Carbon Storage Potential of Trees Outside Forests under Private and Communal Tenure Regimes in Ng'iresi Village, Arumeru District, Tanzania

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Abstract: ***Trees outside Forests (ToF) are described as trees on land not defined as forest and other wooded land. This study was carried out to determine carbon storage potential of Trees outside Forests (ToF) that fall on private and communal tenure regimes in Ng'iresi village, Arumeru district, Tanzania. Stratified random sampling was used and the village was stratified into 5 main strata; trees around homesteads, agroforestry, woodlots, natural springs, and trees growing in line plantings (along borders of farm blocks, village roads and "Songota" river and its tributary known as "Maridadi"). Trees were measured for diameter at breast height (dbh) and total height for the computation of stand parameters; Number of stems per hectare (N), Basal area per hectare (G), Volume per hectare (V) and Carbon per hectare(C). In addition trees basic densities were obtained through laboratory analysis of the tree cores taken at dbh point. The results show that ToF occupied 56% of total area of village land (326 ha). About 99% of ToF land in the study village was part of private tenure regime. Student's t-test revealed that ToF under communal tenure regime stored significantly higher amount of carbon (P<0.05) averaged at 40.35 tC/ha than for private tenure regime estimated at 8.16 tC/ha. Generally, the stock parameters (N, G, V and C) of communal tenure regime were higher than for private tenure regime presumably due to type of management in the former which favours less harvesting of trees so as to conserve the natural springs. It is worth investing on communal ToF land , especially around natural springs/water sheds so as to get extra benefits including carbon storage benefits. ToF should not be ignored in land use planning and development polices at village level (and even at district and national level as they appeared to cover a large area in rural setting. Since best methodologies in assessing ToF are either inadequate or even lacking further study should be made to develop best methodologies for assessing ToF at a given locality. Provided that Grevillea robusta was revealed in this study to dominate ToF in the study area, further studies are welcome to ascertain its popularity among other ToF species.***

Keywords: Trees outside Forests; Ng'iresi village;carbon;carbon storage potential; private tenure regime; communal tenure regime; Arumeru district; Tanzania.

1. Introduction

Trees outside Forests (ToF) are defined as trees on land not defined as forest and other wooded land (FAO, 1998; 2010). Based on this definition, ToF would comprise: (i) trees on land that fulfill the requirements of forest and other wooded land except that the area is less than 0.5 ha ; (ii) trees able to reach a height of at least 5 m at maturity in situ where the stocking level is below 5 percent; (iii) trees not able to reach a height of 5 m at maturity in situ where the stocking level is below 20 percent ; (iv) trees on boundaries, scattered trees and woodlots less than 0.5 ha. (v) permanent tree crops such as fruit trees and coconuts; (vi) trees in shelterbelts and riparian buffers of less than 20 m wide and area of 0.5 ha (FAO, 1998). This study was made on Homestead plantation, Trees in mix with other crops (agroforestry), Trees in line-plantings (Roadside plantation, Riverine trees, and Boundary trees), Woodlots and Trees around springs.

A recent study on ToF has revealed their distribution at a global scale that about 46% of the agricultural land in the world (more than 1 billion ha) has tree cover of more than 10% (Zomer *et al*., 2009). The total area of other wooded land with tree cover was estimated at 79 million ha, but is undoubtedly much higher as information availability was limited (FAO, 2010).

During the 1980s and 1990s, ToF, began to be viewed in terms of their contribution to the environment. It is becoming increasingly clear that the future of trees in Africa is on farmland and other areas outside forests (FAO, 1999). It has been reported that the number of trees on farms is increasing (FAO, 2005) while forests are still being severely degraded. Tenure changes and increased pressure on forest resources, has resulted into establishment of ToF (Lund, 1999).

Interestingly, there is evidence that the increase in on-farm tree numbers occurs in areas where population densities are high and farm size is very small (Leakey, 2010). From a local perspective, there may be more interest in maintaining and improving ToF than forest lands especially if the improvement will benefit the farmers and the local community (Lund, 1999). Though people are getting benefits by favour of ToF in form of lumber, firewood, fruits honey and such products, little has been documented on their potential in carbon storage. It is believed that ToF contain more total wood biomass (Holmgren *et al*., 1994), hence large carbon stocks (van Noordwijk *et al*., 2009), because more land is involved (Holmgren *et al.*, 1994). However, in most countries, ToF are poorly reported in most of official national statistics used to support national decision-making and policy. Generally, the basic information such as location, number, species, spatial organization, biomass, growth and production is often lacking. ToF are thus most often ignored in land-use planning and development policies (FAO, 2010). As carbon storage potential of ToF will be known and mechanisms set at hand, tree owners can enjoy the carbon benefits at a global market.

Ever since attention had increased overtime on carbon trading and mitigating climate change, an enormous need on good accounts of all possible carbon sources and sinks is of no dodging. This study focused on carbon storage potential for ToF, not only because it was a forgotten treasure to be accounted on its carbon storage and other uses but also due to what Holmgren *et al.*, (1994) asserted ToF as the ones most likely to be used by local farmers and villagers. It was thus found very imperative, to study on ToF whose benefits and costs are reflected in the daily life of most people in rural scenery.

The main objective of this study was to assess carbon storage potential of Trees outside Forests under private and communal tenure regimes in Ng'iresi village landscape in Arumeru district, Tanzania. Specifically, the study aimed to identify and determine areas of land occupied with ToF; to identify the species composition of ToF; to estimate stocking of the ToF and to compare stocks of ToF under private and communal tenure regimes in the study village. Understanding carbon stock of ToF under private and communal tenure regimes would bring awareness and enlighten both policy and decision makers on incorporating the ToF carbon values in land use planning.

