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Research Article

Restoration of degraded lands for carbon stock enhancement and climate change mitigation: the case of Rebu watershed, Woliso Woreda, Southwest Shoa, Ethiopia

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Abstract

This study was conducted to estimate carbon stock enhancement and climate change mitigation potential of restoration effort in Rebu Watershed, Woliso Woreda, Ethiopia. Two restored lands of thirteen years old were randomly selected from two kebeles. Biomass and soil data were collected systematically from nested plots. Mensuration of woody species, soil, and grass/litter samples was collected from the subplots of the nested plots. A total of 72 composite soil samples were collected. The results showed the positive impact of restoration activity on enhancing biomass and soil organic carbon stocks. The restored land ecosystem had shown higher carbon stock of (138.51 ± 27.34 t/ha) than the adjacent unrestored land ecosystem (101.43 ± 21.25 t/ha), which confirmed the potential of restoration in enhancing the carbon stock and mitigating climate change. Hence, the restored land use type has been stored about 8.37 t/ha of carbon dioxide equivalent (CO_2e) in biomasses. The restored land use type has mitigated climate change (absorb CO_2) by 7.7 times than the adjacent unrestored land use type in this study. The significant values in restored land use types were due to the enhanced vegetation and land cover, which contributed to the biomass and soil organic carbon accumulation. Moreover, the lower values in unrestored land use type were due to the continuous degradation and disturbance from livestock and human beings. Therefore, the result of this study showed that protecting the degraded lands from any disturbance could enhance the carbon stocks of the ecosystem and mitigate the carbon emission rate.

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Introduction

Population growth, agricultural expansion, overgrazing, and unwise use of natural resources are the underlying causes of land degradation in Ethiopia (Change, 2007; FAO, 2010; Keenan et al., 2015). The increasing demand of rapidly increasing human population in the country has been aggravating the unwise use of natural resources so that the natural forest resources are being utilized beyond their recovering capacity (Hurni et al., 2010). The loss of the fertile soil by water erosion (onsite effect) and siltation of the downstream villages and dams (offsite effect) are the result of this deforestation and land degradation, which is a serious problem that has been challenging the country (Bewket and Teferi, 2009). Ethiopia has lost about 18.6% of its forest cover, or around 2,818,000 ha (FAO, 2010). Similarly, from 2010 to 2015, the estimated forest loss was 768,491 ha, which is about 1.33% per year (FRA, 2015). This deforestation and exploitation of forest resources have been forcing the land degradation problem to be augmented (FAO, 2010). Additionally, it reduces the organic carbon storage of the terrestrial ecosystem by increasing the release of carbon from the biomass and soil carbon pool; which may significantly increase the concentration of greenhouse gas (GHG) in the atmosphere (Noble et al., 2000).

Protecting the degraded land from disturbance is, therefore, one of the remedies for restoration. It can restore the degraded land that was out of use. Severely degraded land can be restored by preventing the disturbance agents, which favors the vegetation recovery (Gidey and Veen, 2014; Mebrat, 2015). It has been taking place in Ethiopia today by mass mobilization to reverse land overgoing land degradation. Consequently, it has been one of the intervention measures of the mobilization (Nedessa et al., 2005; Grey and Joosten, 2016) and recognized as the tool for rehabilitation of degraded ecosystem (MoA, 2016). However, the assessments of its success and baseline data are still limiting, while baseline data are helpful in the upcoming evaluation of the effectiveness of the restored land activities. That is why this study was designed to estimate carbon stock enhancement and climate change mitigation potential of restored land in relation to the adjacent unrestored land use type.

Materials and Methods

Description of the study site

Location

The study site Rebu watershed, Woliso Woreda, Southwest Shoa is located 100 km southwest of Addis Ababa. Geographically, selected kebeles from Rebu Watershed (Karo Simela and Werabu Berio) are located between 8°33'30" and 8°39'30"N latitude and 38°3'30" and 38° 6'00"E longitude (Figure1) and the altitudinal ranges of 1800-2063 meter above sea level (m asl) Restoration activity has been started by sustainable land management (SLM) project in 'Rebu' watershed since 2008GC.

Topography and climate of the study Woreda

Topographically, Rebu watershed has 73.25% flat land, 20% steep, 5% hill, and 1.75% depression (WANRO, 2010). The Wereda has two agro-climatic zones: weinadega (70%) and dega (30%). The rainfall pattern in the area is the bimodal type, i.e., Middle of March to end of May is the smallest (Belg); while July to September is a period of high precipitation (the Kiremt rain). The mean annual rainfall and monthly temperature of the woreda range from 700 mm to 1200 mm and from 17 °C to 29 °C, respectively (EMA, 2010).

