Assessment of Carbon Stock Potential of Parkland Agroforestry Practice: The Case of Minjar Shenkora; North Shewa, Ethiopia

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Abstract

Background: The anthropogenic global climate change has negative impacts on various sectors and communities who particularly rely on rain-fed agriculture. Parkland agroforestry practice can contribute to mitigate and adapt to the forthcoming climate change through carbon sequestration. However, empirical studies on carbon stocks potential of parklands agroforestry practices are scarce in different localities. This study assessed carbon stocks of parkland agroforestry practice at Minjar Shenkora woreda.

Methodology: By using two-stage stratified random sampling technique, 4 kebeles from two agro ecology were selected and 8 farms/plots/ of 40 m*40 m sample size were selected from each kebele for the vegetation inventory. Tree species-specific allometric equations were used to determine carbon stock potential of parkland agroforestry practice.

Results: The result reveal that, AGC, BGC, SOC and Total Carbon have significant variation ($p<0.05$) across kebeles. The mean total carbon stock of Bolo Giorgis, Bolo Slase, Agirat and Korma Agere is 48.87 Mg C ha^{-1}, 58.21 Mg C ha^{-1}, 57.81 Mg C $ha^{-1}$and 73.71 Mg C ha^{-1}; respectively. On average, carbon stock of parklands practice in Minjar shenkora was 59.65 Mg C ha^{-1}.

Conclusions: The parkland agroforestry practice has a large potential to deliver regulating ecosystem services like opportunities to mitigate the impending climate-changing through carbon sequestration and increasing the resilience of the agricultural system at Minjar shenkora woreda. To enhance the multiple ecosystem services of the parkland agroforestry practices in sustainable way: local by-laws should be strengthened to avoid illegal tree cutting and free grazing.

Background

The anthropogenic global climate change has negative impacts on various sectors and communities who particularly rely on rain-fed agriculture. The most prominent factor driving this climate change is increased atmospheric concentrations of greenhouse gases (GHGs) (WMO., 2007). As it is widely documented, the current global climate change is caused by the increase in the average temperature of the Earth's near-surface air and oceans in recent decades and its projected continuation (Asako, 2007).

A key mitigation strategy is to reduce the atmospheric concentrations of GHGs, particularly carbon dioxide (CO_2), through the process of carbon sequestration (Nair, 2011), besides reducing emission at source. Carbon sequestration can be done in terrestrial ecosystems such as in forests and agroforests, woodland scrubland and etc. Agroforestry is the practice of growing trees and crops or pasture in interacting combinations (Nair et al., 2010). It is a tree-based farming system that has been practiced for a long period of time in many countries including Ethiopia. During the past four decades, agroforestry has been known as an integrated approach to sustainable land use because of its production and environmental benefits. Its recent recognition as global climate change mitigation strategy under the Kyoto Protocol has given it an added attention (Nair et al., 2009).

Agroforestry has various systems and practices. Among others, the practices include parklands. Parklands are generally understood as landscapes in which mature trees occur scattered in cultivated or recently fallowed fields (Abdelkadir and Bishaw, 2003); or it is the coexistence of woody plants and grasses in subtropical and tropical savanna ecosystem (Bayala et al., 2006). The practice involves the growth of individual trees and shrubs in wide spaces in the farmland, while field crops are grown in the understory. Some of these trees were left when the natural forest was converted to other land uses; others regenerated after the land was cleared by farmers; and still others are deliberately retained or planted on the farmland (ICRAF., 2006) to provide multiple products and services such as soil structure improvement, moderate local climate, reduce erosion hazards and carbon sequestration.

Carbon sequestration refers to the removal of C from the atmosphere and deposition or storage in a reservoir such as oceans, vegetation or soil (Jose, 2009). Carbon sequestration in terrestrial ecosystems such as agroforestry systems and practices involves primarily the uptake of atmospheric CO_2 through photosynthesis and transfer of the fixed carbon into biomass, detritus, and soil pools for storage (Nair, 2011). The pools are categorized into above-ground and below-ground biomass, litter and soils. The above-ground biomass includes the carbon stored in live stems and leaves of trees and herbaceous plants and in standing and downed dead wood, below-ground biomass contains roots whereas litter/detritus and soils include the carbon stored in dead plant and animal parts, defecates, and the carbon stored in various soil horizons.

The mean carbon stock in soil and above-ground parts are estimated to hold major portions, roughly 60 and 30%, respectively, in tree-based land-use systems (Pan et al., 2011; Jose S., 2012). The estimates of carbon stored in agroforestry systems (AFSs) range from 0.29 to 15.21 Mg ha^{-1} $yr.^{-1}$ above-ground and 30 to 300 Mg C ha^{-1} up to 1 m depth in the soil. Recent studies under various AFSs in diverse ecological conditions showed that tree-based agricultural systems, compared to treeless systems, stored more carbon in deeper soil layers near the tree than away from the tree; higher soil organic carbon content was associated with higher species richness and tree density (Nair et al., 2010).

