EFFECTS OF AREA EXCLOSURE ON ABOVE GROUND, BELOW GROUND AND SOIL CARBON STOCK: THE CASE OF GUNDI-ETKI DISTRICT SITE, AHFEROM WOREDA, CENTRAL ZONE OF TIGRAY REGION, NORTHERN ETHIOPIA

M.Sc. THESIS

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EFFECTS OF AREA EXCLOSURE ON ABOVE GROUND, BELOW GROUND AND SOIL CARBON STOCK: IN CASE OF GUNDI-ETKI STUDY SITE, AHFEROM WOREDA, CENTERAL ZONE OF TIGRAY REGION, NORTHERN ETHIOPIA

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DECLARATION

I declare this thesis entitled " Effect of Exclosure on above ground, below ground and soil carbon stock: the case of Gundi-etki study site, Ahferom Woreda, Central zone Tigray , Northern Ethiopia" is the original thesis work carried out by myself under the supervision of Dr. Mulugeta Zewdie. It has neither been published nor submitted to other degree program. All the materials or ideas of other authors those used in this thesis have been acknowledged and listed in references.

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Name of the student	Signature	Date

Approval Sheet 1

This is to certify that the thesis entitled;" effect of exclosure on aboveground, belowground and soil carbon stock: the case of GUNDI-ETKI, Ahferom Woreda, central zone Tigray region, northern Ethiopia". Submitted in partial fulfillment of the requirement for the degree of master of sciences in forest resource assessment and monitoring of the graduate program of the department general forestry, school of Wondo Genet college of forestry and natural resources is a required of original research carried out by Kinfe Gebreyesus under my supervisor. Therefore, I recommend that the student has fulfilled the requirement and can submit the thesis to the department.

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Approval Sheet 2

We the undersigned members of the board of evaluators of the final open defense by Kinfe Gebreyesus Gebretnsea have evaluates' his thesis entitled "effect of exclosure on aboveground, belowground and soil carbon stocks; the case of Gundi-etki, Ahferom Woreda, central zone of Tigray, northern Ethiopia". This is therefore, to satisfy that the thesis has been accepted in partial fulfillment of the requirement for degree master of sciences in forest resource assessment and monitoring.

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Abbreviations

%OC	percent of organic carbon concentration
AGB	above ground biomass
AGC	above ground carbon
AGLB	Above ground living biomass
BD	Bulk density
BGB	below ground biomass
BGC	below ground carbon
DA's	Development Agent
DBH	Diameter at breast height
DSH	Diameter at stump height
FAO	Food and Agricultural Organization
GHG	Green house gasses
GPS	Geographical positioning system
Ht	Height
IPCC	Intergovernmental panel on climate change
M.a.l.s	meter above sea level
NGO	None Governmental Organization
QGIS	Quantum geographical information system
R:S	Root Shoot ratio
SOC	Soil Organic Carbon
SOM	soil organic matter
$TCha^{-1}$	Tonnes of carbon per hectare
WBOPF	Woreda bureau of plan and finance

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Abstract

Exclosure is one option of in degraded lands to promoting to restore above and belowground biomass productivity and soil carbon contents in Ethiopia especially in Tigray. The study was conducted to assess the total amount of carbon stocks of above ground, belowground and soil organic carbon stock in the exclosure and adjacent open grazing land and soil depth layers. Systematic sampling method was used for collecting the biophysical and soil data for estimating total carbon stocks. To collected field data inventory of diameter at breast or stump height of ≥2.5cm along the two land uses employed 51 plots (41 plots from exclosure and 10 from open free grazing land) a size of 100m^2. The 204 soil samples were taken from two soil layers of 0-15cm and 15-30cm depth to determine soil carbon stock of the two land uses. The soil organic carbon was analyzed in laboratory using Walkely-Black method. Above ground biomass or carbon stocks were estimated using the allometric equation of (Mengesteab Hailu et al., 2018) that is develops in Tigray semi-arid exclosure area. The belowground biomass was estimated using 27% root shoot ratio method. One way analyses of variance (ANOVA) with Tukey's post hoc test were conducted to test the effect of land uses and soil depth on carbon stock density. The total mean carbon stock result of Gundi-etki study area was 20.48±0.72 and 15.38±0.94 tons of carbon per hectare respectively in exclosure and free grazing land and had a significant difference at α 0.01 ($p=0.007$). Soil has higher carbon stock proportion (83.42%) and followed aboveground (13.05%) and belowground (3.52%). The top soil layer had significantly higher total mean soil carbon stock at 95% confidence interval ($p=0.008$) than the lower soil depth of the study area. Conclusion; exclosure had four times significantly higher ecosystem carbon stocks than adjacent open free grazing land. The top soil layer is having significantly higher soil carbon stock than the lower soil depth layer. Recommendation; exclosure had a positive value for improved above ground, below ground and soil carbon stock; it should be necessary to expanded to other non exclosure areas. It should be necessarily establishment area exclosure widely in semi-arid areas of Tigray region and specific study Woreda Ahferom to increases vegetation biomass, carbon stocks restoration potentials and minimizing soil organic carbon stock or soil organic matter depletion.