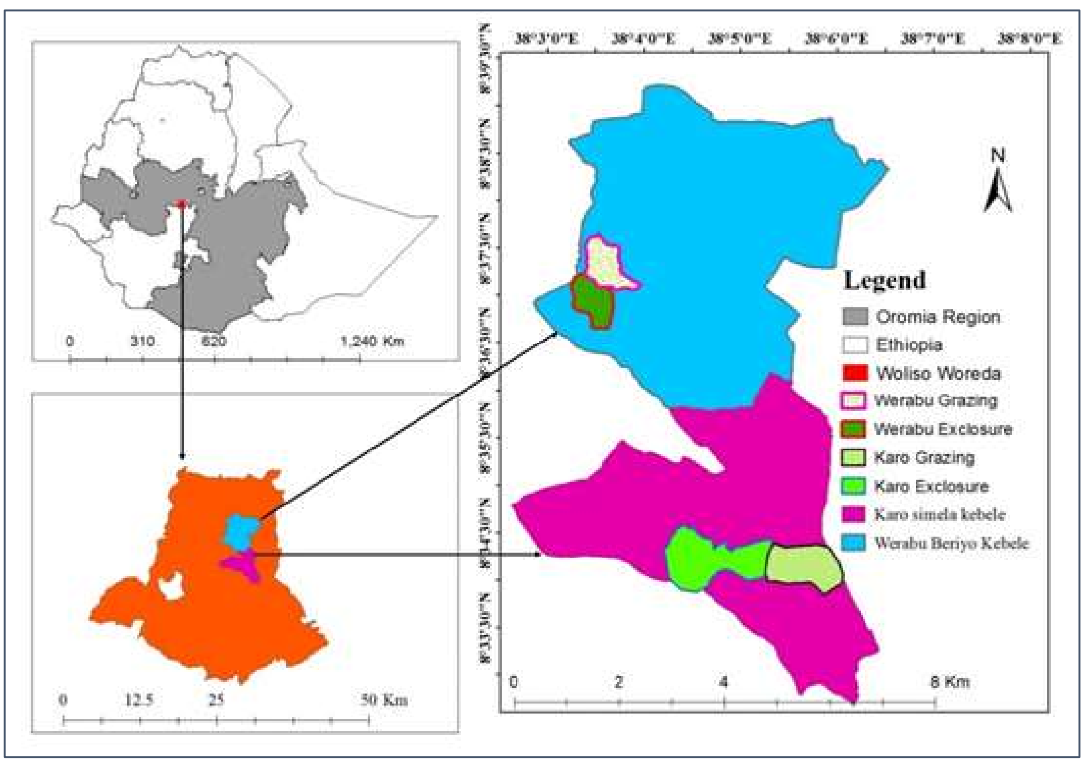

Figure 1: Location map of the study sites.

Soil types

The most dominant soil types in the Woreda are Nitosol and Vertisol. Nitosol is more dominant than Vertisol (covers about 65%) in the study area. Vertisol has dark color, poor drainage, difficulty to plow, limited root penetration, and expandable clay mineral (deep crack upon drying and swell upon wetting).

Nitosol is the most productive soil of the humid tropics that is characterized by its high proportion of silt content, stable soil structure that permits deep rooting, deep well-drained, reddish-brown color, and rich in iron (Fe) and have little water-dispersible clay (FAO, 2006).

Characteristics of the restored and unrestored land use types

The restored lands were established on degraded land with an area covering 46 hectares in two sites (Karo restored land = 22 ha and Werabu restored land = 24 ha) for the goal of restoration of plant species and reduction of soil erosion by water with the help of sustainable land management project since 2008. The restored lands were assisted by different physical soil and water conservation structures (level soil bund and trenches) and plantation of different exotic (*Grevillea robusta* and *Acacia decurrens)* and indigenous (*Cupressus lusitanica*) plant species. The soil type of both land uses is Nitisol with clay loam textural class. The unrestored land is free for livestock grazing and fuelwood extraction by the local communities. The unrestored land covers 49 hectares in two sites (Karo grazing = 24 ha and Werabu grazing = 25 ha). Poor vegetation cover characterizes this land use. It is dominated mainly by bush and shrubs of (*Carissa spinarum, Myrsine africana*, *Rhus glutinosa* etc.) species. Additionally, the unrestored land is exposed for soil erosion by water due to the livestock trampling and very little vegetation and grass cover that is probably called bare land.