Most of the carbon in trees and shrubs are accumulated in above-ground biomass (AGB) and 50% of the total biomass is taken as carbon stock (Aklilu et al., 2015). Above-ground carbon stock is the amount of carbon that is assumed to be 50% of the total vegetation biomass (ICRAF., 2006; Lal. 2005). The below-ground biomass of vegetation is considered as a fraction that takes about 25–30% of above-ground biomass depending on the nature of the plant, its root system, and ecological conditions (ICRAF., 2006; Lal., 2005). Total biomass carbon is the sum of above and below ground carbon in vegetation (Kumar BM., 2011).

Agroforestry systems improve the resilience of smallholder farmers through more efficient water utilization, improved microclimate, enhanced soil productivity and nutrient cycling, control of pests and diseases, improved farm productivity, and diversified and increased farm income while at the same time sequestering carbon (Lasco et al., 2014).

Understanding above-ground tree biomass and soil organic carbon stocks provide opportunities for better management of the carbon pools. However, more rigorous research results are required for agroforestry systems to be used in global agendas of carbon sequestration (Nair et al., 2010).

Agroforestry systems and practices contribute to combat different economic and ecological problems. Studies on agroforestry systems have so far mainly focused on their spatial design, food production, soil fertility management, and system interactions, and little attention has been given to their ecosystem services, such as biodiversity conservation and carbon sequestration (Negash, 2013). In Minjar Shenkora woreda, like many parts of Ethiopia, there is a remarkable experience of traditional agroforestry practices mainly with parkland agroforestry practice on cultivated land. The carbon stock potential of parklands is different in sites due to variation in agro-climatic factors, in tree species, density and structure of tree species, management applied to parkland trees, agricultural land management (fertilization, fallowing, cropping of legumes, etc.), topographic factors (aspect, slope, and altitude), soil types, land-use history, etc. The presence of these large sources of variations and confounding factors highlighted that site-specific data is required to estimate its carbon stock potentials. On top of that, the potential of the parkland agroforestry in Minjar Shenkora for climate change mitigation was not investigated. Understanding the context-specific carbon stock of the parkland agroforestry will help land managers for better management of the carbon pools that are biomass and SOC. As a result, this study intended to carry out this study on parkland agroforestry practices at Minjar Shenkora woreda.

The study generated and documented important information on the role of parkland agroforestry practice in Minjar Shenkora woreda to climate change mitigation through carbon sequestration. This study will contributed to knowledge to the conservation of these unique agroforestry systems and to the recognition of the ecosystems services they provide to the local communities (food production, and income, soil and water protection, maintenance of soil fertility) and beyond (carbon sequestration and climate change mitigation, and conservation of biodiversity) (Negash, 2013). This study aimed at determining the carbon stock potential of parkland agroforestry practice in Minjar Shenkora woreda, North Shewa, Ethiopia. The question that addressed in this experiment are: How much carbon is stored in the parkland agroforestry practice of the study area? How much carbon is stored in above, below ground and soil carbon pools in the study area? Which tree species have the highest carbon stock potential in the study area?

Materials And Methods

Site Description

The study was carried out in Minjar Shenkora Woreda, North Shewa Zone of Amhara Regional State, Ethiopia which is located at about 135 km south-east of Addis Ababa, at 90º 6' and 90º 5' N and 39º 46' and 39º 26' East and has a total area of about 229,463 ha. The altitude of the study area ranges from 1400–2400 m.a.s.l. The topography of lands in the woreda is characterized by diverse geomorphological features. Data from the Woreda agricultural office indicate that plateau or flat plains features (65%), followed by 20% of the land area is mountainous, ravines (10%) and 5% other topographic features.

According to MSDARDO, Minjar Shenkora woreda has different soil types suitable to harvest various kinds of grains. The most dominant soil type in the study area is heavy clay soils known as vertisols and reddish-brown loam known as cambisol.

The woreda falls within three major agro-climatic zones, Dega (high altitude), Weyna Dega (Mid altitude) and Kola (low altitude). The highest mean annual rainfall of the study area within the last ten years was 1028 mm, whereas the lowest mean total was 162.8 mm. According to North Shewa Agricultural and Rural Development Bureau, Minjar Shenkora district has annual average temperature range between 13.21^{0}c and 23.02^{0}c.