2. Study Area and Methods

2.1 Study Area

2.1.1 Site description

The study was conducted in Ng'iresi village in Arumeru District, Arusha, Tanzania. It is located about 6.5 km east of Arusha Town. The village is found at the windward side of mount Meru 4 562 m.a.s.l) at an approximate grid reference $36^0$42'50''E; $31^0$9'36''S and $30^0$20'S; $36^0$45'00''E (Fernandes *et al.*, 1984). The village borders Mount Meru Forest to the north and Oldadai village to the south. It also borders Ebangata village and Songota River to the east. To the west the village borders Olgilai village and Kivesi Mountain (Ng'iresi village executive officer, personal communication, 2010). Topography of the village is undulating.

2.1.2 Soils and climate

Soils are originating from volcanic ash varying from Mollic Fluvisols to Alic Andosols. Ng'iresi village lies in the climatic zone of sub-humid highlands and rainfall reaches to 2000 mm annually. The temperature ranges from 12 to 30°C (Kaihura *et al*., 1998). Rainfall pattern in the village is bimodal. It experiences long rain season from March to May and short rains from November to December (Fernandes *et al.*, 1984). The village is among the areas in Arumeru district where land scarcity is a big challenge.

2.1.3 Flora and fauna

a) Flora

Permanent tree crops planted are *Grevillea robusta* (silk oak), *Pinus patula* (pine), *Cupressus lustanica* (cypress), *Olea capensis* (east african olive), *Ficus cycomorus* (sycamore fig), *Markhamia lutea* (bell bean tree), and many others. Fruit trees like *Citrus cinensis* (orange), *Citrus limon* (lemon), *Citrus reticullata* (tangelin), *Annona squamosa* (custard apple), *Annona muricata* (custard apple), *Mangifera indica* (mango), *Persea americana* (ovacado), *Carica papaya* (pawpaw) and *Punica granatum* (pomegranate) are found in the village. Other plants include C*offea robusta*, *Saccarum spontaneum* (sugarcane)and *Musa* spp. (banana) (Personal observation, 2010).

b) Fauna

The fauna found in Ng'ilesi village are *Cercopithecus pygerythrus* (vervet monkey), *Papio cynocephalus* (baboon) and *Potamochoerus larvatus* (bush pig) which are coming from Kivesi Mountain forest and Mount Meru forests especially during dry seasons (Ng'iresi village executive officer, personal communication, 2010). Other fauna include *Cryptomys hottentotus* (mole-rat), S*accostomus campestris* (pouched mouse) which like the above animals destruct farmers' crops (Ng'iresi village executive officer, personal communication, 2010). Some domestic animals kept in the village are *Bos taurus* (cattle), *Capra hircus (*goat), *Ovis aries* (sheep), *Potamochoerus parvifolia* (domestic pig), *Felis catus* (cat), *Canis familiaris* (dog), and *Equus asinus* (donkey) (Personal observation, 2010).

Some villagers keep *Gallus domesticus* (domestic fowls*)*, *Guttera pucherani (*guinea fowl, kanga in Swahili), *Anas platyrhncha* (domestic duck) and *Anser domesticus* (domestic goose). *Anas sparsa* (water ducks) are found in Songota River. (Personal observation, 2010).

2.1.4 Drainage

The village is drained with Songota River and its tributary known as "maridadi." The River never dries up and originates from Meru Forest reserve. Water from Songota River and maridadi stream is mainly used for irrigation purposes. The village has five (5) natural springs known as Lesendu, Ngoikaa, Mbayani, Engichoru and Manina. The springs also never dry up. The water from the five springs is drawn for domestic uses. The springs are under communal management of the people found in each hamlet but under the supervision of the village environmental committee (Ng'iresi village executive officer, personal communication, 2010).

2.1.5 Population and Economic Activities

The population of people in this village is estimated at 4 114. The inhabitants are mostly farmers of "Waarusha" tribe. Most of the women and sometimes children, in this village are engaged in firewood business. It is a common practice to see women carrying bunch of firewood to sell in town. The demand for firewood and other wood products is high both for household and industrial use in Arusha municipality

(Ng'iresi village executive officer, personal communication, 2010).

2.2 Methods

This study was carried out in two stages. During stage one a reconnaissance survey was carried out in the study village in order to become acquainted with the study area, do village boundary tracking and stratification into different tenure regimes and land use categories. Additionally, a survey was done in each stratum to estimate the variance in tree stocking. For this purpose, basal area was measured using relascope (with BAF=1) from two sample plots established randomly in each stratum. This allowed an estimation of the number of sampling units that were needed to carry out a major inventory.

The number of sampling units needed for a major inventory was calculated using equation 1.

$$n = \frac{N\sum N_i S_i^2}{\frac{N^2E^2}{t^2} + \sum N_i S_i^2} \text{ (Malimbwi,1997)} \qquad (1)$$

Where: n =number of sampling units required for a major inventory, N_i =area of a given stratum, N =total area of all strata, t = expression of confidence that true average is within the estimated range, E = Allowable error and S_i^2 =variance for a given stratum

In this study the allowable error (E) was decided to 0.4078 m^2/ha, being 10% of mean basal area per ha which was estimated to 4.078 m^2/ha. The expression of confidence that true average is within the estimated range (t) was taken as 2. The number of sampling units needed to be allocated to each stratum/sub-stratum was thus calculated using the method of optimum allocation as indicated in equation 2:

$$N_i = \left(\frac{N_i S_i}{\sum N_i S_i}\right)n \text{ (Malimbwi, 1997)} \qquad (2)$$

Where: n = total number of sample plots need for a major inventory.