Research design and data collection

Two restored land areas (one from each kebele) were selected with adjacent unrestored lands from two nearby kebeles. The GPS location of the study sites was collected (Pearson et al. 2005). Two transect lines and three sampling plots per transect line were established systematically (fixed grid) (Pearson et al., 2005). Nested plots (Pearson et al., 2005) of size 40m x 50m (2000 m^2) for restored land and 50m x 100m (5000 m^2) for unrestored land use types were used. The boundaries of the plots were established using a red-coloured rope and pegs at the four corners. Totally, 24 main plots (six main plots per land use x 2 land use types x 2 replication sites) with five subplots of size 1m x 1m per one main plot were established.

Woody species inventory and grass biomass estimation

Tree mensuration was carried out according to Pearson et al. (2005). The species identification was done in the field; local names were recorded and identified by using the field identification manual (Bekele, 2007). Grass, litter and herbaceous biomass measurement were taken from five subplots of size 1m x 1m. The fresh field weight was measured for each sample. From this weighed fresh sample, 100 g composite samples were taken for laboratory analysis.

Soil sampling

One composited soil sample was collected from the three subplots of size 1m x 1m in the bigger plot diagonally from left to right or right to the left direction for the determination of organic carbon content (% OC). A total of 72 composite soil samples (2 land use x 2 kebeles as replication of sites x 2 transect lines x 3 replicates of sample plots x 3 soil depth: 0-30, 30-60, and 60-100cm) were collected for physicochemical analysis.

Carbon stock estimation

The general equation for tropical forests by Chave et al. (2014) was applied to species that do not have their own specific allometric equation. The basic wood density was applied from the database of the International Centre for Research in Agroforestry (ICRAF). For *Acacia decurrens*, the allometric equation developed for *Acacia mearnsii* was adopted due to the lack of a specific allometric equation. Trees, shrubs, and saplings were categorized (Lai et al., 2009: Chave et al., 2014). The biomass carbon was computed by IPCC (2006) method.

AGB carbon = AGB * 0.47-----------------Equation (1)

AGB carbon for *Cupressus lusitanica* = 0.48*AGB --- Equation (2)

Mixed vegetation of dry Afromontane (*Olea europea, Premna schimperi, Rhamnus staddo, Rhus glutinosa, Rosa abyssinica,* etc.) and typical conifers (*Podocarpus falcatus* and *Cupressus lusitanica*) species were recorded in the restored land. Thus, the root to shoot ratio of IPCC (2006) species was used to compute the Belowground Biomass (BGB).

BGB = 0.27 * AGB ------------------------Equation (3)

where: AGB= Aboveground biomass and BGB= Belowground biomass

Hundred (100 g) of herbs, grass and litter biomass were sampled to determine an oven-dry to wet mass ratio (Pearson et al., 2005). The samples were oven-dried for 24 hours at 70 ^{o}C to take the dry weight (Jina et al., 2008; Negash and Starr, 2015).

$$\mathrm{LHGB} = \frac{\mathrm{W\ Field}}{\mathrm{A}} * \frac{\mathrm{W\ subsample(dry)}}{\mathrm{W\ subsample\ (fresh)}} * \frac{1}{10000} \text{------Equation (4)}$$

where: - 'LHGB' is Litter biomass (Mg/ha). 'W field' is the weight of wet field sample of litter sample within an area of size 1 m^2 (g). 'A' is the size of the area in which litter was collected (ha), W-subsample (dry) is the weight of the oven-dry subsample of litter (g), and 'W subsample (fresh)' is the weight of the fresh sub-sample of litter that was taken to the laboratory to determine moisture content (g).

The percent of carbon content was determined by the loss on ignition (LOI) method of Allen et al. (1986). The oven-dried samples were ground by a grinding machine and 3 g was taken for the determination of organic matter contents. The dry-empty crucible was weighed, and the 3-g sample was added to the crucible. The crucible containing the sample was put into the furnace for ignition at 550 °C for 2 hours (Negash and Star, 2015).