The vegetation type is *Acacia wooded grassland* (Ib Friis, 2010). On most of the plain areas on which crop cultivation is dominant, *Faidherbia albida, A. tortilis*, *A. seyal, A. nilotica, Croton macrostachyus, and Ziziphus mauritiana* are scattered across with the farm plots which are the main components of agroforestry type of agricultural system with agricultural crops.

Cereals and pulses are among the commonly cultivated crops in the area for the purpose of household consumption and income through the sale. These include sorghum *(Sorghum bicolor), wheat (Triticum aestivum)*, *teff* (*Eragrostis teff)*, barley (*Hordeum vulgare)*, onion *(Allium cepa)*, pea *(Pisum sativum)*, Chickpea *(Cicer arietinum*) *and* Horse bean *(Vicia faba)*. Currently, due to the introduction of rainwater harvesting technology through ponds, farmers grow vegetables in small gardens as well as in the fields.

Materials

The equipment used for fieldwork should be accurate and durable to withstand the rigors of use under adverse conditions. The type of equipment required depended on the type of measurements (Pearson et al., 2005). The following materials were used for this study to collect available data meter tape for measuring distances of sample plot, hypsometer to measure height of tree, caliper to measure tree diameter, auger to take soil sample, cloth or paper bags to collect soil sample, core sampler to take soil sample for bulk density and Global Positioning System (GPS) to collect coordinate point of study site.

Sampling and data collection Methods

The Minjar Shenkora woreda is selected purposively as a study area by considering the extensive presence of parkland agroforestry practice. A preliminary reconnaissance survey had been conducted to identify the study area. Key informants i.e. development agents, elders and woreda natural resource experts were consulted to identify farmers and study site that contain parklands agroforestry practice on their lands-based accessibility, resource and time. The woreda is composed of 27 kebeles out of which parkland agroforestry practice is found in 21 kebeles. Moreover, the woreda has three agro-ecologic zones: dega with 6 kebeles; weyna dega with 11 kebeles; and kola with 10 kebeles. Based on this information from the woreda office of agriculture, two-stage stratified random sampling technique was used to select the unit of sampling for the study. In the first stage, a total of four kebeles: two kebeles (Bolo Giorgis and Bolo SIase) from weyna dega and two kebeles (Agirat and Korma Ager) from Kola agro-ecologies were selected randomly as specific study areas. In the second stage, by considering the list of farmers who owned farms with parkland agroforestry practice in the kebeles as a sampling frame, a total of 32 farm plot for the carbon stock determination, size 40 m*40 m (Talemos and Sebsebe., 2017; Tadesse, 2015) were randomly selected from Bolo Giorgis, Bolo Slase, Agirat and Korma Ager. The sample size accounts about 7% of the household and therefore considered adequate to balance reliability and cost. There are different mechanisms to determine the number of samples: the census for small populations, imitating a sample size of similar studies, using published tables, and applying formulas to calculate sample size (Israel, 1992). Among the listed methods sample size determination using similar studies was employed for the present study (Asefa and Worku, 2014; Tadesse, 2015).

The plot method was used that involves selecting plots of an appropriate size and number, laying them randomly in the selected strata (Tadesse, 2015). Plots can be marked at four corners in conspicuously (for example, by sinking available material below the ground and navigating to plot using a GPS. The plot size chosen was large enough to encompass the diversity of tree species on the smallholdings (Negash, 2013; Nair et al., 2008).

Carbon stock of woody species (dead trees, live trees), below-ground biomass (stumps plus coarse roots; >2 cm diameter and fine roots) and soil organic carbon were estimated. The farmland of sample households was used as a sample plot for inventory. Accordingly, woody species inventory was carried out on the farmlands of selected households located in the kebeles. In present study, woody species data were collected from 40 m × 40 m sample size quadrates (Nikiema, 2005), but the quadrat size in the study of the mentioned author is 50 m*100 m because of low density of trees on farmland in the study area, However; in our case as the density of trees on farmland is relatively high, a sample plot of 40 m*40 m was considered as an optimum plot size. The collected data were the name of species, tree diameter at breast height, tree height, tree diameter at stump height, soil sample, and location of the plot using GPS. All the woody species in each sample plot ≥ 5 cm DBH (diameter at breast height) were measured because below these DBH there are insignificant amount of biomass (Motuma et al., 2008). At every sampling point, a number of individuals per plot, DBH, height, and DSH of live trees were measured and recorded by using a measuring tape, caliper, and hypsometer.

