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Original Article

Quantification of Aboveground Carbon Stocks in Afromontane Vegetation of Image Forest Reserve (IFR), Southern Highlands of Tanzania

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ABSTRACT

Evaluating the aboveground carbon stocks is important for scientific awareness of the vegetation condition. The study was conducted from August to September 2019 to quantify the aboveground carbon (AGtC Ha-1) stocks in Afromontane vegetation of Image Forest Reserve (IFR), in southern highlands of Tanzania. Ground surveys were conducted to identify the existing land cover types in IFR. A total of 170, 20 m x 40 m rectangular sample plots were systematically set on the land cover types at an interval of 250m.The standing tree species with DBH ≥ 5 cm were identified and measured for their DBH (cm) at 1.3 m from the ground. Tree stumps were measured at 5 cm from the ground. Allometric equations were used to calculate the aboveground biomass and multiplied by a carbon factor of 0.47 (0.5) to get AGtC Ha-1. ANOVA was applied to compare the AGtCHa-1 within land cover types. Grounded on this study's findings, an overall AGtC Ha-1 per land cover type ranged from 7,190.59 ±9.49. Forest stored the largest AGtC Ha-1 (7,190.59) trailed by woodland (1,662.13), shrub land and grassland (171.54), and bare land and rock out crops (9.49). The calculated AGtCHa-1of each tree species per hectare (AGtC Ha-1) ranged from 878.14 ± 0.02. This study revealed a significant difference in AGtC Ha–1 within the forest, woodland, shrub land and grassland, bare land and rock outcrops. Out of the 187 measured tree species, 7 were known to contribute the highest AGtCHa-1 (878.14±411.61), 14 were in the medium category (322.42 ± 103.28), 53 each contributed low (94.31 ± 10.00), and 113 each contributed very low (9.28 ± 0.02). Further study is needed to assess the whole carbon stored by IFR, encourage tree planting at

homesteads to reduce logging in the natural forest, and provision of conservation education.

APA CITATION

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INTRODUCTION

Measuring carbon stock comes up with results which can be used to develop effective mitigation strategies to reduce carbon emissions and equitable adaptation strategies to cope with increasing global temperatures relying on robust scientific information (Duncanson et al., 2019). Systematic assessing of carbon stocks contributes to the transparent analysis of complex and often contradictory science on forest carbon dynamics (Petrokofsky et al., 2018; Mensah et al., 2016). Aboveground carbon stocks are key information criteria to understand the role of forests in regulating global climate (Mensah et al. 2016). It has been stated that the African savannahs and woodlands contribute significantly to the carbon budget of the world but the level of contribution cannot be quantifiably ascertained (Rahlao et al., 2012; Bouvet et al., 2017). Carbon stocking is the ability of the plants to capture and store carbon (Shen et al., 2016). Africa Tropical forests play a crucial role as a source and sink in the global carbon cycle (Gullison et al., 2007; Salunkhe et al., 2018). The global forests store a large amount of carbon, even though, approximately 30% of the global forested land is decreasing with average global deforestation rates amounting to 13 million hectares a year (Achard et al., 2002; Mganga, 2010). Consequently, there is an urgent need to estimate the level of carbon stocks stored in the existing forests for the understanding of forest management strategies in the protected land (Mansah et al., 2016; Mangwaek et al., 2017). In order to analyse the carbon stock variation, the amount of carbon must be evaluated by applying the recommended allometric models (Mugasha et al., 2013; Masota et al., 2014).

The carbon storage is being debated as one of the current ecological topics more so in regard to understanding forest carbon dynamics and carbon credit (Vashum & Jayakumar, 2012; Duncanson et al., 2019). Carbon stocks can be quantified by measuring the tree diameter (cm) and used in the allometric equation to calculate the biomass without collecting any tree material, whereby the non-destructive method is used to assess the carbon stock by taking the tree measurements and then allometric equations are used to calculate the biomass for a given land cover type (Ketterings et al. 2001; Pragasan, 2015). The biomass is then multiplied by a carbon factor of 0.47 (0.5) to get the

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amount of carbon stored by each individual tree species. IFR accommodates high plant species diversity as carbon sinks; however, the area has inadequately been studied for its quantity of carbon stock. Thus, this study intended to quantify the aboveground carbon stocks in Afromontane vegetation of IFR, in southern highlands of Tanzania.

MATERIAL AND METHODS

Description and Location of the Study Area

The study was conducted at IFR which is situated in Kilolo District, Iringa region, Tanzania. IFR falls under three wards namely, Image ward which lies on the south and south-west, Ibumu on the west and northern western side, while in the east the Image Forest Reserve lies on Mahenge ward (*Figure 1*). It is located at 07° 22' 15" - 07° 33' 15" South and 36°08'15" - 36° 12' 25" East (Lovett and Congdon, 1990) in Iringa Region. IFR was of priority due to its high plant species diversity in the southern highlands Afromontane land cover types.

