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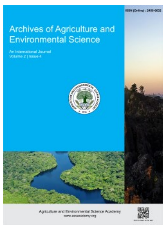

ORIGINAL RESEARCH ARTICLE

Climate change mitigation through carbon dioxide (CO_2) sequestration in community reserved forests of northwest Tanzania

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ABSTRACT

Forests play a key role in climate change mitigation through sequestering and storing carbon dioxide from the atmosphere. However, there is inadequate information about carbon accumulation and sequestered by community reserved forests in Tanzania. A study was carried to quantify the amount of carbon sequestered in two forests namely; Nyasamba and Bubinza of Kishapu district, northwestern Tanzania. A ground-based field survey design under a systematic sampling technique was adopted. A total of 45 circular plots (15 m radius) along transects were established. The distances between transect and plots were maintained at 550 and 300 m, respectively. Data on herbaceous C stocking potential was determined using destructive harvest method while tree carbon stocking was estimated by allometric equations. The collected data were organized on excel datasheet followed by descriptive analysis for quantitative information using Computer Microsoft Excel and SPSS software version 20, while soil samples were analyzed based on the standard laboratory procedures. Results revealed higher carbon sequestration of 102.49±39.87 and 117.52±10.27 for soil pools than plants both herbaceous (3.01±1.12 and 6.27±3.79 t CO_2e/yr) and trees (5.70±3.15 and 6.60±2.88 t CO_2e/yr) for Nyasamba and Bubinza respectively. The study recorded a potential variation of soil carbon sequestration, which varied across depths category ($P < 0.05$). However, there was no difference across sites ($P > 0.05$) and species ($P > 0.05$) for herbaceous and trees. The findings of this study portrayed a significantly low value for carbon stocking and sequestration potential for enhanced climate change mitigation. Therefore, proper management of community reserved forest is required to accumulate more C for enhancing stocking potential hence climate change mitigation through CO_2 sequestration offsets mechanism.

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INTRODUCTION

The effect of climate change has been a major concern globally (Fang *et al.*, 2018; Yao *et al.*, 2018). Greenhouse gases such as carbon dioxide (CO_2) are widely acknowledged by the scientific community as the cause of current climate change and global warming (Bustamante *et al.*, 2012; Huntingford *et al.*, 2012). Therefore, developing effective climate change mitigation strategies and promoting sustainable forest management is of important decision making (Manyanda *et al.*, 2020). Forests and soils act as potential sinks for elevated CO_2 emissions, being considered as the best option for preventing the release of atmospheric CO_2 and enhances carbon storage and offsets (Canadell and Raupach, 2008; Nyong *et al.*, 2007). Many afforestation and reforestation projects have been accomplished as a means to sequester CO_2 into biomass (Durkaya *et al.*, 2013). This results in reducing the effect of climate change that has been a concerned agenda worldwide.

In terrestrial ecosystems, forests and soils are considered among the easiest means for enhancing carbon capture and sequestration (Girma *et al.*, 2014). Forests and soils can be used to reduce the costs for slowing the rate of climate change, global warming and atmospheric carbon dioxide (CO_2) enrichment (IPCC, 2018; Paudela *et al.*, 2017). Data associated with carbon storage capacities of forests and soil pools have become increasingly vital in the context of climate change mitigation and sustainable management. Forests act as potential sinks for elevated CO_2 emissions and are being considered in the list of acceptable offsets (Fletcher, 2005). Forest has the potential to remove CO_2 from the atmosphere and store in wood, leaves and soil, hence reducing the effect of climate change (Yao *et al.*, 2018; Favero *et al.*, 2017; Bushesha, 2017).

This trait facilitates the changing of the structure and function of any habitat including the terrestrial ecosystem and in turn, threatening the lives of species and human existence. Climate change is damaging the environment around us (Yang and Lin, 2016) and greenhouse gases (GHG) or carbon dioxide equivalent (CO_2e) will be increasing emitted into the atmosphere, resulting in an acceleration of global warming (Allen *et al.*, 2010; Wang *et al.*, 2016). The concentration of atmospheric CO_2 has risen from 280 ppm at the beginning of the industrial revolution to the current 394 ppm (Peñuelas *et al.*, 2013).