At every sampling point from the selected study site, 20 m × 20 m subplots were taken for soil sampling from each corner and at the center of the plot. The most common depth for sampling is 30 cm but sometimes SOC is sampled to up to 1 m (David, 2013). The importance of sampling beyond the surface soil cannot be overemphasized while studying tree-based systems such as agroforestry, not only because tree roots extend to deeper soil horizons, but also because of the role of subsoil in long-term stabilization of C. Soil sample taken in the depth of 0–20 cm and 21–40 cm by using auger and core sampler. Two sets of soil samples were taken, one set for the determination of SOC contents and fine root (< 2 cm diameter) biomass and others for the determination of soil bulk density. In each case, samples of the 0–20 cm and 21–40 cm layers were taken from the four corners and center of each of 20 m × 20 m tree inventory plot and composited by layer while following (Negash and Starr, 2015). Two soil samples were taken from each sampling point after compositing the same depths together to get one representative soil sample. Four replication *eight plots for each replication * two soil depth, and hence a total of 64 soil samples were taken for soil carbon analysis.

Data Analysis

The non-destructive method was used for the estimation of carbon stock. The C content of tree biomass had been taken to 48%, the biomass weighted mean value for trees grown in agroforestry systems in Kenya (Kuyah et al., 2012a). To estimate biomass of tree species-specific allometric equation from woody biomass inventory for Ethiopia was used for almost all tree species but for *Citrus sinensis* general allometric equation (Kuyah et al., 2012a) was used.

$AGB = 0{:}0905 * DBH^{2:4718}$; $R^2 = 0{:}98$; n = 72 ———— (1)

This equation was developed in areas having similar environmental conditions (climate and soils) with the study area. CO2 was calculated using this formula; the amount of carbon is multiplied by the ratio of the molecular weight of carbon dioxide to the atomic weight of carbon (44/12) (Tadesse, 2015).

Below ground biomass (BGB) (stump plus coarse roots, > 2 cm diameter and fine root) was estimated by using the allometric equation (Kuyah et al., 2012a);

$BGB = 0.490AGB^{0:923}$; $R^2 = 0.95$; n = 72 ———— (2)

The soil samples were analyzed to determine SOC, soil organic matter, pH, soil texture, and bulk density in Debre Dirhan Agricultural Research Center soil laboratory. We determined the soil bulk density by dividing the weight of oven-dried soil sample by the volume of core.

SOC is determined through laboratory analysis of the soil carbon concentration, volume of the soil sample, and the bulk density of soil samples collected in the study area (David, 2013). The soil samples were dried in oven-dry by 70 ^{o}c for SOC content (%) and 105 ^{o}c for bulk density until getting constant weight and analyzed (Negash and Starr, 2015). Before that, the soil samples were treated with HCL acid to remove inorganic carbon. Then the soil organic carbon was determined following the wet digestion method (Walkley, 1934), A correction factor of 1.33 was applied to account for the incomplete oxidation of organic carbon that is known to occur with the Walkley-Black method (Rosell and Gasparoni, 2000).

Soil organic carbon (SOC) was determined by using the equation (Subedi and Pandey, 2010; Pearson et al., 2005);

SOC (Mg/ha) = BD (g/cm^3) × depth (cm) × carbon%×10^{-1}. ———— (3)

Where: BD = bulk density and 10^{-1} is a unit factor (10^{-9} mg Mg^{-1} × 10^8 cm^2 ha^{-1}).

BD (gm/cm3) = (oven-dry weight of the soil) / (volume of the core) ———— (4)

Results

Biomass Carbon Stocks in Parkland Agroforestry Practice

The species-specific allometric equations that used to estimate biomass of tree species are selected based on their developed agro ecology that relates with the study site (Table 1).

Table 1
The species and their allometric equations were applied in the study area.

Species	Allometric equation used	R^2	Reference
Acacia seyal	AGB=(0.9103*DSH)+(0.6782*(DSHexp1.7))	0.9	(WBISPP, 2004)
Acacia abyssinica	AGB=(0.0497*DSH)+(0.0300*(DSHexp2.8))	0.9	(WBISPP, 2004)
Acacia etbaica	AGB=(-0.1024*DSH)+(0.1502*(DSHexp2.3))	0.88	(WBISPP, 2004)
Acacia nilotica	AGB=(2.3624*DSH)+(0.0035*(DSHexp3.4))	0.96	(WBISPP, 2004)
Acacia tortillis	AGB=(0.1725*DSH)+(0.0106*(DSHexp3.0))	0.97	(WBISPP, 2004)
Carica papaya	AGB=(0.02445*DSH)+(0.2451*(DSHexp2.6))+(-0.1022*(DSHexp2.8))	0.92	(Kuyah et al., 2012)
Croton macrostachyus	AGB=(0.3679*DSH)+(0.0459*(DSHexp2.5))	0.99	(WBISPP, 2004)
Ebretia cymosa	AGB=(0.8808*DSH)+(0.0348*(DSHexp2.5))	0.98	(Larwanou M., 2010)
Faidherbia albida	AGB = 7.985Dbh + 32.277	0.33	(Larwanou M., 2010)
Olea africana	AGB=(0.6806*DSH)+(0.0422*(DSHexp2.7))	0.91	(WBISPP, 2004)
Ziziphus spina-christi	AGB=(0.0340*DSH)+(0.0431*(DSHexp2.6))	0.97	(WBISPP, 2004)
Eucalyptus camaldulensis	$AGB = 0.0155(DBH)^{2.5823}$	0.99	(Hailu, 2002)

