, dry, or nutrient poor soils (Fisher *et al.,* 2000).

Soil carbon was more in top layers of the soil because of the logarithmic nature of carbon with depth, the majority (60% on average) of carbon is found above 40 cm and more than 40% in the top 20 cm (Nantumbwe, 2005). The higher in the profile, the greater influence land use change will have on the carbon levels. This is because surface layers contain the most labile carbon sources which are easily decomposed by soil microbes. Therefore, if carbon inputs are reduced, the microbes will continue to decompose the existing organic matter until the majority of the carbon will exist as stable and inert complexes (Nantumbwe, 2005).

## 5. Conclusions and Recommendations

Agricultural activities have generally decreased within the Protected National Park, whilst, forests are regenerating in areas previously encroached. This is clear evidence that Uganda Wildlife Authority’s efforts to restore forest cover are bearing fruit; which has been possible owing to the active involvement of all stakeholders. Such efforts ought to be extended to other areas where encroachment is still persistent, so that, Mt. Elgon forests’ potential as a carbon sink is harnessed for the region's benefit. There is urgent need to reverse the detrimental land use changes such as loss of intact forests and woodlands so as to enhance terrestrial carbon stocks whose implications on climate stability have been well documented. To this effect, reforestation and tree planting programs ought to be enhanced to cover more areas as this presents an opportunity for increased carbon sequestration. This however requires the active participation of all stakeholders, including the local communities, local leaders and Park Authorities to ensure compliance, long term ownership and sustainability.

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