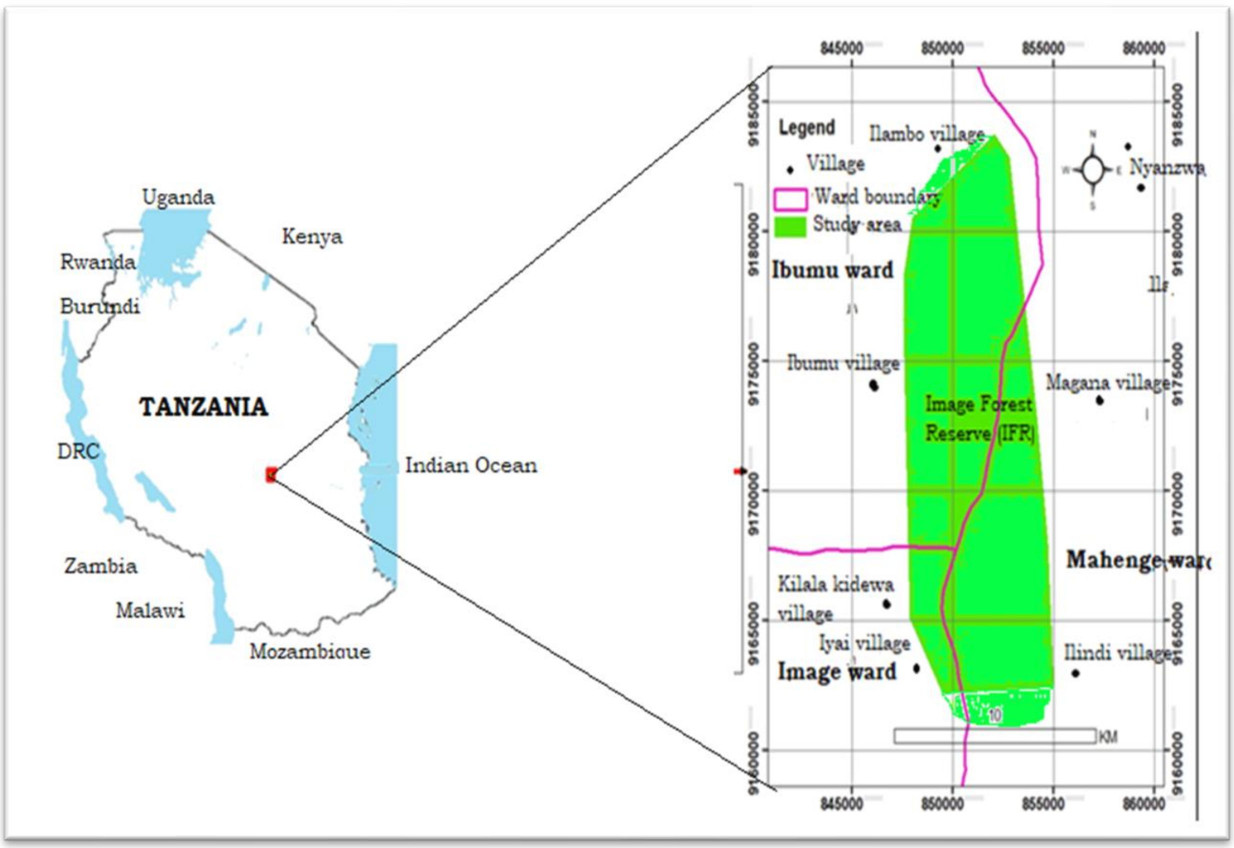

Figure 1: Map of Image Forest Reserve

Vegetation Types

This study classified the land cover of Image Forest Reserve into four types (forest, woodland, shrub land and grassland, and bare land and rocks (*Plate 1*). Forest was a vegetation type comprising of many trees closed together, with a closed canopy cover. It encompassed very tall trees. These were along riverine between the mountain spurs within the woodland, on slopes, valleys at a higher altitude, and plateaus on IFR. This is Afromontane vegetation at an altitude range of 1500-2400 m a.s.l. The Afro-montane forest [Plate 1(A)] was common above 1700 m a.s.l while below that was along

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rivers (*Plate 1*). Among forest plant species were *Hagenia abyssinica, Podocarpus latifolius, Aphloia theiformis, Galiniera saxifraga, Dombeya torrida, Polysias fulva, Macaranga kilimandscharica, Canthium oligocarpum, Brucea antidysenterica, Casearia battiscombei, Cassipourea malosana, Cyathea manniana, Croton macrostachyus, Bersama abyssinica, Bridelia micrantha, Lasianthus kilimandschricus, Cussonia zimmermannii, Phoenix reclinata, Pauridiantha paucinervis,* and *Neoboutonia macrocalyx*.

The study also, identified woodland which was a land cover with lower and open canopy trees than the forest [*Plate 1(B*)] (*Plate 1*). Woodland of Image Forest Reserve consists of *Brachystegia boehmii, B. microphylla, B. spiciformis, B. bussei, Julbernardia globiflora, Uapaca kirkiana, Protea welwitschii, Pittosporum viridiflorum, Faurea rochetiana, Faurea saligna, Acacia sieberiana, Schrebera alata, Psorospermumm febriguga, Rourea orientalis,* and *Vitex doniana.*.

Shrub and grassland was a vegetation type made up of grasses and slender lower woody plants mixed with herbs, sedges and very scattered trees [*Plate 1 (C)]* (*Plate 1*). This vegetation appeared as small to large vegetation patches within the woodland, bare land and rocks, forest, and Image Forest Reserve plateaus. The identified plants were: *Bidens magnifolia*, *Leonotis ocymifolia*, *L. nepetifolia*, *Anthospermum usambarense*, *Artemisia afra*, *Anthrixia rosimalifolia*, *Andropogon gayanus*, *Aneilema aequinoctiale*, *Lantana trifoliata*, *Plectranthus* sp., *Helichryssum* spp., *Commelina africana*, *Helichryssum* spp., *Bothriocline tomentose*, *Acalypha volkensii*, *Kotschya recurvifolia*, *Indigpfera rynchocarpa*, *Spermannia ricinocarpa*, *Kniphofia thomsonii,* mixed with scattereded trees of *Protea welwitschii*, *Brachystegia spiciformis*, *Euclea divinorum*, *Vernonia myriantha*, *Solanecio mannii*, *Rhus natalensis*, *Acacia sieberiana*, *Pittosporum viridiflorum,* and *Lannea schimperi.*

Apart from the above land cover types, there was the bare land and rocks. Bare land and rocks consist of over 90 % without plants [*Plate 1(D*)] (*Plate 1*). The bare land is an area with soil not covered with plants (vegetation), while rocks are the areas with very large rock sheets. Apart from being bare lands and rocks, they are characterized by very scattered plant species such as the lithophytes (rock-loving plants). The found plant species on bare land and rocks include Orchidaceae, *Dodonaea angustifolia*, *Aloe chabaudii*, *A. congdonii*, *Bidens magnifolia*, *Achyranthes aspera*, *Aeollanthus subacaulis*, *Andropogon gayanus*, *Exothecca abyssinica*, *Kotschya recurvifolia*, *Pteridium aquillinum*, *Myrothamnus flabbelifolius*, *Clutia abyssinica*, *Leonitis acymifolia* and *Wahlenbergia virgata.*

The IFR consists of the forest, woodland, shrubland, grassland. Forest vegetation type with the tallest woody plant form with trees exceeding 35 m tall with a canopy cover reaching ≥95%. The dominant tree species included *Ilex mitis*, *Polysias fulva*, *Craibia brevicaudata*, *Rapanea melanophloesa*, *Nuxia congesta*, *Dombeya torrida*, *Podocarpus latifolius*, *Hagenia abyssinica*, *Vepris simplicifolia* and *Zanthoxyllum deremense.* The Miombo woodland [(Plate 1(B)] (*Plate 1*) was dominated with *Brachystegia spiciformis*, *B. utilis*, *B. boehmii*, *Julbernardia globiflora* mixed with *Uapaca kirkiana.*

Shrub land and grassland [*Plate 1(C)*] were revealed to be covered by lower slender multi-stemmed woody plant species and grasses (grassland plains) forming distinct patches within the woodland, forest and mountain ridge tops. The shrub and grass species with a very scattered tree also extended on the known bare land and rock outcrops. The identified plant species on bare land and rocks included: *Hymenodictyon floribunda* and *Dissotis melleri*, *Myrothamnus flabelifolius*, as well as different species of orchids [*Plate 1(D)],* sedges and grasses.