There was a variation in the mean above-ground carbon stock between the kebeles on PLAP in study areas (Table 2). PLAP in Bolo Slase kebele had higher AGC (9.39 Mg/ha.) by 64.64% as compared to

Agirat (3.32 Mg C ha^{-1}). The mean AGC and BGC along kebele were significantly different ($F = 3.09$, $p < 0.05$). The difference in variation in BGC is similar to AGC in study kebels. The carbons stock in below ground of PLAP was higher in Bolo Slase (3.6 Mg C ha^{-1}) than Agirat (1.39 Mg C ha^{-1}.) at 0.05 significance levels. The contribution of above-ground and below-ground biomass carbon stock for total biomass carbon stock in parkland agroforestry practice is 71.58% and 28.42%, respectively. SOC, attitude, and pH (1:2.5) are correlated with each other. Above-ground carbons stock in *Acacia nilotica* (0.46 Mg/tree), *Acacia abyssinica* (0.215 Mg C ha^{-1}) and *Croton macrostachus* (0.193 Mg C ha^{-1}.) were higher than other tree species in parkland agroforestry practice in study areas. *Acacia nilotica, Acacia abyssinica*, and *Croton macrostachus* sequestered *2.12 Mg, 0.98 Mg*, and *0.88 Mg CO_2* respectively. There is strong variation in AGC, BGC and CO_2 sequestration potential of tree in study areas ($F = 4.34$, $p < 0.01$).

Table 2

Mean (± standard error) biomass (Mg ha^{-1}), biomass carbon, SOC and total carbon stocks (Mg C ha^{-1}) for each of the kebele and results of one-way ANOVA (at α = 0.05)

Biomass and carbon pool	**Kebeles**					
	B/giorgis (M.altitude)	**B/slasi (M.altitude.)**	**Agirat (L.altitude)**	**Korma ager (L.altitude)**	**GM.**	**Sig.**
AGB (Mg ha^{-1})	12.71(2.88)^{ab}	19.54(4.81)^{a}	6.92(1.35)^{b}	10.56(1.77)^{ab}	12.44	*
BGB (Mg ha^{-1})	5.07(1.05)^{ab}	7.50(1.72)^{a}	2.89(0.53)^{b}	4.28(0.68)^{ab}	4.94	*
AGC (Mg ha^{-1})	6.1(1.38)^{ab}	9.38(2.31)^{a}	3.32(0.65)^{b}	5.07(0.85)^{ab}	5.97	*
BGC (Mg ha^{-1})	2.43(0.5)^{ab}	3.6(0.83)^{a}	1.39(0.25)^{b}	2.05(0.33)^{ab}	2.37	*
SOC Mg ha^{-1}. 0–20 cm	20.85(1.42)^{b}	23.84(1.18)^{b}	26.55(1.64)^{ab}	33.14(2.65)^{a}	26.09	***
SOC Mg ha^{-1}. 21–40 cm	19.49(1.09)^{b}	21.38(2.38)^{b}	26.55(1.71)^{ab}	33.45(2.22)^{a}	25.22	***
SOC Mg ha^{-1}. 0–40 cm	40.34(1.84)^{b}	45.22(3.36)^{b}	53.10(3.25)^{b}	66.59(4.62)^{a}	51.31	***
TC (Mg ha^{-1})	48.87(2.53)^{b}	58.2(4.56)^{b}	57.81(3.18)^{b}	73.71(2.27)^{a}	59.65	***

Note: Similar letter shows no a significant difference and different letters indicate a significant difference between groups at 5% level significant. *=p < 0.05, ***=p < 0.001. Where; M.altitude = weynadega agro-ecology, L.altitude = lowland agro-ecology. TC = Total carbon, GM = grand mean and Sig. =significance.

Soil Organic Carbon Stock

Unlike AGC and BGC, Soil organic carbons were higher in korma Agree (66.59 Mg ha^{-1}.) than Bolo Giorgis (40.34 Mg ha^{-1}.). Similar to our hypothesis; the mean soil organic carbon along kebele was significant different ($F = 11.29$, $p < 0.001$). The average carbon stock of parkland agroforestry practice in soil organic carbon in the study area was 51.31 Mg ha^{-1}. The bulk density of soil found in the study site was ranged from 1.01 g cm^{-3} of minimum to 1.38 g cm^{-3} maximum value with the average value of 1.21 g cm^{-3}. Soil organic matter was range from 1.14–3.38%. There was strong variation in soil organic carbon stock in parkland agroforestry practice between the studied areas (Table 2).