With no mitigation, a level of GHG concentration in the atmosphere is projected to increase to at least 486 ppm or as high as 1000 ppm, in 2100 with an increase of 4°C global temperature (Carraro *et al.*, 2012; Favero *et al.*, 2017). This rapid increase in the atmospheric CO_2 concentration and other greenhouse gases has the potential to drive current climatic changes more quickly than all previous climatic changes (Bindoff *et al.*, 2007; IPCC, 2011; Peters *et al.*, 2013; Peñuelas *et al.*, 2013).This poses a major threat to global sustainable development (Jia *et al.*, 2018). Currently, the emissions from fossil-fuel combustion and industrial processes reached 9.7 Pg C/yr in 2015, equivalent to 35.7 Pg CO_2/yr), (Le Quéré *et al.*, 2016). These drastic climate variations like rising temperature, diminishing ice and increased sea level, will inevitably give rise to destruction on an ecosystem, biodiversity and human economic activities (Peters *et al.*, 2013). The irreversible damages require global joint forces to deal with these urgent situations and maintain sustainable development. Both developed and developing countries have witnessed a great falling in agriculture yields, and increased desertification (Fang *et al.*, 2018). Thus, this is the war; we should fight against in whatever weapon we have, following the Paris Agreement reached nearly 200 contracting parties of the United Nations Framework Convention on Climate Change (UNFCCC), (IPCC, 2018; Warren *et al.*, 2018).

As climate change is projected to hit the poorest countries the hardest, thus, developing countries need to pay particular attention to the management of natural resources (Kaya and Seleti, 2014; Ruiz-Peinado *et al.*, 2017; UNDP, 2007). The adverse effects of climate impacts to which these countries are exposed are already being felt and exerting considerable stress on important sectors (agriculture and exploitation of natural resources) for national development (Adesina *et al.*, 1999; Bele *et al.*, 2011; Lee, 2007; Thornton *et al.*, 2009). The African continent indeed has limited ability/options to adapt to climate change impacts and functional mitigation measures due to number of factors including limited infrastructures (Cooper *et al.*, 2013; Sanga *et al.*, 2013; Shemsanga *et al.*, 2005). In most developing countries of Africa including Tanzania in particular, the forests can play an important role in achieving broader climate change mitigation goals. One of the options being considered to mitigate the rise of CO_2 in the atmosphere is the use of forests reserves and establishment of forest conservation strategies (Lasco *et al.*, 2002; Njana *et al.*, 2018; Paudel *et al.*, 2019; Pearson *et al.*, 2005). The recognition of the role of forest and its components such as trees, herbs and soils in reducing the emission of carbon is more valuable (Montagnini and Nair, 2004). While climate change is a global phenomenon, its negative impacts are more severely felt by poor developing countries including Tanzania, as is not shielded from global environmental change (Kangalawe, 2017). Extreme climatic events such as droughts and floods have often observed resulted into crop damages and failure (Kangalawe and Liwenga, 2005), similarly, a decrease in the average discharge in most rivers have also been observed (Matondo, 2008). Therefore, several initiatives schemes, such as avoidance of deforestation introduction of reforestation program and agroforestry practices that sequester carbon in vegetation and soil (Crooks *et al.*, 2011). This makes a substantial contribution to global climate change mitigation and reduces the negative consequences of climate change. The main forestry strategies aimed at mitigating climate change through reforestation; avoid deforestation and degradation; maintain or increase the carbon density of existing forests; encourage the use of forest products, thereby improving carbon storage, and increasing the use of bioenergy to substitute fossil fuels (Kurz *et al.*, 2016).

Deforestation and forest degradation result in emissions of CO_2, which contribute to climate change, loss of carbon sequestration capacity, loss of invaluable ecosystem services and possibly loss of tree species (Njana *et al.*, 2018). Forest productivity is important in mitigation of climate change due to its capacity to sequester CO_2. Forest conservation initiatives in Tanzania such as participatory forest management (PFM) through the community-based forest management (PFM), and joint forest management (JFM), (Treue *et al.*, 2014; URT, 2006; Zahabu *et al.*, 2009), which are well-articulated in the National Environmental Policy of 1997, the Village Land Act of 1999 (FAO, 2008) Forest Act 2002 and the Environmental Management Act of 2004 (URT, 2006). These initiatives encouraged and promoted community members to conserve their forests ranging from individual/ private owned forest, community-owned forest and institution-owned forests (Duguma *et al.*, 2013; Mlenge, 2004; Monela *et al.*, 2005; Selemani *et al.*, 2013). Apart from its role in characterizing the terrestrial ecosystem function and structure concerning biodiversity, still these forests services as primary net biomass productivity, carbon stocking and hence climate mitigation (Lee, 2007; Paudela *et al.*, 2017).

As an important source, sink and pool in the global carbon cycle, the forest plays an important role in mitigating global climate change (Lee, 2007). This implies that the functions of forest and its components act as a carbon pool and sink hence decrease the amount of CO_2 in the atmosphere and improves the structure and function of the forest ecosystem. Consequently, data on C storage and sequestration potential by community conserved forests in many developing countries including Tanzania is scanty. The available report focuses on other forest types like *Miombo* woodland of central and southern parts of Tanzania (Osei *et al.*, 2018; TaTEDO, 2009; Zahabu, 2008) and Mangroves forestry (Njana *et al.*, 2018) as well as conservation and management (Chirwa, 2014; Duguma *et al.*, 2019; Malunguja and Devi, 2020; Monela *et al.*, 2005; Otsyina *et al.*, 2008; Pye-Smith, 2010; Rubanza *et al.*, 2006; Selemani *et al.*, 2013). However, the community reserved forests receive little emphases on the study of C storage and sequestration concerning climate change mitigation.