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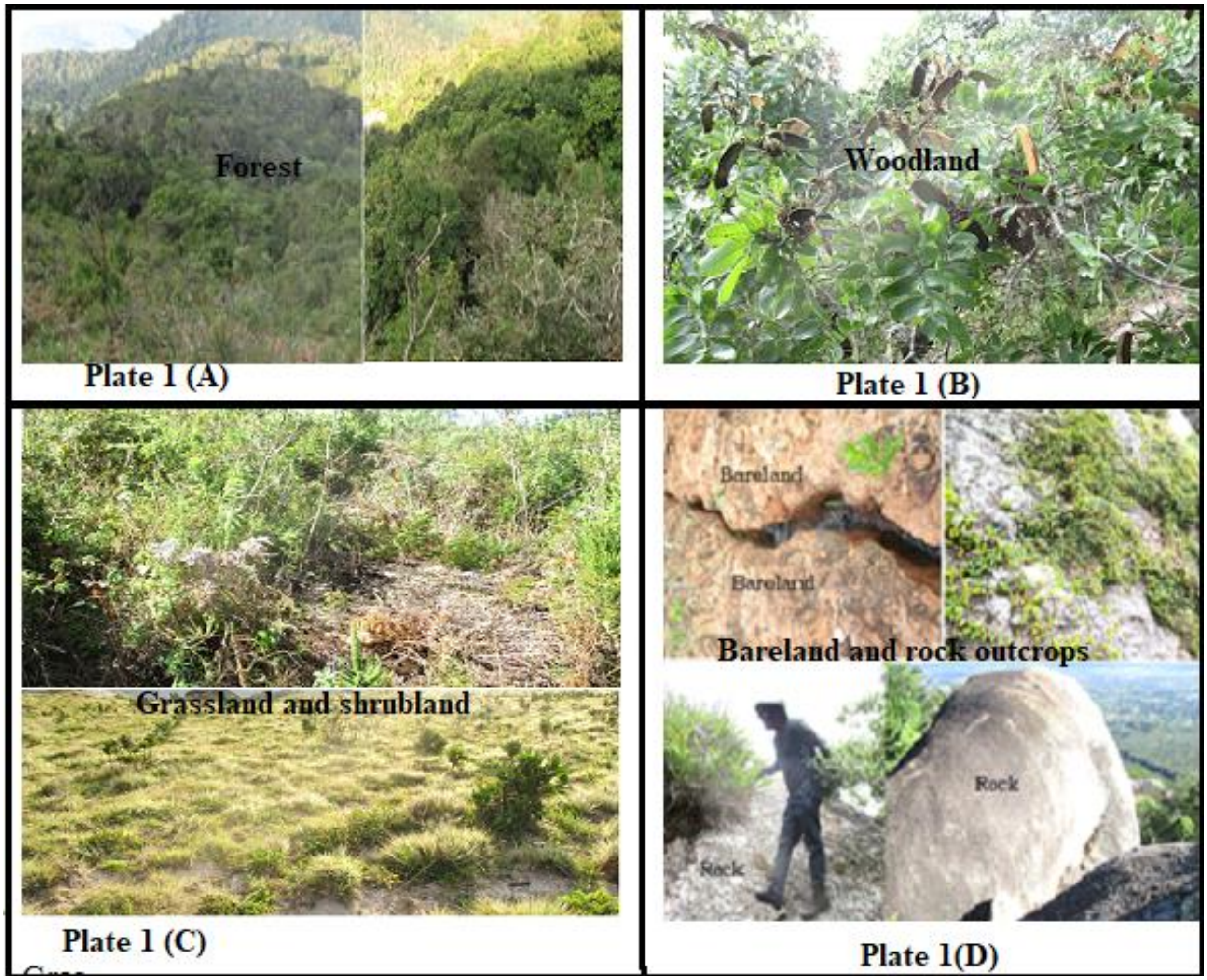

Plate 1: Vegetation Types of IFR

Topography and Climate of Image Forest Reserve

Image Forest Reserve lies on the zone characterized by rolling scenery and plateau at an altitude range of 1640 to 2440 m a.s.l. (Ruffo, 1991). IFR experiences oceanic rainfall with continental temperatures (Minja, 1991). The area experiences one season of rain from November to April with an annual rainfall of 1500 mm (Lovett and Congdon, 1990). The annual temperature ranges from 15^0 – 20^0 C (URT, 2013). Also, Image Forest Reserve borders three wards with the high human population.

Data Collection

Above Ground Carbon Stocks

None destructive method was used to quantify the carbon stock within the 170, 20 x 40 m rectangular sample plots (Shirima et al., 2015) laid systematically along with the land cover types in Image Forest Reserve. The units of measuring of 20 m x 40 m (0.08ha) are preferred as it covers as much variation as possible (Goslee, 2006). The $800m^2$ were divided into 10m by 10m subplots in which measurements were taken systematically to avoid repetition. The trees species with a diameter of ≥5 cm were measured for diameter at 1.3 m height from ground for standing trees and at 5 cm above its base for stumps imitating Matula et al. (2015) as was done during their study on carbon stocks

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analysis using a diameter tape, even though Manyanda et al. (2019) measured a stump diameter (SD) at least 30 cm from the ground.

Heskanen et al. (2013) stated that for the measurement of aboveground carbon stocks, woody plants have to be classified and all woody plants having the diameter at breast height (DBH) ≥4 cm have to be classified as trees. McNicol et al. (2018) in their survey on Aboveground Carbon stocks in eastern Tanzania considered the diameter of trees from 5 cm and above, whereby the small-diameter trees ranged from 5 – 15 cm, medium-size trees ranged from 15 – 40 cm and large trees were above 40 cm diameter. Kuyah et al. (2016) during the formulation of a generalizable mixed-species allometric model considered the trees ranging in diameter at breast height (DBH) from 5 - 105 cm. It has been reported that the minimum diameter of trees of greater than 10 cm and sometimes as large as 50 cm is used; however, this excludes smaller trees which can account for more than 30% of the biomass. This has been supported by other scholars including Levine (1996) who explained that for most forests or trees formation, biomass density estimates are based only on trees with diameters greater than or equal to 10 cm, the usual minimum diameter measured in most inventories of closed forests, however, for the forest or trees of small stature such as those in the arid tropical zones degraded forests, the minimum diameter could be as small as 2.5 cm. The tree stumps were also, measured for the diameter and counted for their number.

Data Analysis

The existing allometric equations for Miombo vegetation developed by Mugasha et al. (2013) and montane vegetation by Masota et al. (2014) were used to estimate aboveground carbon developed. This allowed estimating the stocks per hectare, as well by individuals, species and diametric classes of each land cover types. The calculated biomass (kg) was converted into carbon (tons) per tree by multiplying by a carbon factor of 0.47 (Grais and Casarim, 2013) to get the carbon stock (tons). Analysis of Variance (ANOVA) was used to compare carbon stocks among the different land cover types.

Woodland: $AGB = 0.1027*(dbh)^{2.4798}$ (Mugasha et al., (2013) ………………………..….[1]
Monaten forest: $AGB = 0.9635*(dbh)^{1.9440}$ (Masota et al., (2014) …………………….[2]
Where, AGB = Aboveground Biomass (kg); dbh = diameter at breast height (preferably at 1.3m from ground).
The tree stump biomass was calculated as per Manyanda et al (2019).
For miombo woodland biomass equation:-
$a \times (SD)^b$ ……………………………………………………………………[3]
Where; a = equation; 0.000032 = constant; b = 2.7992
For the montane forest biomass equation: -
$a \times (SD)^b$ ……………………………………………………………….…………….…[4]
a = equation factors (a = 0.00035); b = 2.77406

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RESULTS

Aboveground Carbon Stocks of Standing Trees

The overall AGtC Ha^{-1} per tree species from the 170 plots ranged from 878.14 ± 0.02. Wheras an overall AGtC Ha-[1] for the four identified land cover types ranged from 7,190.50 ± 9.49 (Figure 2). The forest accumulated the greatest AGtC Ha^{-1} of all other land cover types, trailed by woodland, shrub land and grassland, and rock outcrop and bare land (*Figure 2*).