Then, the following formulas were applied.

$$\% \text{ of Ash} = \frac{(\text{Weight of Ash + Crucible}) - \text{Weig} \quad \text{of empty crucible}}{\text{Sample Weight}} x\ 100$$
---Equation (5)

%C = 0.5 * (100 - %Ash) (IPCC, 2006) ---Equation (6)

LHG carbon stock = LHGB* % C---------Equation (7)

where, OM = Organic matter, %C= Carbon fraction, LHGB= Litter, grass, and herbs biomass

The soil sample was facilitated for laboratory analysis. The soil was air-dried at room temperature for two days, then digested by mortar to pass through a 2 mm sieve in order to test soil organic carbon and texture. A standard laboratory procedure was followed. The soil sample collected for BD analysis was oven-dried at 105 ºC for 48 hours and weighed. Coarse-fragmented were separated by 2 mm sieve and the mass of the coarse-fragmented were recorded. The soil bulk density was computed as Pearson et al. (2005).

$$\text{BD} = \frac{\text{DM}}{\text{CV} - (\frac{\text{M}-\text{Coarsefrag}}{\text{Dens}-\text{rockf}})}$$ --------------------Equation (8)

Where: - ‘BD’= Bulk density (g cm^{-3}), ‘DM’= Dry mass (g cm^{-3}), ‘CV’= Soil core volume (cm^3) ‘M-coarse-frag’ = Mass of coarse fragmented (g), ‘Dens-rock-frag’ = Density of rock fragmented (g cm^{-3}) which is equivalent to 2.65 g/cm. Then, the soil organic carbon stock was analyzed as Pearson et al. (2005).

$\text{SOC stock} = (\text{BD} * \text{d} * \%\ \text{C})$ --------------Equation (9)

Where, ‘SOC’ = Soil organic carbon [Mg/ha], ‘BD’ = Bulk density [g/cm^3],‘d’ = depth of the soil [cm], ‘%C’ = Percent of carbon

The total carbon stock of the ecosystem was the sum up of all carbon pools: -

$\text{Carbon stock} = \sum \text{CAGB} + \text{CBGB} + \text{CLHGB} + \text{SOC}$
---Equation (10)

where, Carbon stock = Carbon stock density [Mg/ha], ‘CAGB’ = Carbon stock in aboveground biomass [Mg/ha], ‘CBGB’ = Carbon stock in belowground biomass [Mg/ha], ‘CLHGB’ = Carbon stock in litter, herbs, and grass biomass [Mg/ha], ‘SOC’ = Soil organic carbon from each depth [Mg/ha].

Finally, the current ecosystem biomass carbon storage was converted into CO_2e (t CO_2/ha) by multiplying carbon storage (t C/ha) with the molar conversion factor of 3.67 or 44/12 (Olschewski et al., 2005).

Statistical analysis

The data was organized on Microsoft Excel 2013 and analyzed using SPSS software version 16.0. The soil organic carbon stocks in the three depths (0-30, 30-60, and 60-100 cm) were summed up to give the SOC stock in the entire stratum (1 m depth). The total carbon pools in the two land use (restored land and unrestored land) were compared using t-test. Two-way ANOVA was also performed to test the differences of bulk density (BD) and soil organic carbon (SOC) in relation to land use system and soil depth (cm).

Results and Discussions

Biomass carbon stocks

Above and belowground biomass carbon stocks

In the restored land, three planted species had contributed about 48.6% of the total above and belowground biomass carbon stocks (Figure 2); of which *Grevillea robusta* accounted for (25.37%), *Acacia decurrens* (18.18%), and *Cupressus lusitanica* (5.05%). The remaining 51.4% was the contribution of natural regeneration. There was a significant variation in above and belowground biomass carbon stocks of naturally regenerated tree species under the two land use types ($p = 0.001$) (Figure 3). The total biomass carbon stock in restored land (17.72 ± 7.28 t/ha) was significantly higher than in unrestored land (2.28 ± 1.16 t/ha) (Figure 4). It was due to the presence of a higher number of stems (woody vegetation, shrubs, and saplings) and higher ground cover in restored land than in unrestored land. It confirmed the effectiveness of restored land on enhancing the above and belowground biomass carbon stocks by supporting the vegetation recovery and restoring the degraded unrestored land. This was confirmed with the justifications of Abebe et al. (2006), Mekuria (2007), Mekuria et al. (2009), Mekuria and Veldkamp (2012), Mekuria et al. (2017), in which higher total biomass carbon was stocked in restoration land use systems. It was comparable with the mean AGB carbon stock in the restored land of age between fifteen and twenty years old, in Tigray region, Ethiopia (about 15 t/ha) (Mekuria et al.,2009); Mekuria and Veldkamp, 2012). On the other hand, it was higher than the restored land of age less than ten years old in the same region in which a total aboveground biomass carbon 9.9 ± 1.7 t/ha was reported. The variation might be due to the ecological difference and variation in vegetation types. As well, the age of the restored land would have an influence on the biomass carbon stocks. That is, the above and belowground biomass carbon stock would increase with increasing age of the restored land through time until a constant value would be achieved (Mekuria et al., 2009; Mekuria and Veldkamp, 2012). Whereas, in this study, the difference in ecological zones, vegetation type, and model used might be the source of variation rather than the restored land ages.