Therefore, this was carried to quantify the amount of carbon stored by plants and soil pools for estimating of CO_2 sequestered and hence climate change mitigation. The study intends to test whether: there are significance stocking and sequestration potential within and across community conserved forests of Nyasamba and Bubinza in Kishapu district, Tanzania.

MATERIALS AND METHODS

Study Site

The study was conducted in 2017 to 2018 among two community conserved forests, namely, Nyasamba and Bubinza of Kishapu district, Shinyanga region, located in northwest Tanzania (Figure 1). The district lies between 3° 15'' and 4° 05'' South of the equator and longitudes 31° 30''E and 34°15'' E east of the Greenwich meridian (URT, 2009). The district has a total area of 4,333 km^2, of which 101 km^2 is covered by forests. The district is characterized by a dry tropical (semi-arid) climate with temperatures ranging from 22°C to 30°C and 15°C to 18.3°C for maximum and minimum, respectively. It is a semi-arid area that receives 450 to 700 mm of rainfall per annum (NBS, 2012). Rainfall starts in late October/early November and ends in April/May while the dry season begins in June and lasts in November. The district is characterized by flat and gently undulating plains covered with low and sparse vegetation. The soil varies along with relief features such that on hilltop soils are moderately well drained greyish brown and sandy (KDP, 2013) whereas low-lying valley bottom soils are moderately deep well-drained and greyish brown sand.

Study Design and Forest Inventory

A ground-based field survey design (Brand *et al.*, 1991) under the systematic sampling technique (Philip, 1994) was adopted to assess the forest carbon stocking potential and soil organic carbon status. In this study, temporal circular plots of size 15 m radius (with inner sub-plot of 5 m) along transects were used for vegetation sampling (Figure 2). Before the transects were laid, a reconnaissance survey was made across the forest to obtain an impression in site conditions and physiognomy of the vegetation, collect accessibility information and to identify sampling sites. Following a reconnaissance survey, the coordinates range of the forest was determined from GPS reading and transects were laid. A total of 45 (Nyasamba 15, Bubinza 30) sample plots were established within transects. The distance was maintained at 550 m and 300 m, between transects and plots, respectively. In each plot, parameters such as herbaceous biomass productivity, trees stocking parameters (standing density, diameter at breast height and tree height), and soil samples were enumerated and recorded as per (Behera *et al.*, 2017; Pieper, 1988; Rubanza *et al.*, 2006) as shown below:

Within 5 m radius: four quadrats were thrown randomly in each of the four quarters of the plot to collect both herbs and soil samples for determination of herbaceous stocking and soil organic carbon (SOC) respectively.

Within 15 m radius: all trees with Dbh ≥ 5 cm were identified; the number of trees or stem numbers in case of forked trees was recorded. The diameter at breast height (cm) was measured using tree calliper while the tree height (m) was measured by using Suunto hypsometer.

The plant species were identified with the help of local floras and recorded based on both local (with the help of local botanist) and botanical names. Plant species that provided difficulty to identify in the field, the herbarium was prepared for identification at the Department of Biology, the University of Dodoma, Tanzania.

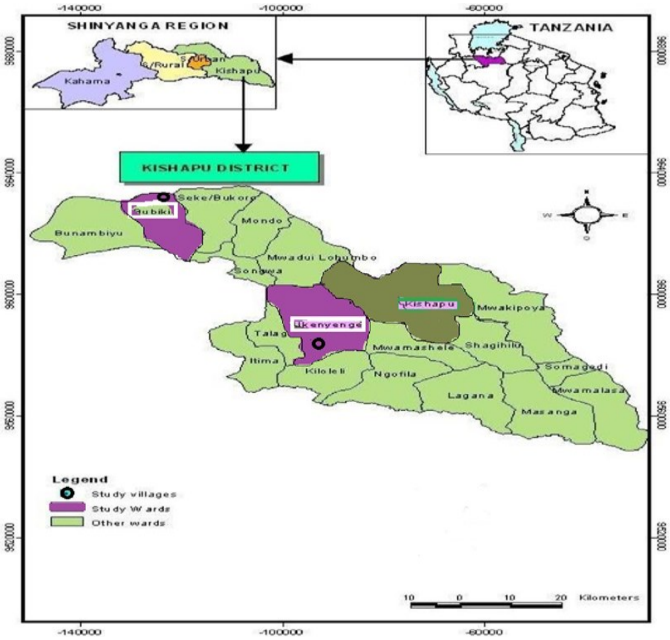

Figure 1. *The Map of the Kishapu to show the studied community conserved forests.*