Stage two involved major inventory of 43 sampled plots. The areas of these plots ranged from 0.05 ha to 0.5 ha and the average sample plot measured 0.2 ha. For line features of ToF, like roadsides and riverine tree plantings, plot sizes used were laid at 10 m x 100 m on each side of the road and/or river as suggested by Prasad *et al.* (2001). Other line-plantings which measured less than 100 m length (like ToF bordering farms/other crops in one side) a plot chosen at random was established at 10 m times available length. For ToF bordering crops in many sides their plot size were taken by summation of; 10 m x length of each side.

The size of sampling frame for each stratum/substratum consisted of 5 units of spring, 19 blocks of woodlot, 627 blocks of homestead and 190 blocks of agroforestry. The sampling frame for line-plantings involved; 84 strips of 10 x 100 m from approximately 8.403 km total length of the eight identified roads in the village, 196 blocks of trees bordering other crops in four sides, 137 strips of trees bordering other crops in single side and 50 strips of 10 x 100 m from approximately 5 km total length of both the Songota River and Maridadi stream.

The sample plots were laid in each stratum at random. For this case each and every plot was chosen equiprobable of the other. All trees in a selected plot were measured. Tree measurements made include dbh ≥ 5cm typically measured at 1.3 m above ground using a calliper. Heights of standing trees were measured using hypsometers. Trees dbh of all trees and height of sample trees (mostly trees with smallest, medium and largest diameter) were measured directly in the plots. Basic densities of only 14 out of 59 tree species sampled were found in Bryce (1967). Increment borer was used to extract cores (at dbh point) of 45 trees (out 59 identified) whose basic density was not indicated in Bryce (1967). Laboratory data was collected by analysis of the 45 wood cores to obtain basic density. Appendix 1 shows the basic density of all 59 trees sampled in this study.

2.2.1 Data analysis

a) Estimation of tree stock (basal area, volume, biomass and carbon)

i) Basal Area (BA) and Tree volume

Basal area was estimated using the general formula for calculating basal area of trees. Tree volume was estimated using the formula:

Tree Volume =Basal area*Height*form factor (estimated at 0.5).

Tree dbh and heights of sample trees were used to fit a height dbh equation that was used to estimate heights of trees not measured in the field. The dbh height model fitted is indicated by equation 3 as follows;

$$H = 0.5022dbh+5.1001 (R^2 = 0.69, n = 186) \qquad (3)$$

Whereby:
H =Height (m), dbh =diameter at breast height (cm), R^2 = coefficient of determination, n = number of observations

ii) Estimation of biomass and Carbon

The tree biomass was estimated as a product of total tree volume and its wood basic density as suggested by (Negi *et al*, 2003; Munishi and Shear, 2004). Carbon was estimated using the formula; Carbon (kg) = 0.49 x Biomass (kg) (MacDicken 1997 and Brown, 2003).

iii) Plot and stand parameters

Plot parameters were estimated as a summation of all tree stock values in a plot. Stand parameters were estimated as a ratio of plot parameter to plot area as indicated below (equation 4)

$$\text{Stand parameter} = \text{Plot}\left(\frac{parameter}{area(ha)}\right) \qquad (4)$$

iv) Comparing stock values between state and private tenure regimes

Student's t-test was used to compare the estimated carbon data between private and communal tenure regimes. The F-test was conducted prior to running the t-test and decision was made on the use of a paired t-test assuming equal variance as an appropriate test to compare the means of stock values between private and communal tenure regimes.

Results and Discussion

3.1 Areas of land occupied with ToF under private and communal tenure regimes in the study village

The total land area in the studied village was 326 ha. Results from this study show that the area of land occupied by ToF is about 56% of the total village land area. Appendix 2 shows general view of the village. A detailed description of identified five main categories of land occupied with ToF in the study village is indicated under Appendix 3.

The first four categories fall under private tenure regime while the last falls under communal tenure regime. In terms of land area, ToF under private tenure regime accounted for 99% of ToF land and about 55% of total village land while those under communal tenure accounted for 1% of ToF land and about 0.4% of the whole village land. This finding is supported by Kleinn *et al.*, (2001) and Pandey (2008) who asserted that most of the ToF land which is under human management falls in private ownership of smallholders.

3.2 Species composition of ToF under private and communal tenure regimes in the study village

The species composition in the five strata is as follows; Stratum one (homestead) composed of 41 different tree species, stratum two (agroforestry) 15 tree species, stratum three (line-plantings) 24 tree species, stratum four (woodlot) 16 tree species and stratum five (springs) composed of 17 tree species (Appendix 4).

The 15 tree species encountered in agroforestry are higher than 8 tree species recorded by Mugasha (2009) in Matombo, Morogoro, Tanzania. A total of 59 tree species were identified in this study and are higher compared to number of species reported for ToF project (2000) in Cañas, Guanacaste where pasture bordered by trees constituted 40 tree species but 69 tree species were enumerated for pasture not bordered with trees. Also this study reports higher number of species than 11-40 ToF species enumerated by Yossi and Kouyaté (2002) and 20 species of ToF reported by Kojwang and Chakanga (2002) both conducted in Mali. Additionally Glen (2002) in Sudani reported lower species composition estimated at 33 tree species.

ToF were found richer in species, likely due to deliberate planting of different tree species, especially for category of ToF around homesteads so as to meet different family and/or people uses as would be deemed necessary.

As indicated in Appendix 3, seven species were found distributed in all five strata. These are *Grevillea robusta, Croton macrostachyus, Jakaranda mimosifolia, Markhamia lutea, Persea americana, Pinus patula* and *Rauvolvia caffra.* In communal tenure regime, the dominant tree species was *P.americana* as illustrated in Figure 1.