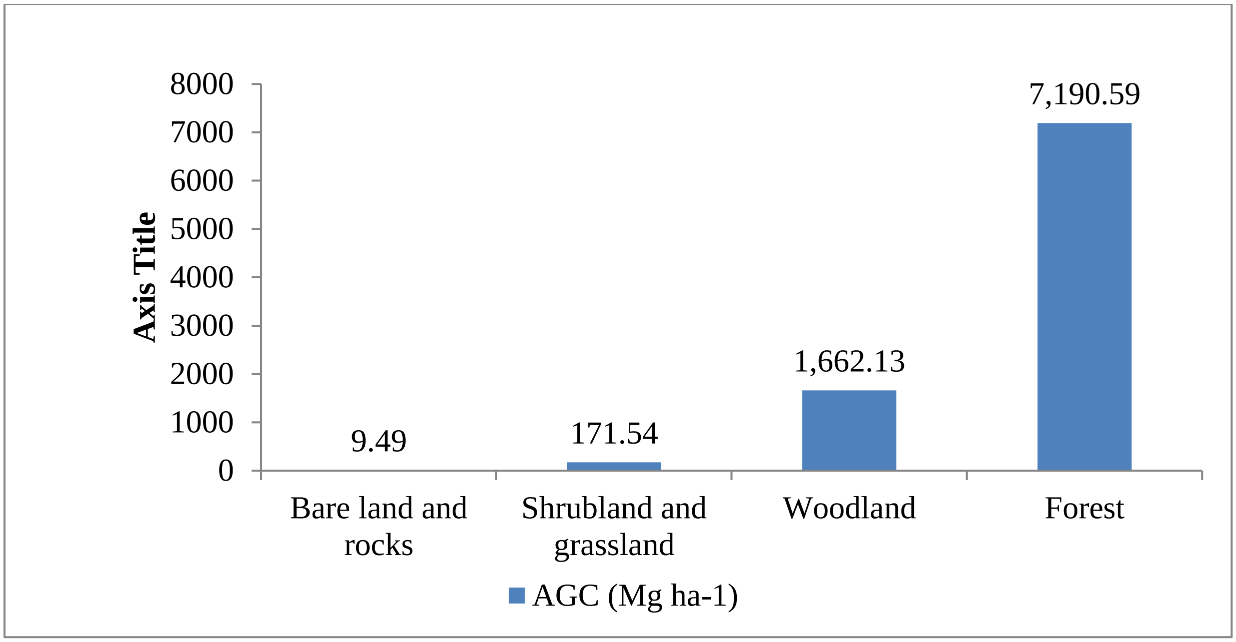

Figure 2: Contribution of aboveground carbon stocks (AGtC Ha^{-1}) per land cover in Image Forest Reserve

Aboveground Carbon Stocks per Diameter Classes

The diameter classes showed greater variation in the amount of aboveground carbon (AGtC Ha^{-1}). The AGtC Ha^{-1} for the forest and woodland increased with the DBH- class, while for the bare land and rock outcrops, and shrub land and grassland were not steadily increasing with the DBH-class (*Table 1*). The DBH-class >40 accumulated the highest AGtC Ha^{-1} as a contribution of 7.68%, followed by DBH-class of 20-30 that contributed 18.088%, 30-40 with contribution of 15.22%, 10-20, and 0-10 which contributed 1.57% (*Table 1*).

Table 1: Distribution of aboveground stocks (AGt C Ha^{-1}) across different land covers

DBH- class	Bare land and rocks	Forest	Shrub land and grassland	Woodland	Total
5≥10	2.00	43.19	6.05	90.83	142.06
10-20	2.51	360.37	19.36	288.99	671.23
20-30	1.84	975.06	35.96	621.19	1,634.05
30-40	3.14	1,028.34	35.77	308.12	1,375.37
40>	-	4,783.64	74.40	353.00	5,211.04
Total	**9.49**	**7,190.59**	**171.54**	**1,662.13**	**9,033.76**

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The forest plots had the highest mean and standard deviation of AGtC Ha^{-1} than woodland, shrub land and grassland, and bare land and rocks (*Table 2*).

Table 2: Aboveground carbon for sample plots across different land cover

Land cover	Mean	Standard error
Bare land and rocks	1.19	0.97
Forest	107.32	14.08
Shrub land and grassland	7.46	2.21
Woodland	25.97	2.96

The distribution of tree species AGtC Ha^{-1} varied within the land cover types. In the bare land and rocks, *Syzygium guineense* had the highest AGtC Ha^{-1} of all, while *Brachystegia spiciformis* had the least AGtC Ha^{-1} among trees with the nine (9) tree species with the highest carbon (*Figure 3*).