Total Carbon Stock of PLAP

Total carbon stock of parkland agroforestry practice across kebele have statistically significant difference ($F=7.74$, $P<0.001$). Total carbon stock potential of parkland agroforestry practice in M/Shenkora on average was 59.65 Mg C ha^{-1}. The highest total carbon stock density scores in korma Ager (73.71 Mg C ha^{-1}) and the lowest in Bolo Giorgis (48.87 Mg C ha^{-1}). The contribution of AGC, BGC, and SOC for total carbon was 10.02%, 3.98%, and 86.08%; respectively. Low altitude agro ecology has the higher carbon stock by 33.7% than mid altitude agro-ecology in the study area.

Discussion

Biomass Carbon Stock of PLAP

Biomass carbon stock of parkland agroforestry practice showed that there is significant variation along with different kebele of agro ecology; these are due to biomass affected by stand age, tree species and structure, managements, diversity and composition (Chave et al. , 2004). Our result indicates that mean biomass and its carbon stock of PLAP was higher in mid altitude (B/Giorgis and B/Slase) agro-ecology than low altitude (Agirat and Korma Ager*)* agro-ecology. These are due to number of tree per hectare was higher in mid altitude agro ecology because of the presence of favorable environmental condition than low altitude agro-ecology so that; the presence of species characterized by large individuals and also possibly due to the favorable conditions for tree growth in the middle altitude, because few large individuals can account for a large amount of above and below ground carbon (Rahayu et al., 2005). The biomass carbon stock is higher in high gradient elevation than low gradient elevation. This agrees with the results of Gebrewahid et al., 2018 that was carried out in Tigray, North Ethiopia. However, the result of (Leuschner et al., 2007; Zhu et al., 2010) who reported that above and below-ground tree biomass and its carbon stock decline with an increase in altitude is not agree with the result of this study.

The present study show that, individual tree's biomass carbon stock range from 0.002-0.29 Mg C. Carbon storage in individual tree species varies from 0.04 Mg C to 25.65 Mg C (Mishra et al., 2012). Tree species as they vary widely in properties that drive carbon sequestration such as growth, mortality, decomposition and their dependency on climate (Purves and pacala, 2008).

The mean total biomass carbon stock of PLAP in the study area was 8.34 Mg C/ha. The result was substantially higher than the parkland agroforestry system in Gununo Watershed, Wolayitta Zone, Ethiopia (Aklilu et el., 2015), However lower than that of the study of (Gebrewahid et al., 2018) that was carried out in Tigray and (Montagnini and Nair, 2004). This could be due to lower diameter trees documented in my study. The average above-ground carbon storage potential of agroforestry systems in semiarid, sub-humid, humid and temperate regions has been estimated to be 9, 21, 50 and 63 Mg C ha^{-1}, respectively (Montagnini and Nair, 2004). The total biomass carbon stock of PLAP in the study area was in the range of 0.98-26.89 Mg C/ha. Therefore, this result was within the range reported on a global scale Agroforestry system stores 12 to 228 Mg C ha−1 (Dixon, 1995). The trees on farmland frequently are managed by pollarding, thinning and coppicing every year at the end of the dry season to reduce its shading effect and competition for light and nutrition on the crop; that case to reduce tree biomass (Jandl *et al*., 2007).

Soil organic carbon

Soil organic carbon is a significant carbon pool because it has the longest residence time among organic carbon pools (Lugo and Brown, 1993). Our results show that soil organic carbon had an inverse relationship with soil pH (Kundu *et al*., 2017) and elevation gradient (Mawer *et al*., 2018; Negash and Starr, 2015). At low soil pH the decomposition rate is reduce due to that there are high accumulation of SOC (Mcclaugherty, 2007). Soil organic carbon of PLAP in the study area ranged between 29.66 Mg C ha^{-1} and 92.86 Mg ha^{-1}. These results are in line with the range of 18.5–52.5 Mg C ha^{-1} and 22.4– 54.0 Mg C ha^{-1} that reported in stocks of cultivated and grazing land of East and West Africa (Brown et al., 2012) and that of parkland agroforestry practiced in southern Ethiopia was ranges in 28.2–98.9 Mg ha^{-1} (Demessie et al., 2013). The result shows that, SOC is higher in low land agro ecology than midland agro ecology due to SOC has an inverse relationship with elevation gradient (Mawer *et al*., 2018; Negash and Starr, 2015). The increasing tendency of carbon density with decreasing altitude may be because of soil leaching, better mineralization and stabilization of SOC at lower altitudes (Mawer *et al*., 2018). The range of SOC that in the study that was carried out in Tigray, was 2.28 and 40.5 Mg C ha^{-1} (Gebrewahid et al., 2018). The mean soil organic carbon of PLAP in the study area was 51.31 Mg C ha^{-1}. SOC in our study was remarkably high as compared to results conducted in semi-arid *Acacia etabica* woodland in southern Ethiopia (43 Mg ha^{-1}) (Lemenih, 2004), carried out in Tigray (20.07 Mg C ha^{-1}) (Gebrewahid et al., 2018), in the wolayitta zone (49.05 Mg ha^{-1}) (Aklilu et al., 2015) and agroforestry systems in Central India (27 Mg ha^{-1}) (Swamy and Puri, 2005). However, the SOC in our study remarkably lower as compared to results that conducts in Cheha woreda, Gurage zone for cultivated land (73 Mg C ha^{-1}.) (Semere, 2017).