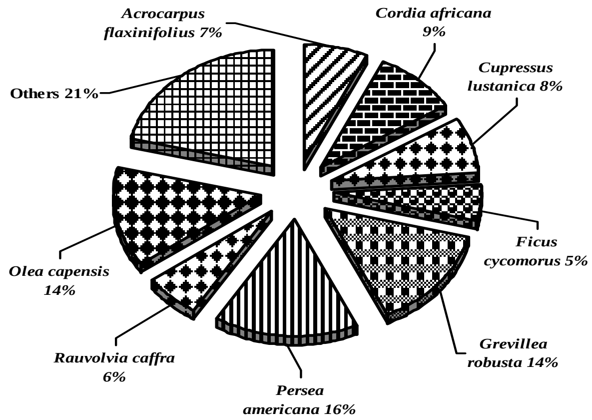

Figure 1: Species dominance in communal tenure regime in Ng'iresi village

The reason for its dominance is probably due to what Holding *et al.,* (2004) reported that fruit trees like *P.americana previously* grown as a source of fruits, was now also being converted to timber and firewood for commercial purposes in the lower zones of Kenya.

G. robusta was a dominant species in private tenure regime as denoted by figure 2.

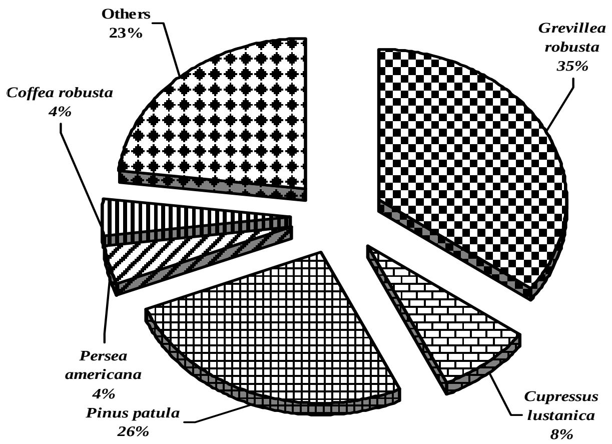

Figure 2: Species dominance in private tenure regime in Ng'iresi

G. robusta found to dominate the village probably due to its recognized potential in increasing farmers' income in terms of timber, poles, firewood, and fodder. The species also provide shade due to its less competition with adjacent crops. Kweka *et al.* (2007) observed that ninety six percent (96%) of the farmers who grow trees do so for business and/or for financial security.

Literature reveals further that *G. robusta* was both most abundant and as the single most readily traded species grown on farms (Holding *et al.*, 2004). Ngayambaje and Mohren (2011) report that most farmers in Rwanda use *G. robusta*, to demarcate farm and plot boundaries, stabilization of roads and windbreaks. In addition to fuelwood, the species is also used for construction poles and timber. *G. robusta* is used as a windbreak tree presumably due to fact that the tree may grow high enough (at favourable conditions) and its spreading branching system protect other plants from mechanical damage by strong wind, high rates of transpiration and surface evaporation. Munishi (2007) on his study on distribution and diversity of ToF in the southern sides of Mount Kilimanjaro found that *G. robusta* was commonest tree species found at the area. Apart from the above opinions on the popularity of *G. robusta*, also its popularity might be caused by probability of leaf litter from the plant to naturally fertilize the soil.

3.3 Estimating and comparing stocking of the ToF under private and communal tenure regimes in the study village.

3.3.1) Number of stems per hectare (N)

Table 1 shows the tree stocking levels in terms of number of stems, basal area, volume and carbon per hectare for the five categories of ToF in the studied village.

Table 1: Socking levels of the five strata observed in this study

Stratum	N	G	V (m^3/ha)	Biomass (t/Ha)	Carbon (t/Ha)
1	192 ± 25	4.07 ± 0.58	30.41 ± 4.60	14.41 ± 1.84	7.06 ± 0.90
2	149 ±43	2.57 ± 0.52	18.06 ± 4.94	8.73 ± 1.89	4.28 ± 0.92
3	211 ± 29	4.56 ± 0.61	39.72 ± 7.06	20.53 ± 3.49	10.06 ± 1.70
4	497 ± 134	5.79 ± 0.75	39.29 ± 6.02	21.02 ± 2.80	10.30 ± 1.37
5	295 ± 75	16.72 ±2.65	176.16 ±31.3	82.35 ± 9.85	40.35 ± 4.83

Results in Table 1 show that the average density of trees was highest in stratum four(woodlots) compared to other strata. This stocking is also higher compared to 400 stems/ha reported by Munishi *et al.,* (2004). Stratum two (agroforestry) had the lowest tree density (about 149 stems/ha) for provision of enough space for other crops in the system. The tree density in the strata one (trees around homesteads) was estimated at 192 stems/ha and the figure is higher than what was reported by Pandey (2002b) in state of Kerala India where homesteads contained 113 trees/ha. Also this study reports higher tree stocking than 180 trees/ha, in home gardens reported by Rawalt *et al*., (2002). Strata three (trees in line plantings) had 211 stems/ha which can be compared with 250 stem/ha of trees in hedgerows, reported by Bertomeu (2006).

A comparison of the stocking levels between communal and private regimes is shown in table Table 2.