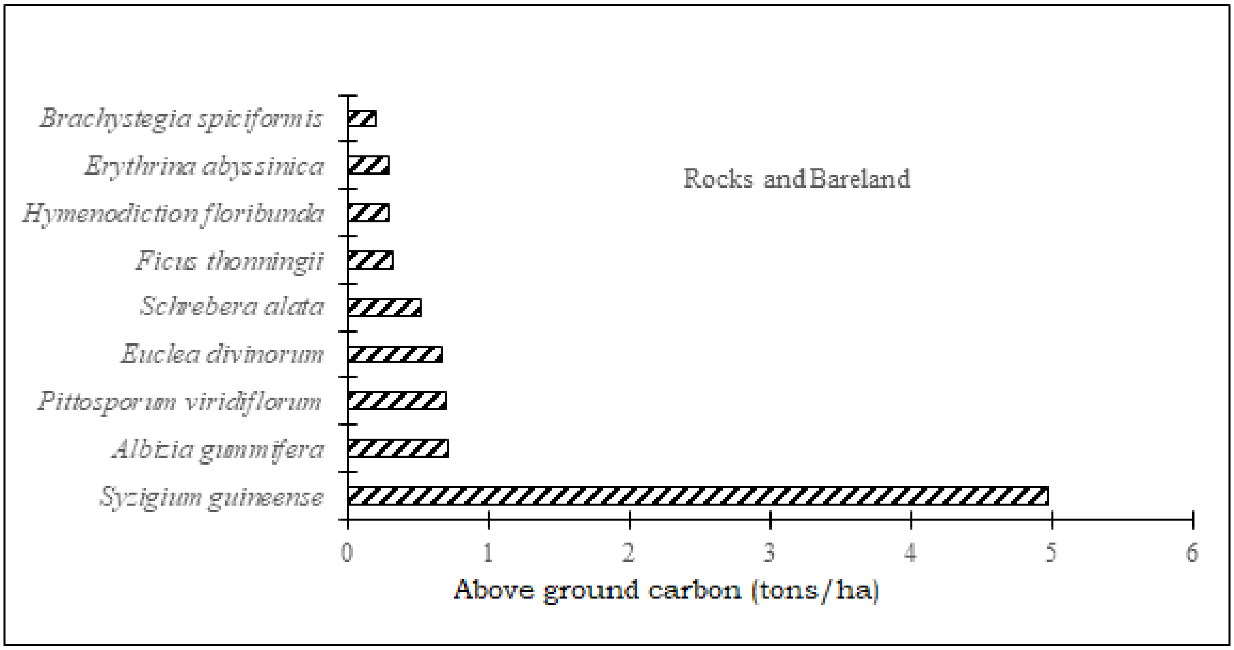

Figure 3: Distribution of AGtC Ha^{-1} by species in the rocks and bare land

Shrubland and grassland had 8 tree species with the highest contribution of AGtC Ha^{-1} of all others, led by *Brachystegia spiciformis, Uapaca kirkiana, Acacia sieberiana, Syzygium cordatum, Brachystegia utilis, Julbernardia globiflora, Faurea saligna, Shrebera alata* and *Combretum mole* (*Figure 4*).

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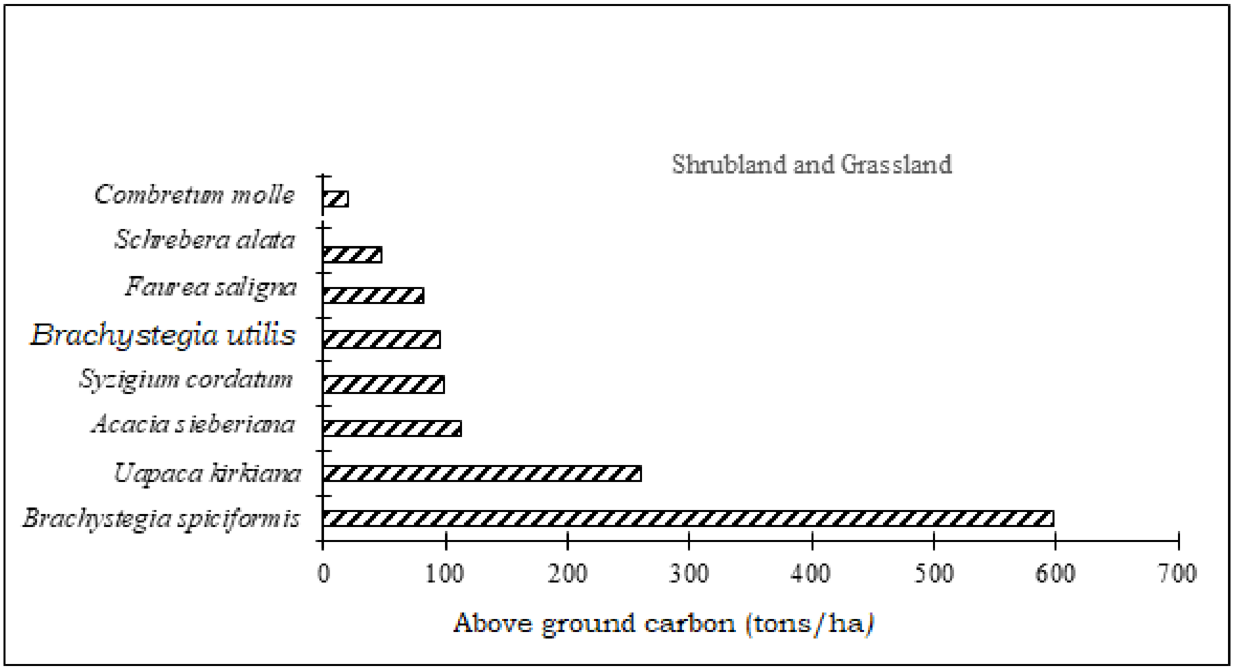

Figure 4: Distribution of AGtC Ha^{-1} by species in the Shrub land and Grassland

Nine (9) tree species from the woodland contributed most to an overall AGtC Ha^{-1} within the vegetation types. *Brachystegia spiciformis* was leading followed by *Uapaca kirkiana*, *Acacia sieberiana*, *Syzygium cordatum*, *Brachystegia longifolia*, *Julbernardia globiflora*, *Faurea saligna*, *Schrebera alata and Combretum molle* (*Figure 5*).

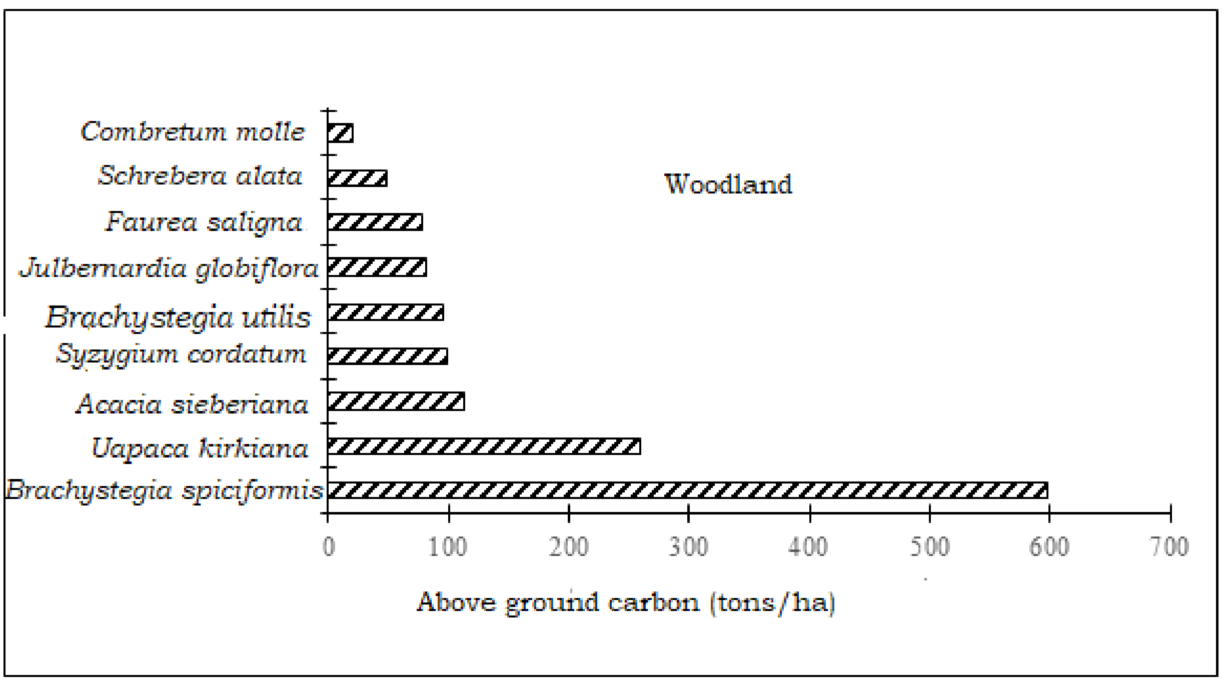

Figure 5: Distribution of AGtC Ha^{-1} by species in the woodland

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Nuxia congesta had the highest contribution of AGtC Ha^{-1} of all tree species in the forest vegetation (*Figure 6*). The other tree species that were treated in the group of trees with the highest AGtC Ha^{-1} were *Podocarpus latifolius, Dombeya torrida, Prunus africana, Maesa lanceolate, Rapanea melanophloesa, Neoboutonia macrocalyx, Casearia battiscombei, Boscia angustifolia* and the *Bersama abyssinica*.