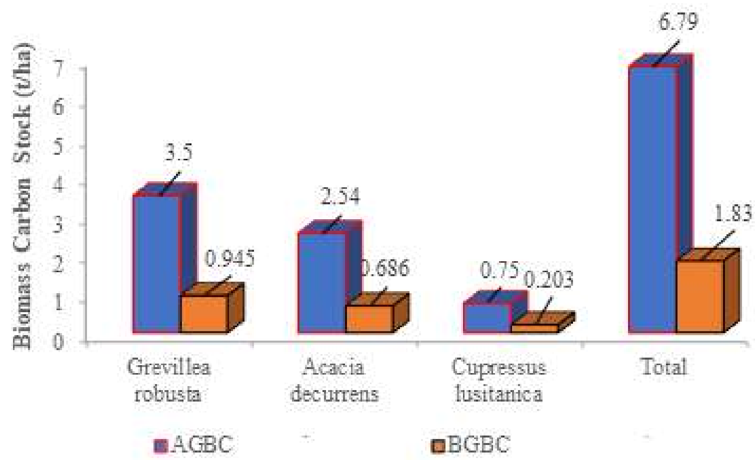

Figure 2. Biomass carbon stock of the assisted plantations by species type (t/ha). AGBC = Aboveground biomass carbon, BGBC = Belowground biomass carbon.

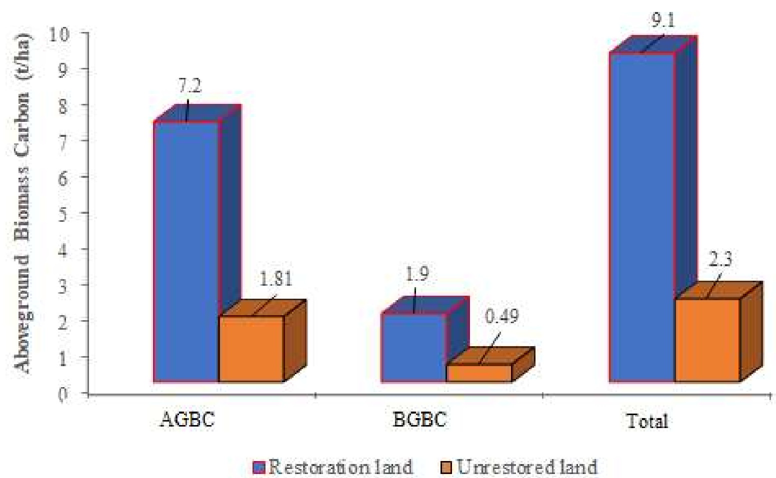

Figure 3. Above and belowground biomass carbon stocks of natural vegetation under restored and unrestored land use types (t/ha). AGBC = Aboveground biomass carbon, BGBC = Belowground biomass carbon.

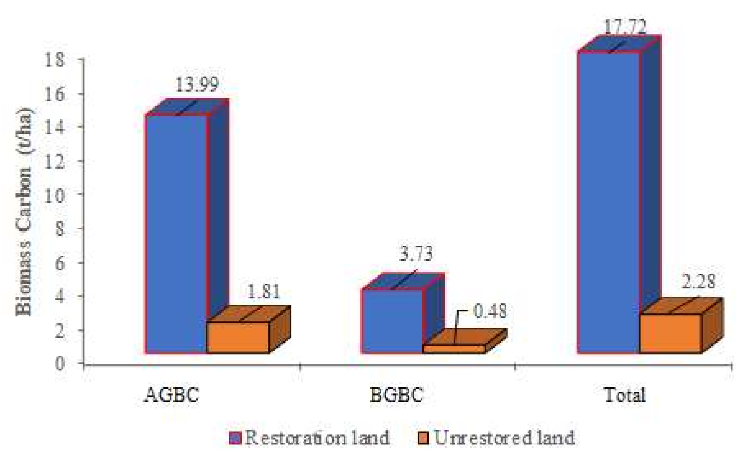

Figure 4. The overall above and belowground biomass carbon stocks under restored and unrestored land use types (t/ha). AGBC = Aboveground biomass carbon, BGBC = Belowground biomass carbon.