Table 2: Comparison of mean for the five parameters sampled in the two tenure regimes

Parameter	Private	Communal	P value	Calculated/test statistic	Critical/ tabulated t-value	Ruling claim
	Mean 1	Mean 2				
N	229	295	0.60	-0.53	2.02	mean 2 not significantly greater than mean 1
G	4.1892	16.7176	2.57E-09	-7.58	-2.02	mean 2 significantly greater than mean 1
V	32.9455	176.1597	1.9E-10	-8.40	-2.02	mean 2 significantly greater than mean 1
Biomass/ha	16.6427	82.3466	4.35E-08	-6.74	-2.02	mean 2 significantly greater than mean 1
Carbon/ha	8.1549	40.3499	4.35E-08	-6.74	-2.02	mean 2 significantly greater than mean 1

Though number of stems per hectare was statistically not different (P >0.05) between private and communal tenure regimes (Table 2), on aggregate the average stems per hectare in private tenure regime are lower (229 stems/ha) compared to communal regime (stratum five) with 295 stems/ha. This is because stratum five (trees around springs) composed of standalone trees while other strata are composed of trees mixed with other crops. Due to owner's free access for ToF under private tenure, trees might be highly exposed to harvesting than for ToF under communal tenure regime where access is restricted by community members.

The overall mean tree density of ToF in the study village was estimated at 232 stems/ha. This can be compared with findings by Njuguna *et al.,* (1998) on tree farms in Kenya who reported tree density of 250 trees/ha. In their study on ToF, Sangeda *et al.,* (2001) reported lower tree density than this study ranging from 47 ± 4 stems/ha to 67 ± 6 stems/ha. ToF Project (2000) reported lower mean tree density in pasture bordered by trees and one not bordered by trees estimated at seven and nine trees/ha respectively. Another comparison, is made to Yossi and Kouyaté (2002) who studied a ToF in Mali and came up with stocking density of 8-20 stems/ha in village fields which had been cultivated over a long period of time. A ToF study done by Mhirit and Et-Tobi (2002) in Morocco, reports stocking of carob tree (*Ceratonica siliqua L.*) of estimated at 16 stems/ha.

The mean tree density distribution for private tenure regime was highest in dbh class (5cm-20cm) about 198 stems/ha and most negligible in dbh class (>60 cm) about 0.22 stems/ha as shown in figure 3.

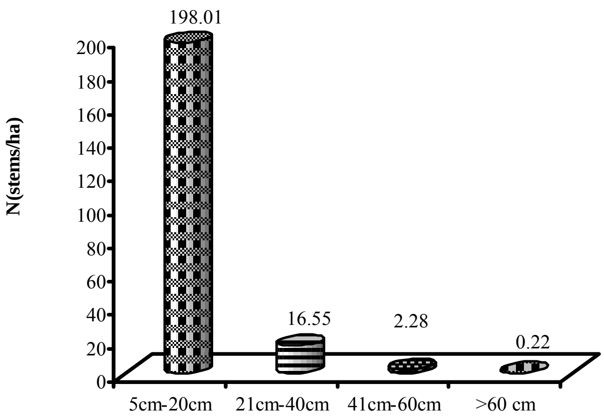

Figure 3: Distribution of number of stems/ha for private ToF tenure regime in Ng'iresi village

Likewise, in communal tenure regime the mean tree stocking was found highest in dbh class (5 cm to 20 cm) about 156 stems/ha and lowest in dbh class (>60 cm) about 3 stems/ha as indicated in figure. 4.

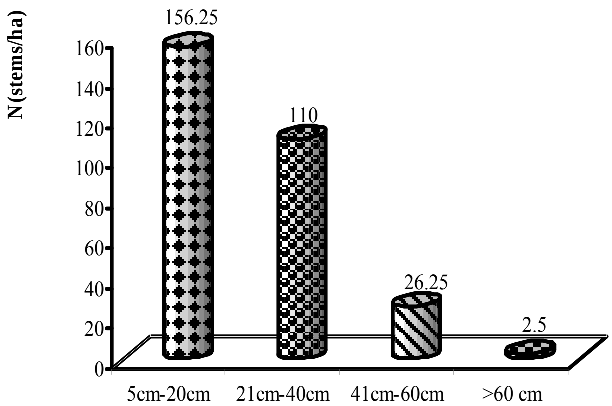

Figure 4: Distribution of number of stems/ha for communal ToF tenure regime in Ng'iresi village

Distribution of number of stems/ha in the strata under communal tenure regime (natural spring) follows a reversed J-shaped trend as expected for a naturally grown forest with active regeneration and recruitment (Philip 1994). This is not the case with the strata under private tenure regime where most of the trees are not naturally grown.

3.3.2) Basal area, Volume and Carbon per hectare

a) Basal area

Results reveal that average basal area was highest in stratum five while stratum two had the lowest basal area (Table 1). Based on the types of tenure regimes, average basal area per hectare was statistically higher ($P<0.05$) in communal tenure regime than for private tenure regime (Table 2). These values are within the range reported by Sangeda *et al.*, (2001) on ToF where basal area was found to vary between 4.12 ± 1.01 to 8.61 ± 3.00 m^2/ha. However the basal area for communal tenure regime is higher due to dense population of large trees as pointed out in section 3.3.1.

Fig.5 and 6 below show mean basal area distributions in the four dbh classes for the two tenure regimes.