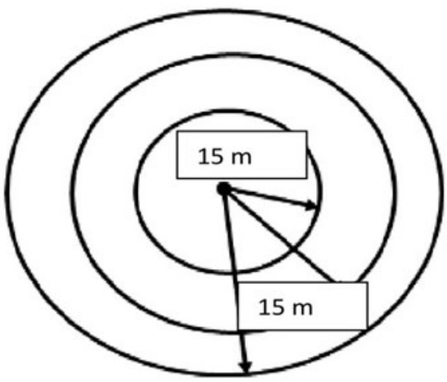

Figure 2. *Plot layouts showing the shape of 15 m radius plot and its sub-plots.*

Field Data Collection

Herbaceous Carbon Stocking and CO_2 equivalent

Data on herbaceous stocking and sequestration were determined by a destructive harvest method (Chambers and Brown, 1983). A technique which involves clipping off, the herbaceous individual's species contained in the quadrat at 1.5 cm above the ground using hand sickles. The clipped herbaceous species were immediately transferred to pre-weighed labelled paper bags and instantly weighted for fresh weight using a weighing balance (Model: CG 2002L ±0.001g accuracy). The samples were taken into the laboratory for a forced-air oven at 60°C for 48 h to constant weight to obtain dry matter (DM). The dry matter content was used to compute biomass productivity as described by Chambers *et al* (Chambers and Brown, 1983; Rubanza *et al.*, 2006) followed by C storage and sequestration estimation in t DMha^{-1} as shown in equation (1).

$$\text{Herb productivity} = \frac{\text{Total Dry weight (DM)}}{\text{Total number of quadrat}} * \text{Quadrat Per Area} \quad (1)$$

Tree Carbon stocking and CO_2 equivalent potential

Tree carbon stocks were estimated by a non-destructive field measurement method (Chave *et al.*, 2005; Chave *et al.*, 2014; Vesa *et al.*, 2010), which employs the use of allometric equations, taking into account measurable parameters like diameter (girth) at breast height, tree height, basal area and tree volume (Nath *et al.*, 2019; Paudela *et al.*, 2017).

The aboveground and belowground biomass was used for total tree carbon estimation. The use of site or region species-specific allometric equations was adopted to minimize sources of error during estimations (Nath *et al.*, 2019. The choice of the equation follows its region specificity, characterized by semi-arid, sub-tropical ecosystem (Malimbwi *et al.*, 1994; Philip, 1994) as shown in equations (2-7) below.

i) Above-ground tree biomass (AGB) was computed as per (Vesa *et al.*, 2010).

$$\text{AGB (tha}^{-1}) = \text{Tree bio-volume (m}^3\text{ha}^{-1}) * \text{Tree density (kgm}^{-3})/1000 \quad (2)$$

A single tree bio-volume equation was used to calculate the volume of each tree.

$$\text{Tree bio-volume (V, m}^3\text{ha}^{-1}) = g*f*h \quad (3)$$

Whereby, "*g*" stands for tree basal area (m^2) "*h*" for height (m) and "*f*" for form factor (0.5), while the single equation for tree basal area was

$$\text{(TBA)} = \pi\ (\text{Dbh}/2)^2 = 0.0000785*\text{Dbhi}^{th} \quad (4)$$

Where: π =3.142857, Dbhith =diameter at breast height for the ith tree (cm).

ii) Below-ground tree biomass (BGB) was calculated by multiplying the aboveground biomass (AGB) into 0.26 (shoot-to-root ratio).

$$\text{BGB (tha}^{-1}) = \text{AGB} \times 0.26 \quad (5)$$

iii) Total tree biomass (TB) was computed as the sum of the AGB and BGB

$$\text{TB (tha}^{-1}) = \text{AGB} + \text{BGB} \quad (6)$$

Conversion of Biomass to Carbon

Generally, for any plant species, 47% of its biomass is considered as carbon equivalent (Vesa *et al.*, 2010), therefore, the obtained results from herbaceous and tree species were converted into carbon stocks using the 'Default Carbon Conversion Factor' of 0.47.

$$\text{Carbon (tha}^{-1}) = \text{Biomass} * 0.47 \quad (7)$$

Soil Sampling, Carbon Stocking and CO_2 equivalent potential

Carbon stock inventory for the soil was done for the upper 30 cm depth in the nested plot, by collecting samples from 0-10; 10 -20 and 20-30 cm depth categories. The soil samples were composited for each depth class per plot. The soil sample was analyzed based on standard laboratory procedures. Bulk density was determined by core method using a 5 cm dia. 9 5 cm long steel core sampler for each depth class (Gandhi and Sundarapandian, 2017; Osei *et al.*, 2018) while soil organic carbon (SOC) was determined using Walkley-Black oxidation method (Walkley and Black, 1934) equation (8).

$$\text{C stocks} = \%\ \text{C} * \text{BD} * \text{Depth} \quad (8)$$

Where, C stocks = C expressed in Mg ha^{-1} for a given depth, % C = % Concentration of C in soil measured for each soil depth, BD = Bulk density, tones m^{-3} for each soil depth, Depth = Sampling depth.