As Lal., 2004 report the soil organic carbon stock for the tropical forest, tropical savannah, and tropical agricultural land was 121–123 Mg C ha^{-1}, 110–117 Mg C ha^{-1}, and 80–103 Mg C ha^{-1} respectively.

Soil organic carbon stock studied in different agro ecology has a significant difference. These are due to the composition, land-use history, management and structure of vegetation along the agro-ecology zone, which may accumulate the different amount of organic matter due to high inputs from root biomass and above-ground (Laganière et al., 2010; Jose, 2009 ; Sauer et al., 2007). Diversified tree species have high fine root production due to that the SOC is high. Thinning and pruning of trees may reduce SOC sequestration by reducing litter fall and accelerating decomposition due to changes in understory light, air/soil temperature, and soil moisture regimes (Lorenz and Lal, 2014).

Total Carbon Stock of PLAP

The distribution of carbon stocks between biomass and soil differed among agro ecology and varied among kebeles. The mean total carbon stock of PLAP in the studied area was 59.65 Mg C/ha. This is higher than total carbon stock of parkland agroforestry practice in the wolayitta zone (51 Mg C ha^{-1}) (Aklilu et al., 2015), carried out in Tigray (31 Mg C ha^{-1}) (Gebrewahid et al., 2018), and 46 Mg C ha^{-1} in the Sahel (Luedeling and Neufeldt, 2012). The total carbon stock of the study area is in the range of 36.24 Mg C ha^{-1} - 94.08 Mg C ha^{-1}. The average total carbon stock of PLAP was within range of tropical agroforestry 7.9–105 Mg C ha^{-1} (Montagnini and Nair, 2004), Cocoa-based agroforestry practiced in Nigeria that ranged 16–96.01 Mg C ha^{-1} (Oke and Olatiilu, 2011) and traditional agroforestry system of humid subtropical ranges 10.29–31.86 Mg C ha^{-1} (Yadava, 2010).

The difference of total carbon stock of the practice in the study areas between kebeles arise from difference in farm size, socio-economic needs, species diversity, the age of trees, local climate, number of tree coverage, and tree spacing among agroforestry system (Kumar, 2011) and higher levels of disturbance (pruning and damage), intensive management practices, and small land size that forces scattered trees on farmland not only having a higher density of woody perennials but also an accumulation of other plants and crops per unit area.

Conclusions

The parkland agroforestry practice in the woreda has stores 59.65 Mg C ha – 1. However, this carbon sequestration potential of the practice varied among sites (i.e., among each kebele), which is due to differences in vegetation structure, the density of trees per hectare and management practice. In spite of the aforementioned ecosystem services of the practice, the parkland agroforestry practice of Minjar Shenkora woreda has faced some challenges like: cutting of trees by theft due to high demand for tree products, change of plowing and harvesting techniques such as use of tractors and machine harvesters and free grazing that threatened its long existence. Hence, this calls for an integrated action in all levels to control the problem and avoid the damage on the trees and the growth of naturally regenerated seedlings that are important to sustain the practice. The practice should be conserving and promote by climate change program to sustain the practice and improve carbon storage potential of the practice. The governments should give attention for agroforestry practice because of its role for climate change mitigation.

List Of Abbreviations

AFS Agroforestry system

AGB Above ground biomass

AGC Above ground carbon

AGCO2 Above ground carbon dioxide

BGB Below ground biomass

BGC Below ground carbon

BGCO2 Below ground carbon dioxide

C Carbon

CO2 Carbon dioxide

Cof. Correlation coefficient

CO2e Carbon dioxide equivalent

DBH Diameter at Brest height

DSH Diameter at stump height

GHG Greenhouse gases

GPS Global positioning system

HCL Hydrochloric acid

IPCC Inter-governmental Panel on Climate Change

MSDARDO Minjar Shenkora woreda Agriculture and Rural development office

MSCO Minjar Shenkora Woreda Communication office.