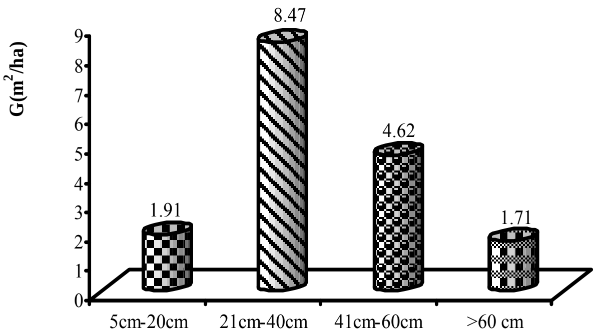

Figure5: Distribution of basal area/ha for communal ToF tenure regime in Ng'iresi village

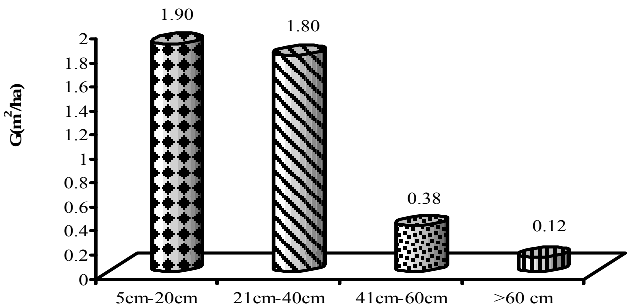

Figure 6: Distribution of basal area/ha for private ToF tenure regime in Ng'iresi

Basal area in communal tenure regime was higher in dbh class 21 cm to 40 cm while dbh classes "5cm to 20 cm" and "60 cm" contained trees with least basal area. For the private tenure regime, basal area was high in dbh class of 5cm to 20 cm (about 1.98 m^2/ha) almost equal to that of dbh class of 21 cm to 40 cm (about 1.88 m^2/ha) and lowest in dbh class (>60 cm) estimated at 0.12 m^2/ha.

b) Volume per hectare

It was observed that the volume per hectare was highest in stratum five (trees along springs) and lowest in stratum two (agroforestry). ToF around springs showed highest volume due to tendency of people not to frequently remove trees around water sources avoiding disturbing the ecosystem around the watersheds, the practice that would have fostered drying of springs. Stratum three (trees in line plantings) and

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four (trees in woodlots) had almost equal volume per hectare (Table 1).

The volume per hectare in stratum one (homestead) of 30.41 m^3/ha is within the range reported Kumar and George (1994) where volume of home gardens ranged from 6.6 to 50.8 m^3/ha. Additionally this study reports higher volume than 26.6 m^3/ha reported by Pandey (2002) in homesteads of Kerala state, India. Volume of trees in line plantings is lower compared with 69 m^3/ha of hedge rows reported by Bertomeu (2006) in Philipines.

The volume per hectare was statistically higher ($P<0.05$) in communal tenure regime 176.16 m^3/ha than for private tenure regime 32.95 m^3/ha (Table 2) due to presumably trees with larger diameter observed in communal tenure than private tenure regime. These values are almost consistent with ToF volume in Machame ranging from 43.92 ± 12.22 m^3/ha to 104.68 ± 48.44 as reported by Sangeda *et al.,* (2001). Furthermore, volume reported in this study is higher than 19.9 m^3/ha reported by Njuguna *et al.,* (1998) and lower than 50 m^3/ha of ToF reported by Giri (2004) in Chasimba village Tanzania.

Results show that the diameter class "21 cm to 40 cm" for private regime contained trees with highest volume while diameter class ">60 cm" contained trees with lowest volume (Fig.7). For communal tenure regime highest volume were contained in dbh class "21 cm to 40 cm" but lowest in dbh class "5 cm to 20 cm" (Fig.8).

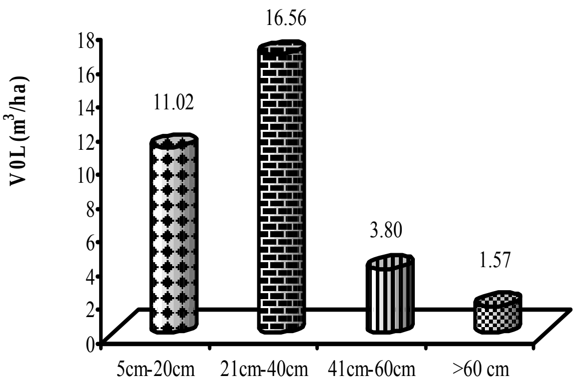

Figure 7: Distribution of volume/ha for private ToF tenure regime in Ng'iresi village

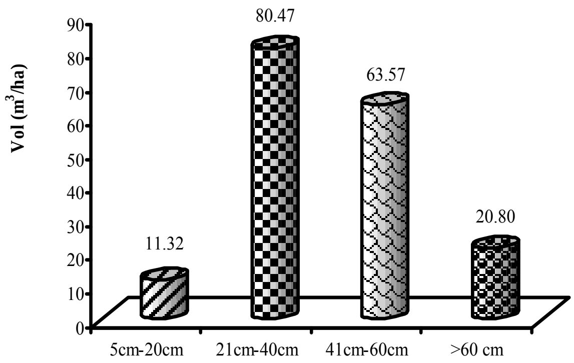

Figure 8: Distribution of volume/ha for communal ToF tenure regime in Ng'iresi village

c) Carbon per hectare (tC/ha)

Results show that, stratum five (trees along springs) contained the highest mean carbon per hectare while stratum two (agroforestry) had the lowest carbon per hectare followed by stratum one (homestead). Stratum three (trees on line plantings) and four (woodlot) had almost the same values for carbon per hectare (Table 1). The average carbon per hectare was statistically higher ($P<0.05$) in communal tenure regime than in private tenure regime. These values are within the range reported in Philippines tree farms by Sales *et al.,* (2005) where carbon figures ranged from 0.98 tC/ha to 63.94 tC/ha. In his study Mugasha (2009) reported that ToF contain 56 tC/ha out of 155 tC/ha stored in agroforestry systems (soil, herbs, litter, banana and trees) in Matombo village Tanzania. A study done by Seeberg-Elverfeldt *et al., (*2009) reported that the net carbon accumulation in three agroforestry systems to ranged from 17 to 18 tC/ha).