Estimation of CO_2 equivalent (CO_2e) from different Carbon pools

The amount of CO_2 equivalent in different pools was estimated by multiplying the carbon stored by a factor of 3.67 (Iticha, 2017; Lasco *et al.*, 2002). This has generated from the relationship between carbon dioxide and carbon (the ratio of CO_2 to C is (44/12) = 3.67 (Siraj, 2019) (i.e. CO_2 is composed of one molecule of Carbon and 2 molecules of Oxygen).

The atomic weight of Carbon is 12.001115 and the atomic weight of Oxygen is 15.9994, the weight of CO_2 is C + O*2 = 43.999915. Then the ratio of CO_2 to C is 43.999915/12.001115 = 3.6663). As 1 Mg of soil and vegetation carbon = 3.67 Mg of CO_2 sequestered (Allen *et al.*, 2010; Siraj, 2019). Therefore, the equivalent CO_2 sink (Mg) in Nyasamba and Bubinza forest was estimated based on the total C stock as shown in equation (9).

$$CO_2 \text{ equivalent } (CO_2e) = 3.67 * \text{total carbon} \quad (9)$$

Data Analysis

The collected data were organized and recorded on the excel datasheet, followed by descriptive analysis for quantitative data using Microsoft excel of 2010 and SPSS software version 20.

Table 1. Carbon stocking and sequestration potential by herbaceous species in Nyasamba and Bubinza community reserved forests.

Forest name (s)	Vegetation type	Scientific name	Carbon stocks & sequestration		
			B(t/DM/ha)	C(t/DM/ha)	tCO_2 e/yr
Nyasamba	Grass	*Cynodon dactylon* (L.) Pers.	12.73	5.983	21.958
	Grass	*Echinochloa colona* (L.) Link	6.904	3.245	11.908
	Grass	*Sporoborus spicatus* Kunth	2.972	1.397	5.126
	Grass	*Dactyloctenium aegyptium* (L.) Willd.	2.596	1.22	4.477
	Grass	*Branchiaria mutica* (Forssk.) Stapf	2.193	1.031	3.783
	Grass	*Cyperus esculentus* L.	1.504	0.707	2.595
	Forb	*Cucumis anguria* L.	1.441	0.677	2.485
	Grass	Aristida funiculata Trin. & Rupr	1.37	0.644	2.363
	Forb	*Commelina benghalensis* L.	1.249	0.587	2.155
	Grass	*Rhynchelytrum repens* (Willd.) C.E.Hubb.	0.937	0.44	1.616
	Forb	*Rottboellia exaltata* L. f.	0.48	0.225	0.827
	Grass	*Digitaria scalarum* (Schweinf.) Chiov.	0.401	0.188	0.692
	Grass	*Panicum trichocladum* Hack. ex K. Schum	0.302	0.142	0.521
	Forb	*Oxygonum sinuatum* (Hochst. & Steud.)	0.263	0.124	0.454
	Forb	*Abelmoschus esculentus* (L.) Moench	0.226	0.106	0.391
	Forb	*Sida spinosa* L.	0.225	0.106	0.389
	Forb	*Sonchus luxurians* (R. E. Fr.) C. Jeffrey	0.223	0.105	0.385
	Forb	*Ipomoea batatas* (L.) Lam.	0.2	0.094	0.346
	Forb	*Corchorus capsularis* L.	0.175	0.082	0.302
	Forb	*Monechma debile* (Forssk.) Nees	0.173	0.081	0.298
	Grass	*Echinochloa colona* (L.) Link	0.16	0.075	0.276
	Sub-total carbon		36.724	17.259	63.347
	sub-total CO_2e		134.77708	63.34053	
	Mean±SE				3.01±1.12
Bubinza	Grass	*Aristida funiculata* Trin. & Rupr	44.941	21.122	77.519
	Grass	*Themada quadrivalvis* (L.) Kuntze	6.423	3.019	11.079
	Grass	*Cynodon dactylon* (L.) Pers.	3.498	1.644	6.035
	Forb	*Monechma debile* (Forssk.) Nees	3.389	1.593	5.846
	Grass	*Sphaeranthus suaveolens* (Forssk.) DC	2.822	1.326	4.868
	Grass	*Dactyloctenium aegyptium* (L.) Willd.	1.889	0.888	3.258
	Forb	*Sonchus luxurians* (R. E. Fr.) C. Jeffrey	1.415	0.665	2.44
	Grass	*Chloris barbata* Sw.	1.297	0.61	2.237
	Grass	*Rhynchelytrum repens* (Willd.) C.E. Hubb.	1.162	0.546	2.004
	Forb	*Lycopersicon lycopersicum* (L.) H. Karst	1.113	0.523	1.919
	Forb	*Ipomoea batatas* (L.) Lam.	1.091	0.513	1.882
	Grass	Chloris gayana Kunth	0.786	0.369	1.356
	Forb	*Oxygonum sinuatum* (Hochst. & Steud.)	0.696	0.327	1.201
	Forb	*Commelina benghalensis* L.	0.624	0.293	1.076
	Grass	*Heteropogon contortus* (L.) P.Beauv	0.392	0.184	0.677
	Grass	*Panicum trichocladum* Hack. ex K. Schum	0.309	0.145	0.533
	Forb	*Leucas martinicensis* (Jacq.) R.Br.	0.283	0.133	0.488
	Forb	*Amaranthus spinosus* L.	0.202	0.095	0.348
	Grass	*Sporoborus spicatus* Kunth	0.184	0.086	0.317
	Forb	*Cleome gynandra* L.	0.16	0.075	0.276
	Sub-total carbon		72.676	34.156	125.359
	sub-total CO2 e		266.72092	125.35252	
	Mean±SE				6.27±3.79
	Gland total tCO_2 e/yr				188.706