Grass, herb, and litter biomass carbon stock

The mean values of grass, herb and litter biomass carbon stock had shown a significant variation (Figure 5) under restored land and unrestored land (p = 0.001), due to the exclusion of human disturbance and livestock grazing from the restored land; while the unrestored land remained under the continuous livestock grazing (Mekuria and Yami, 2013). Livestock grazing can degrade the regenerative capacity of grasses, herbs, and woody vegetation (Sun et al., 2011; Mekuria and Yami, 2013, Lu et al., 2017). That is why the grass and herbs' biomass carbon was lower in the unrestored land than in the restored land.

The total litter, herb, and grass biomass carbon stock in the restored land of ten years in this study were lower than the litter-biomass carbon stock (5.175 ± 2.25 t/ha) that was reported in central Ethiopia by Tefera and Soromessa (2015). The variation could be due to:-the management difference, degree of vegetation cover, the specific site condition (soil fertility status), vegetation composition (species competition for light, nutrient, and moisture in dense vegetation), seasonal variation of collecting the grass and herb's samples and age of the restored land (Pandey et al., 2000; Descheemaeker et al., 2006; Salunkhe et al., 2014).

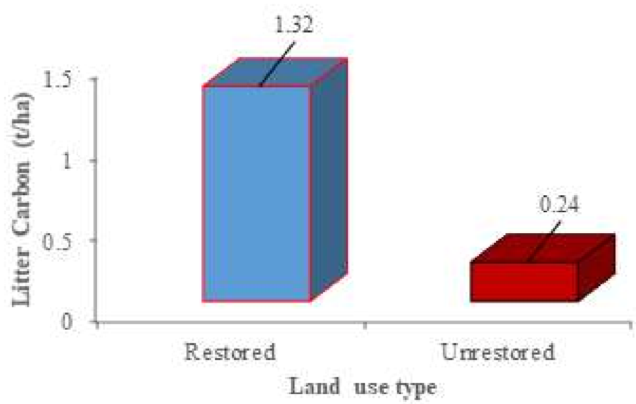

Figure 5. Grass, herbs, and litter carbon stock under the two land use types (t/ha).

Soil organic carbon stock

The soil bulk density showed that the variation (increased) with the soil depth (upper layer to bottom) and land-use types (restored land and unrestored land) (Figure 6); however, the variation was not significant except at the upper stratum (0-30 cm) (p = 0.044). As well, the variation within the restored land and soil depth was also significant (p = 0.047), while the variation within the unrestored land was significant at the third layer (60-100 cm) (p = 0.48).

The clay-loam textural class with land-uses and soil depth (Table 1) have indicated the similarity of parent materials that the soil derived from and implementation of the restored land did not affect the textural class of the study site yet (Mekuria and Yami, 2013; Yimer et al., 2015). The separation of the coarse-fragmented from the soil particles prior to the bulk density computation could minimize the overestimation of soil organic carbon stock due to the presence of course-fragmented (Pearson et al., 2005; Poeplau et al., 2017). Hence, the unrestored land had stored lower soil organic carbon stock in relation to the restored land regardless of the bulk density.

The significant variation in soil organic carbon stock under the restored land (119.47 ± 19.39 t/ha) than in the unrestored land (98.91 ± 19.96 t/ha) (Figure 7) was in line with Mekuria and Veldkamp (2007); Yimer et al. (2015), in which higher SOC was reported in the restored land than in unrestored land. Whereas, it was against the finding of Mekuria et al. (2017), in which insignificant SOC variation was reported between the restored land of seven years old and unrestored land. In order to notice significant SOC improvements, restored land requires extra years (more than 7 years) (Mekuria, 2013; Mekuria et al., 2017). The result of this finding (SOC = 119.47 ± 19.39 t/ha) in restored land was greater than the finding of Mekuria (2013), in which average SOC of (71 ± 7.83 t/ha and 93.63 ± 9.27 t C/ha) was reported in the restored land of ten and twenty years old respectively, at the highlands of the Tigrai region, Ethiopia. This might be due to the soil depth that had been considered (0-20 cm). The higher SOC stock in restored land was due to better vegetation and grass cover; those had stored higher organic matter through litterfall from the vegetation, grasses, and herbs (Yimer et al., 2015). Moreover, this justification had been approved by IPCC (2006) good practice guideline report "the large proportion of input is from aboveground litter in forest soils".