For communal tenure regime highest mean carbon values were falling in diameter class "21 - 40 cm" and lowest in diameter class "5 - 20 cm" (Fig.9) estimated to an average of 2.97 tC/ha. Results reveal further that diameter class "21- 40 cm" in private tenure regime contained highest mean carbon per hectare while lowest values were indicated in diameter class ">60 cm" (Fig.10). Fig. 9 and 10 below show the carbon distribution in the four diameter classes for the two tenure regimes.

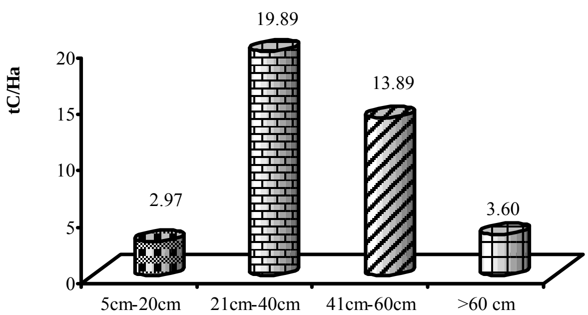

Figure 9: Distribution of carbon/ha for communal ToF tenure regime in Ng'iresi village

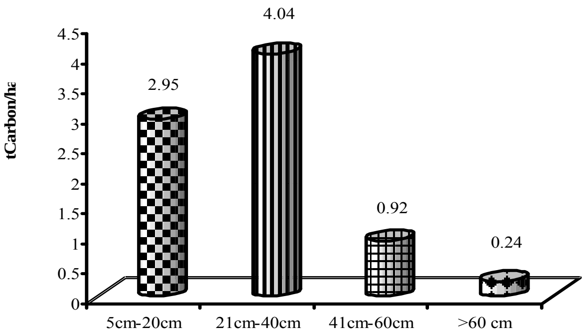

Figure 10: Distribution of carbon/ha for private ToF tenure regime in Ng'iresi village

Conclusions and Recommendations

3.1 Conclusions

This study has shown that ToF are found in two main categories of ownership, private and communal tenure regimes. A large area of land occupied by ToF around human environment falls in private tenure regime. In the studied village landscape, TOF appear in five main categories which are; trees in line plantings, agroforestry, homesteads, woodlots and natural springs. These ToF categories cover a large area (56% of total village land area of 326 ha) in rural scenery and are valuable to local farmers. A total of 59 tree species were encountered in this study. The dominant tree species were *G. robusta* and *P.americana* in communal regime. The stock parameters of communal tenure regime are higher than for private tenure regime presumably due to type of management in the former which favours less harvesting of trees so as to conserve the natural springs. Generally, the stock parameters (N, G, V, Biomass and Carbon) revealed in this study are consistent with findings of other ToF studies.

3.2 Recommendations

Based on the general field work and findings for this study, the following recommendations were worth given. Firstly, ToF should not be ignored in land-use planning and development policies at village level (and even at district and national levels) as they appear to cover a large area in rural setting. Dominance of two species *G. Robusta* and *P. americana* in the study village imply that smallholders decisively plant them due to immense benefits they provide. While *G. Robusta* provides valuable timber *P. americana* provides edible fruits. In addition to these benefits, people should plant more ToF in order to increase chances of tapping extra benefits including carbon.

Due to working within objectives of sponsor, budget and time limitations it was not possible to study on many aspects of TOF. This study thus recommends the following areas for further study.

- Provided that the best methodologies in assessing TOF are inadequate and almost lacking emphasis should put on developing best methodologies for assessing TOF at a given locality. This study has in one way or another adapted some conversion factors/figures established from forest trees, due to lack of models that express TOF.
- More research work should be made on fitting growth and yield models for TOF. For trees planted in mix with other crops studies need to be done to help in determination of both best spatial and vertical formation of trees and other crops.
- Since this study has revealed *G.robusta* to dominate ToF further study should be done to ascertain why it is popular among other ToF species.

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Appreciation is made to the Tanzania-Norway NUFU programme under the project on assessing the impact of forestland tenure changes on forest resource and rural livelihoods in Tanzania, for funding this study. Acknowledgment is extended to the Arumeru district council for giving permission to conduct the research in Ng'ilesi village. Special thanks go to Mr.Richard Alphonse and Canicius Kayombo their support in plant species identification.

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List of Appendices

Appendix 1: Wood basic density of tree species identified in the study village

SPECIESCODE	BASIC DENSITY (KG/M^3)	SPECIESCODE	BASIC DENSITY (KG/M^3)	SPECIESCODE	BASIC DENSITY (KG/M^3)
1	603	21	**545**	41	443
2	**689**	22	**721**	42	496
3	430	23	402	43	753
4	**545**	24	**465**	44	689
5	515	25	253	45	454
6	601	26	**801**	46	**529**
7	426	27	**609**	47	665
8	511	28	690	48	536
9	586	29	409	49	475
10	455	30	470	50	**423**
11	510	31	608	51	438
12	64	32	325	52	432
13	673	33	334	53	301
14	**449**	34	**609**	54	427
15	**609**	35	330	55	230
16	619	36	489	56	**705**
17	634	37	480	57	**550**
18	661	38	486	58	568
19	535	39	455	59	698
20	219	40	412		

- Values in bold indicate basic density indicated in Bryce (1967)
- Values not bolded indicate basic density obtained by laboratory data collection through analysis of wood cores extracted from different species.
- The corresponding botanical name of numbered species in appendix 1 (under species code column) can be found in the species botanical name under appendix 4.