RESULTS AND DISCUSSION

Herbaceous carbon stocking and CO_2 equivalent

Results on herbaceous carbon stocking and CO_2 e potential is presented in Table 1. Carbon storage capacity was variable ($p<0.05$) across both species and sites, with a total of 188.71 t CO_2e/yr. Bubinza community forest recorded relatively higher herbaceous carbon stocks (125.36 t CO_2e/yr) than Nyasamba community forest (63.35 t CO2e/yr). *Aristida* spp., are the individual herbaceous species with relatively higher stocking and carbon sequestration (77.52 t CO_2e/yr) potential for climate change mitigation, others species with relatively high stocking are indicated in Figure 2 (A and B). The noted low herbaceous stocking potential of selected forests of Kishapu district suggest a great disturbance of the forests such as grazing pressure and poor of land use management practice by the village government.

With references to biomass productivity, the finding of this study concurs to the previous findings which were reported from other districts of the region (Otsyina *et al.*, 2008; Rubanza *et al.*, 2006). However, this study recorded a slightly lower average mean of biomass as compared to the work reported by Rubanza *et al.* (2006) and Otsyina *et al.* (2008). The noted slight variations on herbaceous biomass productivity observed in the

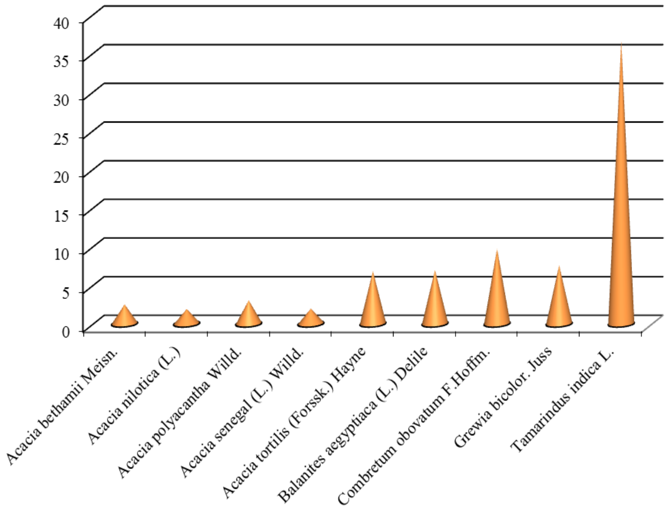

Figure 3 (A). *Tree species with relatively high stocking and CO_2e potential in Bubinza community conserved forests.*

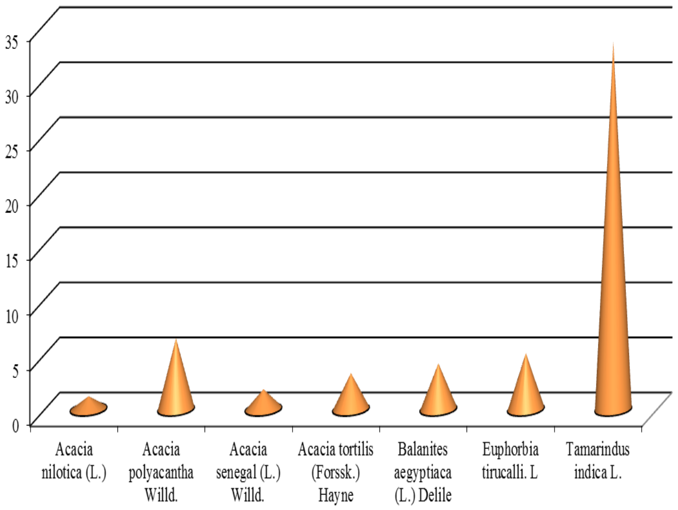

Figure 3 (B). *Tree species with relatively high stocking and CO_2e potential in Nyasamba community conserved forests.*