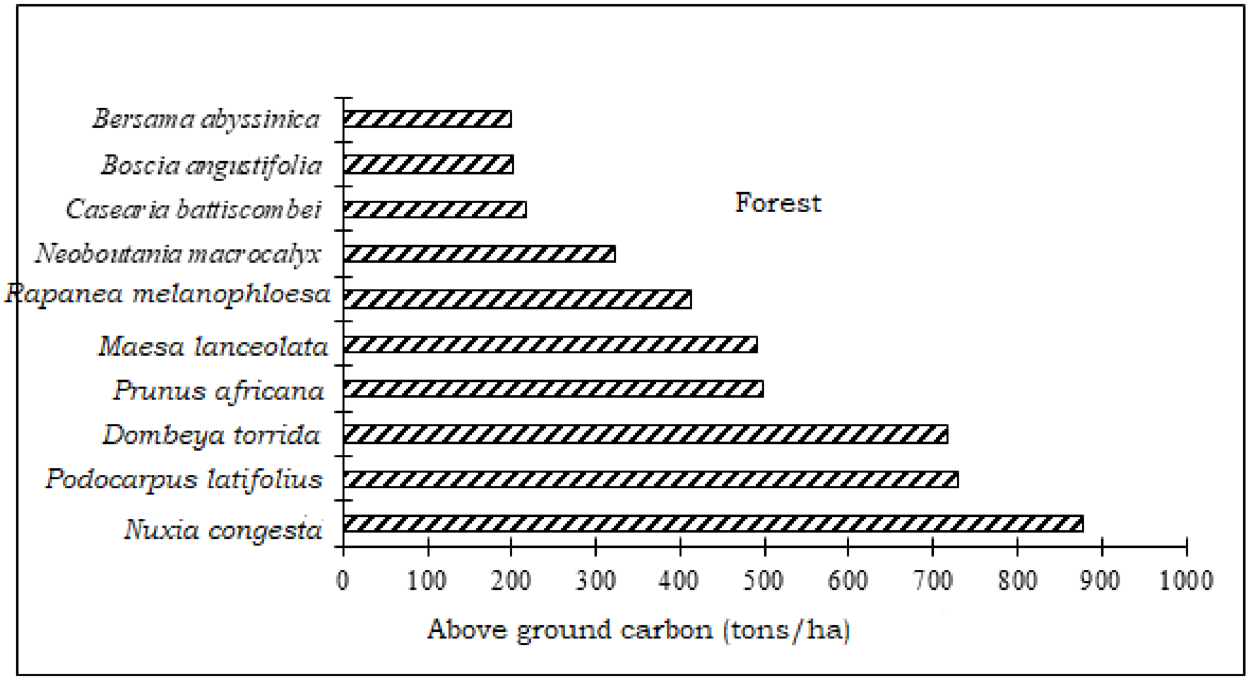

Figure 6: Distribution of AGtC Ha^{-1} by species in the forest

Aboveground Carbon Stocks per Tree Species in Image Forest Reserve Land Cover Types

In this study, the findings were categorized into tree species highest in terms of AGtC Ha^{-1} (4433.72), medium (2669.86), low (1711.41), and very low (218) (*Table 3*). The tree species which scored the highest in the highest AGC category was *Nuxia congesta* (878.14 ± 411.61) (*Table 4*); *Neoboutania macrocalyx* had the highest AGC in the medium AGC category (322.42 ± 103.28) (*Table 5*); *Maytenus heterophylla* had the highest in the low category (94.31 ± 10.00) (*Table 6*) while and the tree species with the highest AGC in the very low category had 9.28 ± 0.02 AGtC Ha^{-1}. Most of the tree species were revealed to fit in very low category (113) trailed by low (53), medium (14), while the Highest was ranked the least in terms of species richness (7).

Table 3: Total tree species and AGC per category in Image Forest Reserve

AGC category	Total tree species	AGC
Highest	7	4433.72
Medium	14	2669.86
Low	53	1711.41
Very low	113	218

The seven (7) tree species, apart from the least of all captured the highest AGtC Ha^{-1}.

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Table 4: Contribution of AGtC Ha^{-1} by species across different land covers types for the highest category

Tree species	Bare land & rocks	Forest	Shrub land & grassland	Woodland	Total
1. *Nuxia congesta*		878.14			878.14
2. *Dombeya torrida*		792.28			792.28
3. *Podocarpus latifolius*		730.59			750.38
4. *Brachystegia spiciformis*	0.2		15.23	597.41	612.85
5. *Prunus africana*		497.83			497.83
6. *Maesa lanceolata*		490.57		0.07	490.63
7. *Rapanea melanophloesa*		411.61			411.61
Total		**3801.02**	**15.23**	**597.48**	**4433.72**

The medium category, apart from having more tree species than the high category, got less AGC than the only seven tree species in *Table 4* (*Table 4 & 5*).

Table 5: Contribution of AGtC Ha-1 by species across different land covers types for the medium category

Tree species	Bare land & rocks	Forest	Shrub land & grassland	Woodland	Total
1. *Neoboutania macrocalyx*		322.42			322.42
2. *Acacia siberiana*			50.26	211.57	261.83
3. *Uapaca kirkiana*			1.92	259.14	261.06
4. *Syzygium cordatum*		151.16	7.29	95.9	254.35
5. *Casearia battiscombei*		215.52			215.52
6. *Boscia angustifolia*		200.28		2.67	202.95
7. *Bersama abyssinica*		197.8			197.8
8. *Ficus thonningii*	0.32	176.84		0.79	177.95
9. *Craibia brevicaudata*		158.52			158.52
10. *Galiniera saxifraga*		156.35			156.35
11. *Ehretia cymosa*		122.17		0.97	123.14
12. *Bridelia micrantha*		108.63	6.12	7.33	122.08
13. *Rawsonia lucida*		112.61			112.61
14. *Aningeria adolfii*		103.28			103.28
Total	**0.32**	**2025.58**	**65.59**	**577.4**	**2669.86**

More tree species with low AGtC Ha^{-1} were recorded and measured from the low category than the highest and medium AGtC Ha^{-1} category, but with lower overall AGC (*Table 3 & 6)*. On the other hand, the very low AGC tree species number (richness) was more than the low category in terms of richness (*Table 6*).