The significant variation of soil organic carbon stock under restored land (52.19 ± 11.96 t/ha) and unrestored land (37.98 ± 8.97 t/ha) at the upper stratum (0-30 cm) of soil depth was in agreement with Klopatek (2002); Hiederer (2009); Yimer et al. (2015); Iticha (2017). They had illustrated the decrease of the soil organic carbon concentration with increasing of the soil depth. This higher soil organic carbon stock accumulation in the upper layer than the lower might be due to the higher vegetation cover in the restored land that organic matter had been accumulated from decomposed litter and roots in the upper layer for the last decade in the study site; justified by IPCC (2006) and Yimer et al. (2015).

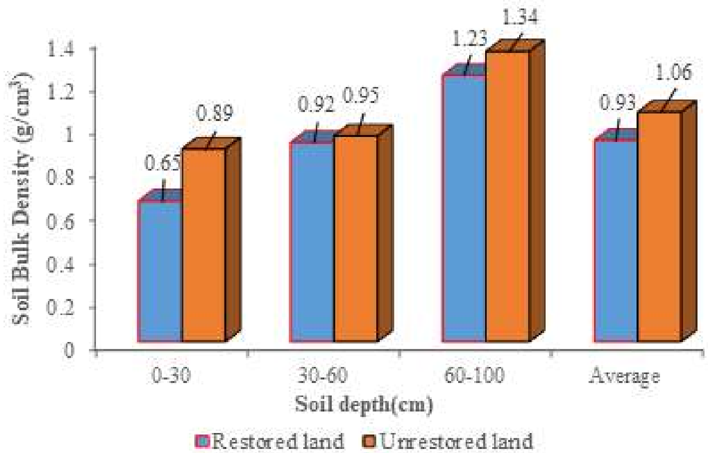

Figure 6. The soil bulk density of the restored land and unrestored land (g/cm^3)

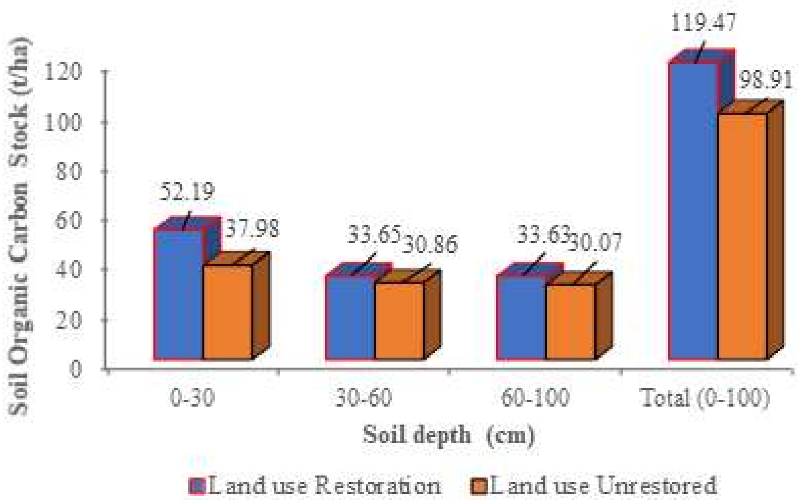

Figure 7. Soil organic carbon stock in relation to land use systems.

Table 1. The soil textural classes of the two land use types (Mean ± SD).

Variable	Land use type	
	Restored	Unrestored
Sand	32.94 (±5.21)	29.35 (±4.7)
Clay	31.85 (±4.60)	32.9 (±5.01)
Silt	35.21 (±6.62)	37.75 (±7.41)
Txt. Class	Clay Loam	Clay Loam

Note: Txt= Texture.

Ecosystem carbon stocks

The total ecosystem carbon stocks under the restored land use type were significantly ($p = 0.001$) higher than in the unrestored land (Figure 8). From the carbon pools (AGBC, BGBC, LHGC, and SOC) in this study, SOC pool was the largest carbon pool (86% of the total ecosystem carbon pools in the restored land and 97% in the unrestored land use types). This has confirmed with the reports of Chinasho et al. (2015), in which 55.5% of the total ecosystem carbon pool were SOC in forest ecosystem; Assaye and Asrat (2016), who had reported the largest SOC percentages (74.43%) of the total ecosystem carbon pools. Moreover, Mekuria et al. (2009); Ullah and Amin (2012); Mekuria (2013); Hailu (2017) had reported the largest SOC pool in the natural forest ecosystem than biomass and litter carbon pools; whereas, Ordonez et al. (2007), had reported the lower SOC pool than the biomass carbon pool. It could be due to the soil depth that had been considered (30 cm), if extra soil depth (1 m) was considered; the SOC pool would be higher than the biomass carbon pool.