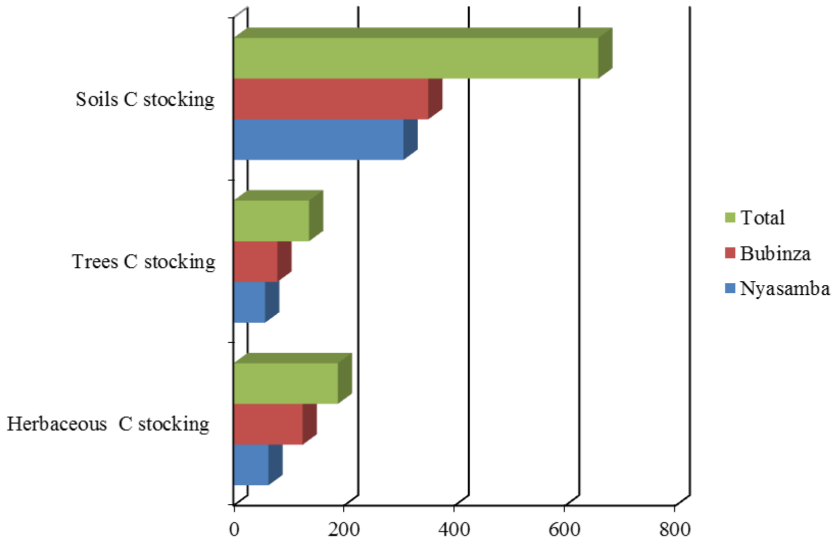

Figure 4. *Variations of carbon stocking and CO_2e potential in different C pool of Nyasamba and Bubinza community conserved forests.*

current study could be partly explained by differences in the management of the forests as well as sites specific characteristics. Anthropogenic disturbances including resource exploitation, deforestation, and overgrazing, have altered the understory forest structure and species composition making a serious impact on the sustainable herbaceous stocking and productivity potential in the study sites.

Tree carbon stocking and CO_2 equivalent potential

Results on tree sequestration in the surveyed community forests of Kishapu district are indicated in Table 2. There was no significant difference (P > 0.05) across tree species and sites. However, Bubinza had a relatively higher CO_2e (79.22 tCO_2e/yr) than Nyasamba (57.37 tCO_2e/yr). In both sites, *Tamarindus indica* recorded the highest sequestration of 37.7 and 33.4 t CO_2e/yr, in Bubinza and Nyasamba respectively. Other trees species with relatively high stocking and carbon sequestration are shown in Figure 3 (A and B).

The recorded tree stocking parameters were lower than that observed other districts of Shinyanga region (Monela *et al.*, 2005; Otsyina *et al.*, 2008) and other parts of Tanzania (Zahabu, 2008). The noted low forest stocking potential in the current study could be due to the high level of forest degradation and deforestation observed in most semi-arid areas of Tanzania. On the other hand, the high degree of disturbance particularly illegal tree cutting evidenced by a large number of stump cut trees might have influenced the recorded forests' stocking. The dry and semi-arid condition of the Shinyanga ecosystems could have influenced the poor tree stocking and hence climate change mitigation through sequestration. This observation is contrary to high stocking (1859.45 t ha^{-1}), reported in Ethiopia (Siraj, 2019) as part of East Africa. Of which 1549.54 and 309.91 t ha^{-1} was contributed by the above ground and below ground carbon, respectively. The forests are characterized by a small-sized tree with low dbh and short in height that acts as an important parameter for stocking. Therefore, proper forest management for good stocking potential and enhances climate change mitigation and CO_2 offset through carbon sequestration thereby reduce the effects of global warming is essential.

Table 2. Carbon stocking and sequestration potential by tree species in Nyasamba and Bubinza community conserved forests.

Forest name	Scientific name	AGB	BGC	TC	tCO_2e/yr
Bubinza	*Tamarindus indica* L.	0.752	0.13	0.65	36.731
	Combretum obovatum F.Hoffm.	0.15	0.038	0.188	9.73
	Grewia bicolor. Juss	0.117	0.029	0.146	7.589
	Balanites aegyptiaca (L.) Delile	0.108	0.027	0.135	6.989
	Acacia tortilis (Forssk.) Hayne	0.105	0.026	0.132	6.84
	Acacia polyacantha Willd.	0.047	0.012	0.059	3.045
	Acacia bethamii Meisn.	0.039	0.01	0.049	2.526
	Acacia senegal (L.) Willd.	0.03	0.008	0.038	1.969
	Acacia nilotica (L.)	0.029	0.007	0.037	1.912
	Ormocarpum kirkii S. Moore	0.011	0.003	0.014	0.715
	Capparis tomentosa Lam.	0.01	0.003	0.013	0.651
	Acacia drepanolobium Harms ex Y.Sjöstedt	0.008	0.002	0.01	0.524
	Sub-total carbon	1.406	0.295	1.471	79.221
	Sub-total CO_2e	5.16	1.0827	5.3986	
	Mean±SE				6.60±2.88
Nyasamba	*Tamarindus indica* L.	0.52	0.13	0.65	33.41
	Acacia polyacantha Willd.	0.1	0.025	0.125	6.48
	Euphorbia tirucalli. L	0.079	0.02	0.099	5.125
	Balanites aegyptiaca (L.) Delile	0.065	0.016	0.081	4.186
	Acacia tortilis (Forssk.) Hayne	0.051	0.013	0.064	3.299
	Acacia senegal (L.) Willd.	0.028	0.007	0.036	1.842
	Acacia nilotica (L.)	0.019	0.005	0.023	1.201
	Senna siamea (Lam.)	0.009	0.002	0.012	0.606
	Dichrostachys cinerea Wight et Arn.	0.008	0.002	0.009	0.487
	Acacia drepanolobium Harms ex Y.Sjöstedt	0.006	0.002	0.008	0.412
	Sub-total carbon	0.885	0.222	1.107	57.369
	Sub-total CO_2e	3.248	0.8147	4.0627	
	Mean±SE				5.70±3.15
Grand total tCO_2e/yr					136.59