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Table 6: Contribution of AGtC Ha-1 by species across different land covers types for low category

Tree species	Bare land & rocks	Forest	Shrub land & grassland	Woodland	Total
1. *Maytenus heterophylla*		94.15		0.16	94.31
2. *Cussonia zimmermannii*		93.85			93.85
3. *Xymalos monospora*		91.76			91.76
4. *Brachystegia utilis*				81.25	81.25
5. *Julbernardia globiflora*				77.8	77.8
6. *Chrysophyllum gorungosanum*		75.54			75.54
7. *Schrebera alata*	0.52	41.74	8.97	20.59	71.81
8. *Mystroxylon aethiopicum*		67.13		0.02	67.15
9. *Afrocrania volkensii*		59.23			59.23
10. *Faurea saligna*		2.33	7.91	48.73	58.97
11. *Albizia gummifera*	0.72	56.1			56.82
12. *Ilex mitis*		42.51		8.81	51.32
13. *Cussonia spicata*		42.8		0.87	43.66
14. *Vepris simplicifolia*		42.41			42.41
15. *Acacia abyssinica*			38.49		38.49
16. *Hagenia abyssinica*		37.46			37.46
17. *Cassipourea malosana*		35.71			35.71
18. *Phoenix reclinata*		32.59	0.52		33.11
19. *Ficus sur*		26.6		5	31.6
20. *Croton macrostachyus*		26.55			26.55
21. *Acacia polycantha*		25.76			25.76
22. *Morella salicifolia*		8.12	6.59	9.55	24.27
23. *Ekebergia capensis*		24.17			24.17
24. *Combretum molle*			3.28	19.69	22.97
25. *Diospyros whyteana*		21.76			21.76
26. *Garcinia volkensii*		21.14			21.14
27. *Lepidotrichilia volkensii*		20.26			20.26
28. *Protea gaguedii*			0.27	19.55	19.82
29. *Ochna holstii*		19.27			19.27
30. *Ackocanthera oppositifolia*		18.77			18.77
31. *Euclea divinorum*	0.67	12.31		4.84	17.81
32. *Syzigium guineense*	4.98	12.27		0.28	17.53
33. *Erica mannii*				16.67	16.67
34. *Ficus ingens*		13.29	3.14		16.43
35. *Polysias fulva*		16.27			16.27
36. *Faurea rochetiana*	0.1		5.09	10.27	15.46

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Tree species	Bare land & rocks	Forest	Shrub land & grassland	Woodland	Total
37. *Apodytes dimidiata*	0.12	7.62		7.44	15.19
38. *Kigelia africana*		14.71			14.71
39. *Parinari curatellifolia*				14.31	14.31
40. *Canthium oligocarpum*		14.09			14.09
41. *Macaranga capensis*		14.04			14.04
42. *Brachystegia boehmii*				13.89	13.89
43. *Scloppia rhamniphylla*		13.72			13.72
44. *Ficus natalensis*		10.11		3.41	13.51
45. *Dombey rotundifolia*		0.19	0.79	12.37	13.35
46. *Brachystegia bussei*				13.28	13.28
47. *Acacia robusta*				13.12	13.12
48. *Aphloia theiformis*		13.11			13.11
49. *Chionanthus battiscombei*		13.05			13.05
50. *Vernonia myriantha*		12.12		0.15	12.27
51. *Dovyalis abyssinica*		11.43			11.43
52. *Halleria lucida*		11.18			11.18
53. *Maytenus acuminata*		10			10
Total	**7.11**	**1227.03**	**74.26**	**402.05**	**1711.41**

Aboveground Carbon Stocks for Stumps (AGtC Ha^{-1})

The forest had the highest number of stumps aboveground carbon, followed by woodland, and bare land and rocks, while no stump was found on the shrubland and grassland land. The tree species which were measured for their stumps in the forest were *Acacia polyacantha, Galiniera saxifraga, Hagenia ayssinica, Maesa lanceolata, Podocarpus latifolius* and *Syzygium cordatum*. The identified tree stumps in the woodland were; *Brachystegia boehmii, B. utilis, B. microphylla, B. spiciformis, Faurea saligna, Julbernardia globiflora, Schrebera alata*, and *Syzygium cordatum*. Only one stump of *Rhus natalensis* was measured from bare land and rocks (*Table 7*).

Table 7: Tree species stumps (G), AGBS (kg) and AGtC Ha^{-1}

Tree species name per land cover type	Sum of DBH (cm)	Sum of $G(m^2)$/Ha	Sum of AGB (kg)/Ha	Sum of AGtC Ha^{-1}
Bare land and rocks				
Rhus natalensis	6.3	0.000155783	0.005247629	0.002466386
Sub-total	**6.3**	**0.000155783**	**0.005247629**	**0.002466386**
Forest				
Acacia polyacantha	28.5	0.003188081	0.380097468	0.17864581
Galiniera saxifraga	25	0.002453125	0.264263696	0.124203937
Hagenia abyssinica	61.2	0.014700852	3.1668223	1.488406481
Maesa lanceolata	33	0.002139125	0.167282978	0.078622999
Podocarpus latifolius	665	0.103317775	16.5677356	7.78683573

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Tree species name per land cover type	Sum of DBH (cm)	Sum of G(m^2)/Ha	Sum of AGB (kg)/Ha	Sum of AGtC Ha^{-1}
Syzygium guineense	10	0.0003925	0.020803099	0.009777457
Sub-total	**822.7**	**0.126191458**	**20.56700514**	**9.666492414**
Woodland				
Brachystegia boehmii	32.5	0.000913544	0.036630638	0.0172164
Brachystegia utilis	93.9	0.005953715	0.429929119	0.202066686
Brachystegia microphylla	46.1	0.004239039	0.406407046	0.191011311
Brachystegia spiciformis	219.9	0.027947295	3.477890262	1.634608423
Faurea saligna	45	0.007948125	1.26066833	0.592514115
Julbernadia globiflora	16.8	0.001107792	0.080832356	0.037991207
Schrebera alata	25.2	0.002492532	0.270170066	0.126979931
Syzigium cordatum	160	0.03395125	6.278026553	2.95067248
Sub-total	**639.4**	**0.084553292**	**12.24055437**	**5.753060554**
Grand Total	**1468.4**	**0.210900534**	**32.81280714**	**15.42201935**

**AGB=Aboveground biomass; .G = Basal area; AGtC Ha-1= Aboveground carbon stocks (AGtC Ha-1);*

DISCUSSION

Aboveground Carbon Stocks of Standing Trees

The estimation of the accumulated biomass in the forest ecosystem is important for assessing the productivity and sustainability of the forest (Vashum and Jayakumar, 2012). The highest aboveground carbon stocks (AGtC Ha^{-1}) of the forest is related to the size of trees which store a large amount of carbon than the small size trees. The small size trees, apart from being more than the big trees in terms of individuals, still remain the least in the stored carbon stocks. Ekoungoulou et al. (2014) reported that tropical forests store a higher amount of carbon as compared to other vegetation types. For the shrubland and grassland, and bare land and rocks, it is obvious that they will contain less woody aboveground carbon due to being dominated by non-woody plants and very small size woody plants.