The significant variations of the total ecosystem carbon stocks under the two land use types (restored land and unrestored land) were due to the combined effect of the total biomass carbon and soil organic carbon stock. The above and belowground biomass carbon stock was the second larger carbon pool in the restored land, which was accounted for 12.81% of the total carbon stock in the system. The higher ecosystem-biomass carbon stock in the restored land (17.72 t/ha) than in the unrestored land (2.28 t/ha) was estimated to be 65 t CO_2e/ha. It was the ecosystem CO_2 storage in above and belowground biomasses in the restored land use type for the last ten years. The amount of CO_2 gas that has been stored in the above and belowground biomass of the unrestored land was 8.37 t CO_2e/h. Here, the restored land has shown the implication of mitigating climate change (absorb CO_2) by 7.7 times than the unrestored land in this study.

The litter, grass, and herbs biomass carbon stock were the least carbon pool (0.85% and 0.21% of the total ecosystem carbon pool under the restored land and unrestored land, respectively. This has confirmed the finding of Salunkhe et al. (2014), Tefera and Soromessa (2015), Iticha (2017), in which the least litter-carbon stock was reported of the ecosystem carbon stocks.

The total ecosystem carbon stock (138.51 ± 27.34 t/ha) under the restored land in this study was higher than the total ecosystem carbon stock of the restored land of age ten years old (86.1 t/ha) and 15 years old (94.9 t/ha) in the lowlands of Tigray by Mekuria et al. (2009). Whereas it was lower than the report by Tefera and Soromessa (2015) in central Ethiopia (267.9 t/ha). The variation might be due to the variation in topography, vegetation type, soil types, and site-specific management.

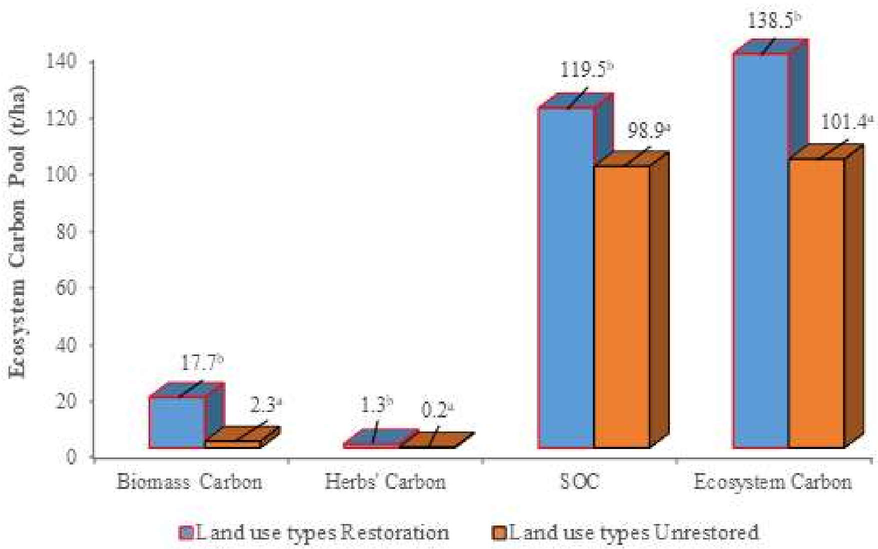

Figure 8. The ecosystem carbon pools (mean ± SD, t/ha).

Conclusion

The establishment of the restored land enhanced the biomass and soil organic carbon stocks of the ecosystem. Ended, the unrestored land contributes less due to the continued livestock grazing. The recorded higher biomass and soil organic carbon stocks in the restored land were due to the accumulations of shrubs and woody species following the restoration effort of ten years old. Consequently, restored land had stored 8.37 t CO_2e/ ha in above- and belowground biomass in relation to the unrestored land. Here, the restored land has mitigated climate change (absorb CO_2) by 7.7 times than the unrestored land in this study. This had validated the effectiveness of the restoration activities on mitigation of climate change and ecosystem resilience. It was the outcome of excluding disturbing factors (human and livestock grazing) from the given restored land area. Likewise, restoration of the degraded lands can improve the biomass and soil organic carbon storage by enhancing the vegetation, grasses, and herbaceous plant species. Thus, providing sufficient protection from human disturbance and livestock grazing in restoration could have enhanced the vegetation recovery, soil and biomass carbon storage besides mitigating climate change.

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