Appendix 2: General view of the village

Appendix 3: The five main categories of land occupied with Trees outside Forests

a. Homestead plantation: Trees appearing in the villagers residences and especially around house premises

b. Trees in mix with other crops (agroforestry): Trees appearing in farms mixed with other crops such as banana, maize, beans and such crops.

c. Trees in line-plantings: Trees appearing in lines along village roads, river, stream and farm borders:

i. Roadside plantation: Trees appearing along sides of wide ways connecting different parts of the village

Riverine trees: Trees appearing along the sides of large natural stream of water in the village (trees along Songota River and its branch (Maridadi)

ii. Boundary trees: Trees planted along borders of farms to encompass other crops either on one side or four sides

d. Woodlots: Trees appearing in the premises of a piece of land (at mostly 0.5 ha) set aside for growing trees particularly for firewood, building poles, lumber and such uses

e. Trees around springs: Trees appearing at the premises of village land where water is naturally flowing from the underground

Appendices 4: Species composition /checklist of ToF in the study village

Species ode	Botanical name	Gener.	Private	Com*	Hom*	Agro*	Line*	Wood*	Spring
1	*Acacia meansii*	√	√	X	X	x	X	√	X
2	*Acacia melanoxylon*	√	√	√		x	√	x	X
3	*Acrocarpus flaxinifolius*	√	√	√	√	x	√	x	√
4	*Albizia gummifera*	√	√	X	X	√	√	x	√
5	*Anguelia madagascariensis*	√	√	X	X	√	X	x	X
6	*Annona muricata*	√	√	X	√	x	X	x	X
7	*Annona squamosa*	√	√	X	X	x	X	√	X
8	*Araucaria heterophyla*	√	√	X	√	x	X	x	X
9	*Basama abisinica*	√	√	√	X	x	√	x	X
10	*Bridelia micrantha*	√	√	√	X	x	√	x	√
11	*Callistemon speciousus*	√	√	X	√	x	X	x	√
12	*Carica papaya*	√	√	X	√	x	X	x	X
13	*Casuarina cunninghamiana*	√	√	X	X	x	√	x	X
14	*Cedrera odorata*	√	√	√	√	x		x	X
15	*Celtis africana*	√	√	X	X	x	√	x	√
16	*Citrus lemon*	√	√	X	√	x	X	x	X
17	*Citrus reticulate*	√	√	X	√	x	X	x	X
18	*Citrus cinensis*	√	√	X	√	x	X	x	X
19	*Coffea robusta*	√	√	X		√	X	x	X
20	*Cordia Africana*	√	√	√	√	√	√	x	X
21	*Croton macrostachyus*	√	√	X	√	x	√	√	√
22	*Croton megalocarpus*	√	√	X	√	√	X	x	X
23	*Cupressus goveniana*	√	√	X	√	x	X	x	X
24	*Cupressus lusitanica*	√	√	√	√	x	√	√	X
25	*Cussonia holstii*	√	√	X	X	√	√	√	√
26	*Diospyros mespiliformis*	√	√	X	X	√	X	x	X
27	*Ekebergia capensis*	√	√	X	X	√	X	x	X
28	*Eriobotyra japonica*	√	√	X	√	x	X	x	X
29	*Eucalyptus grandis*	√	√	X	√	x	√	√	X

Appendix 4: Continues…

Species ode	Botanical name	Gener.	Private	Com*	Hom*	Agro*	Line*	Wood*	Spring
30	*Eucalyptus maidenii*	√	√	X	√	X	X	√	X
31	*Eucalyptus saligna*	√	√	X	X	X	√	X	X
32	*Ficus sycomorus*	√	√	√	X	X	√	X	X
33	*Ficus thonningii*	√	√	X	X	√	X	X	√
34	*Grevillea robusta*	√	√	√	√	√	√	√	√
35	*Jakaranda mimosifolia*	√	√	√	√	√	√	√	√
36	*Leucaena leucocephala*	√	√	X	√	X	X	X	X
37	*Macaranga kilimandscharica*	√	√	X	X	X	√	X	X
38	*Maesa lanceolata*	√	√	√	√	X	√	X	√
39	*Mangifera indica*	√	√	X	√	X	X	X	X
40	*Markhamia lutea*	√	√	√	√	√	√	X	√

Species ode	Botanical name	Gener.	Private	Com*	Hom*	Agro*	Line*	Wood*	Spring
41	*Melia azedarach*	√	√	X	√	X	X	X	X
42	*Morus alba*	√	√	X	√	X	X	X	X
43	*Olea capensis*	√	√	√	√	X	√	√	√
44	*Olea europaea*	√	√	X	√	X	X	√	X
45	*Persea Americana*	√	√	√	√	√	√	√	√
46	*Pinus patula*	√	√	√	√	√		√	√
47	*Prunus persica*	√	√	X	√	X	X	X	X
48	*Psidium quajava*	√	√	X	√	X	X	X	X
49	*Punica granatum*	√	√	X	√	X	X	X	X
50	*Rauvolvia caffra*	√	√	√	√	√	√	√	√
51	*Senna senguena*	√	√	X	√	X	X	X	X
52	*Senna spectabilis*	√	√	X	√	X	x	x	X
53	*Sesbania sesban*	√	√	X	x	X	x	√	X
54	*Solindea madagascariensis*	√	√	X	x	X	√	x	X
55	*Spathodea campanulata*	√	√	√	√	X	x	x	√
56	*Syzigium cuminii*	√	√	X	x	X	√	√	X
57	*Terminalia superba*	√	√	X	x	X	x	x	X
58	*Thuja orietalis*	√	√	X	x	X	x	x	X
59	*Vepris simplicifolia*	√	√	X	√	X	x	x	X

Where:
Gener* =General checklist
Comm.* =communal checklist
Home* =Homestead checklist
Line* =line-plantings checklist
Wood* =woodlot checklist
√ and x = species sampled and species not sampled respectively