Salas Macías et al. (2017) who conducted a study in Ecuador found a total carbon stored in the aboveground biomass was higher in the Dry Semi deciduous Forest (DSF), decreasing in the dry deciduous forest and dry scrubland, and that the situation responded to the fact that in the DSF there were trees of larger size and diameter and more diversity. The estimates have revealed most tree stumps AGtC Ha^{-1} from the biomass of all stumps illegally harvested or logged forest and or woodland (Melin, 2014). The higher the number of stems entails higher AGtC Ha^{-1}. The more the herbaceous plants meant less woody AGtC Ha^{-1}. McNicol et al (2018) reported that the amount of AGtC Ha^{-1} differences was contributed by the size of trees; also, the Highest trees class contributed more AGtC Ha^{-1} than the medium, and lowest class, even though at some stage there was no significant difference between the medium class and large trees DBH-class, especially when the medium class possessed more stems than the large DBH – class. The significant difference in the total and mean aboveground carbon stocks of stumps (AGtC Ha^{-1}), implied that there were differences in the number of stumps, size of DBH and amount of AGB within the land cover types. It has been stated that the biomass gains suggest carbon gains, while the biomass loss means reducing in carbon (Rohlingl, 2016).

Furthermore, there is an agreement between the IFR in terms of variation in AGtC Ha^{-1} and the findings by Barah et al. (2010) who conducted a study at five different forest types in Nepal and found that there was a variation in the AGtC Ha^{-1} depending on the forest vegetation type and size if tree stems; aboveground carbon was found to be highest in Hill Sal forest and lowest in *Alnus nepalensis* forest. Mensah et al supported that tree species with the largest AGC are the most influencing variables. The

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variation in aboveground biomass meant variation in aboveground biomass to as when multiplied by 0.47 carbon factor; AGtC Ha^{-1} is obtained. Also, results by Amara et al (2019) who revealed that forests and woodlands had significantly higher mean AGtC Ha - 1 and tree species richness than bush land, wooded grassland ($p < 0.05$), and also, in the forest and bush land, a small number of large-diameter trees covered a large portion of the total AGtC Ha^{-1}. The variation in the amount of AGtC Ha^{-1} has also been reflected by Srinivas and Sundarapandian (2018) who stated that there is always variation in the amount of AGtC Ha^{-1} within the diameter classes.

The Highest AGtC Ha^{-1} for the DBH-class >40 implied that the Highest stems contributed more AGtC Ha^{-1} than the small size stems, except for the bare land and rocks where the Highest diameter trees did not exist. Vashum and Jamar (2012) conducted the same study in India and suggested that forests are the highest carbon pool on earth. It has been known from similar studies that the forest stores the highest AGtC Ha^{-1} of all other vegetation types (Shirima et al., 2015). The Highest trees were measured in the forest cover type. This was supported by results from other studies such as Srinivas and Sundarapandian (2018) who conducted their study in India and found that the larger DBH contributed to higher AGtC Ha^{-1} than the small sizes. The mean AGtC Ha-1 for the sample plots across different land cover types showed a statistically significant difference ($P<0.05$).

Aboveground Carbon for Stumps (AGtC Ha^{-1})

Abella and Springer (2014) stated that logging for different needs leaves behind a number of tree stumps. The land-use changes especially afforestation and deforestation can have major impacts on carbon storage; enhanced forest growth store more carbon, but cut vegetation release or leaves carbon in the atmosphere (Ekoungoulou et al., 2014). The total plant carbon biomass (CB) up and down at a patch level is approximately constant at the level of a forest or forested landscape in the absence of logging and other human disturbance (Hairiah, 2011). Forest vegetation is always richer in AGtC Ha^{-1} of standing trees than others; human disturbances leave stumps that entailing that carbon that was meant to be stored are remaining in the atmosphere. The small amount of AGtC Ha^{-1} for stumps was due to a small number of stumps as compared to the left standing trees. Comparing within different land cover types, forest, woodland, and shrub land and rocks varied in AGtC Ha^{-1} reflecting the number of stems and size variation among themselves. The more tree stumps in forests meant more timber tree species availability in such vegetation types, while the rest continually got less.

The standing trees and stumps AGtC Ha^{-1} high difference was a result of a very small number of stems as timber poaches were harvesting in a rushing manner while hiding for patrol teams conducted by the Tanzania Forest Service (TFS). The level of significance at 0.05 ($0.2238 > 0.05$), witnessed an insignificant difference in the aboveground carbon stocks of tree stumps (AGtC Ha^{-1}) within the land cover types. The AGtC Ha^{-1} mean differences at 0.05 confidence level were significant within the forest, woodland, shrub land and grassland, and bare land and rocks (Table 8), while within each land cover type, shrub land and grassland, and bare land and rocks showed no significant difference in AGtC Ha^{-1} (*Table 8*).

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Table 8: Post hoc test for multiple comparisons

(I) land cover	(J) Land cover	Mean Difference (I-J)	P-value	Significance
Forest	Woodland	80629.27*	<0.05	Significant
	Shrub land and grassland	99141.86*	<0.05	Significant
	Rocks and bare land	105413.36*	<0.05	Significant
Woodland	Forest	-80629.27*	<0.05	Significant
	Shrub land and grassland	18512.59	18576.78	Insignificant
	Rocks and bare land	24784.09	28654.71	Insignificant
Shrub land and grassland	Forest	-99141.86*	<0.05	Significant
	Woodland	-18512.59	>0.05	Insignificant
	Rocks and bare land	6271.50	>0.05	Insignificant
Bare land and rocks	Forest	-105413.36*	<0.05	Significant
	Woodland	-24784.09	>0.05	Insignificant
	Shrub land and grassland	-6271.50	>0.05	Insignificant

CONCLUSION AND RECOMMENDATIONS

Aboveground carbon stocks are critical to addressing the drivers of vegetation alteration, plant species richness differences, and the carbon pool storage. This study revealed a significant difference in the amount of AGtC Ha-1within the forest, woodland, shrub land and grassland, and bare land and rocks. The variation in AGtC Ha^{-1} is associated with the type of vegetation. The land cover types with many large trees stem such as forest and woodland sequester a large amount of aboveground carbon. The bare land and rock outcrops, apart from being a very difficult habitat to support the growth of plants, still can favour very few trees with roots penetrating into rock crevices even though cannot qualify for assigning as either wooded grassland, woodland or forest. The significant differences in AGtC Ha-1 were reflected by the size of trees diameters (DBH-cm) and the number of stems per hectare. The least number of tree species from the highest category in terms of AGC captured the highest total AGC due to the largest size of trees, while those categories with many stems still got less AGtC Ha-1 due to small size of DBH (cm). The conservation strategies are of importance to rescue the potential biological species in IFR. IFR is among potential areas contributing to carbon sequestration. Further research is needed to assess the whole carbon stocks sequestered by IFR as this study dealt with aboveground wood carbon stocks only, encourage tree planting at homesteads to discourage logging for timber, firewood, and building poles in natural forests, education provision on negative impacts of any human illegal activity that can lead to damage of forest resources such as encroachment, grazing, and logging for poles, firewood and timber.

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