PLAP Parkland agroforestry practice

SOC Soil organic carbon

WBISPP Wood Biomass Inventory and Strategic Planning Project

WMO World metrological organization

Declarations

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Authors’ contribution

Reta E. Designed and conducted the experiments at field, data collection, analysis, interpret the results and finally prepared the draft manuscript. Seid M. and Solomon M. Designed the experiments, interpret the results, review the full manuscript and improve the contents of these manuscripts.

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Ethics declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interest

The authors declare that they have no competing interests in this section.

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Figures

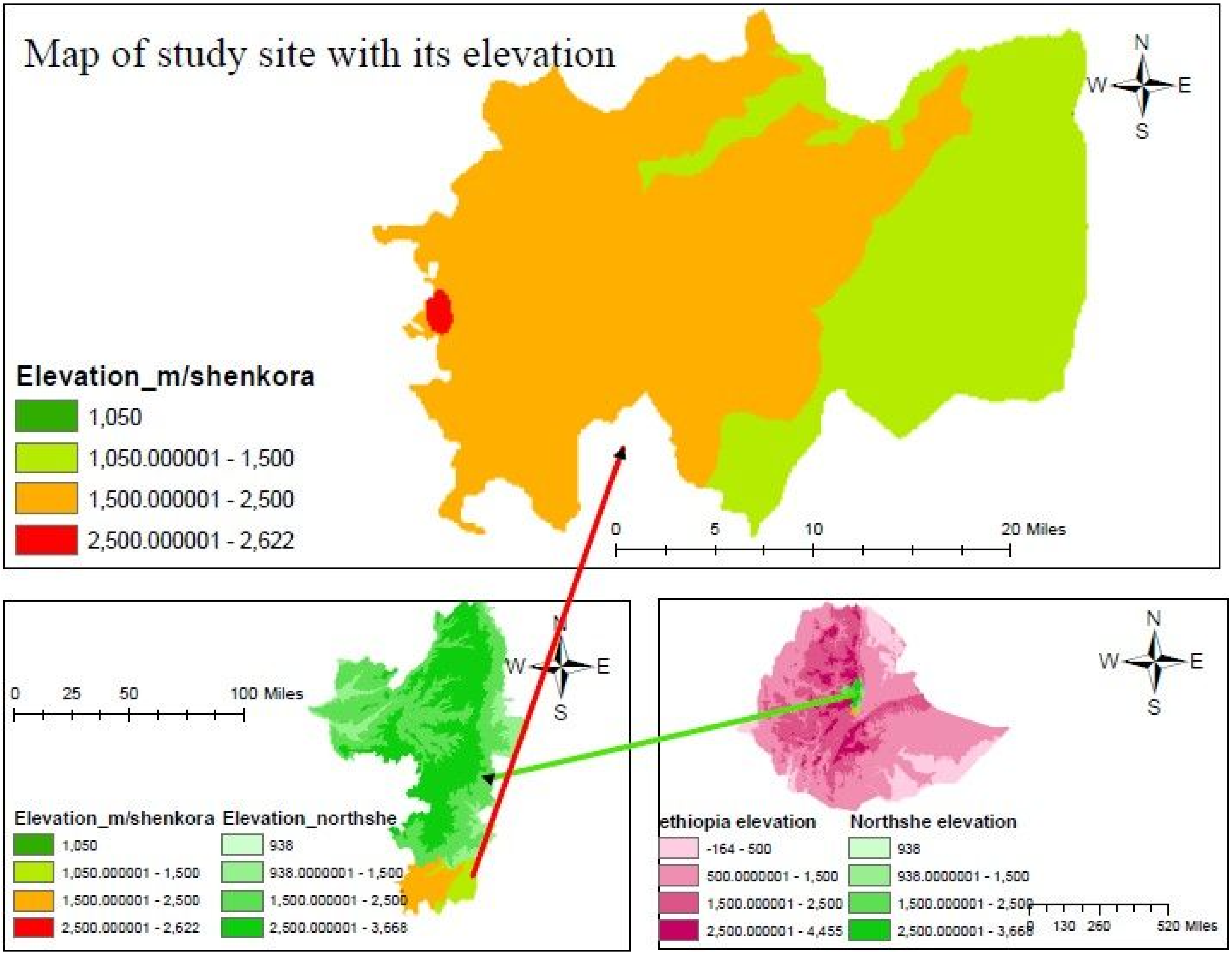

Figure 1

Location map of Minjar Shenkora woreda. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Photo of the study area.