Table 3. Carbon stocking and sequestration potential by soils in Nyasamba and Bubinza community conserved forests.

Forest name	Depth (cm)	BD (Mgm^{-3})	SOC ($t\ C\ ha^{-1}$)	$t\ CO_2e/yr$
Nyasamba	0-10	3.02	48.84	179.24
	10-20	2.82	22.57	82.83
	20-30	3.07	12.37	45.40
	Mean±SE			102.49±39.87
	Sub-total			307.47
Bubinza	0-10	3.03	37.17	136.41
	10-20	3.08	31.36	115.09
	20-30	2.94	27.54	101.07
	Mean±SE			117.52±10.27
	Sub-total			352.57
	Gland total CO_2e			660.04

Soil carbon stocking and CO_2 equivalent potential

Results on stocking and sequestration by soil pool are presented in Table 3. Carbon sequestration potential within soil varied across depths category (P <0.05), but not across sites (P >0.05). The soil pool recorded higher sequestration potential of 660.04 t CO_2e/yr (Nyasamba being 307.47 while Bubinza was 352.57) with a maximum value at 0-10 cm depth categories than other carbon pools (Figure 4). The noted soil stocking potential in this work denotes the potential of the forest for the supply of plant required macro and micronutrients for maintaining the ecosystem and preventing soil erosion and thereby improve ecosystem services and conservation for enhanced climate change mitigation. The noted higher carbon stocking potential in the uppermost layers (0-10 cm) depth category (179.24 and 136.41 tCO_2e/yr) than the lower layers (20-30) cm depths (45.40 and 101.07 t CO_2e/yr) in Nyasamba and Bubinza respectively, suggests a high rate of build-up of organic matter from plant litter in the topsoil layers than to subsoils, which are less altered by the vegetation type.

The same observation was reported by Osei *et al.* (2018) in other districts of the region. However, the observed variation on soil pool stocking could be attributed to the current trend of climate change due to great unpredictable precipitation. Other factors could be the previous history of the land-use system; For instance, Bubinza community forest was established on degraded sites for purposes of land restoration in 1980s HASHI programs (HASHI-ICRAF, 1997). As carbon sequestration rate of soil depends upon the input of dead organic matter provided by plants (Ussiri and Lal, 2017), similarly (Ruiz-Peinado *et al.*, 2017) reported soil properties, their aggregations and climate tend to influence stocking.

Conclusions and Recommendations

The findings from this study portray a significant low contribution of community conserved forest in carbon stocking and hence climate change mitigation, as it has small value for carbon stocks as well as the potential for carbon sequestration for enhanced climate change mitigation. This may provide a poor generation of carbon credits as financial benefits to the indigenous population, which supports the dedicated management of forest resources for the REDD+ initiatives in developing countries, Tanzania in particular. There is a need of strong participation of the local community as forest user groups and minimizing the disturbances caused by human interferences, such as grazing pressure, encroachment and logging economically and ecologically important tree species to enable the natural forest to sustain important role in climate change mitigation. The conservation of forest ecosystems is important in ensuring the health and productivity of forests that provide sustainable livelihood benefits to the local community and mitigate the negative impacts of climate change. There is a need for promoting reforestation and regrow of natural forest, using traditional available strategies. This is because indigenous knowledge has a value not only for the culture in which it evolves but also for scientists and planners striving to improve conditions in rural localities.

Therefore, the study suggests proper management of traditional conservation system that could largely enhance stocking potential and conservation, reduce the vulnerability to extreme climatic events and appropriate strategies are important not only as regards the conservation of these forests but also to improve the provision of ecosystem services and develop the strategies suitable for carbon trade for implementing the Reducing Emissions from Deforestation and Forest Degradation (REDD+) policy introduced in Kyoto Protocol.

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Conflict of interest

The authors declare no conflicts of interest.

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