Keywords: carbon stock, Exclosure, free grazing land, soil depth, soil organic carbon.

1. INTRODUCTION

Forests are the major component of the carbon biomass store in the world's ecosystem. They have the capacity to store huge carbon stock and release CO_2 gas to the atmosphere (IPCC et al., 2003). Most carbon in a tropical forest is stored in the aboveground living woody biomass and understory vegetation, in dead litter mass, standing or fallen woody debris and soil organic matter (Gibbs *et al.*, 2007). The world land area estimates the forests coverage extent; woodland to be 31% or one-third of the total land area of global forest cover (F A O, 2010). For instance, Tropical forest store a large quantity of carbon and accounting half of the total global vegetation biomass and store 40 % (428GtC) of terrestrial carbon stock (Brown, 2004).

The aboveground woody living biomasses (AGWLB) of trees/shrubs are the largest and easily visible carbon pool and the one receives high impact from deforestation and forest losses (Keenan, 2015). Human-made activity is one of the most causes of climate change issues of the 21st century and the large tropical country greenhouse gas emission through deforestation and forest degradation (FAO, 2011). The global tropical forests after 1990 in two ten year's interval were decreased from 8.3million ha to 5.2million ha by 0.2% per year (Tashi *et al.*, 2017). Since 2000 the plantation coverage was 5million ha/yr but, still now deforestation and land degradation are the major environmental problems of tropical forest (MacDicken, 2015). But today global community address the forest carbon dioxide emission from degradation and deforestation through developing a mechanism for reducing emission and enhancing carbon stock of forest by conserving and sustainable management (Pearson *et al.*, 2017). Land degradation was affected on land productivity decline, biodiversity, depletion, soil fertility or soil organic carbon loss and above vegetation biomass ecosystem services decrease (Nyssen *et al.*, 2015).

Ethiopia is one of the most affected countries by land degradation in sub-Saharan African region. The natural high forest coverage of Ethiopia is 2.7% but with inclusion of woodland and plantation reaches 15.5 % (MEFCC et al., 2017). The above ground forest or carbon stock coverage of Ethiopia showed a decline from 40% to 10% during the last 19^{th} century (FAO, 2015). Because more than 85% of the total population depended on forest resource and goods directly or indirectly, it has high altitudinal variability or environmental gradients, population pressure (Tesfay Atsbha et al., 2018). Due to this, high deforestation and land degradation of above and below ground carbon storage in forests or change to communal rangeland. The changes of carbon pools are due to forest succession, disturbance, and management practices may results in the sinks for C or atmospheric levels of CO_2.

In 2013, Ethiopia's national emissions were 146 Mt CO_2 equivalent, or 0.4 % of global emissions if it has not taken different forest resource mitigation activity the carbon emission to the atmosphere reaches 400 Mt CO_2eq in 2030 (MEFCC et al., 2017). At present, small remnant forests, woodlands or shrub lands have become restricted to inaccessible areas such as hillsides, mountaintops, and around churches, monasteries, mosques, particularly in all area of Tigray region (Mulugeta Lemenih and Habtemariam Kassa, 2014). The natural vegetation that occurs in remote inaccessible area of the species is affected by several factors, such as expansions of agricultural activity, wood consumption, lack of viable land use policy, illegal settlement in forests, low forest investment, low awareness creation, low local community participation in plan developing or implementation and low forest owners sense (Emiru Birhane *et al*., 2017)

To minimize such pressure were taken a different measurement; conservation of degraded natural vegetation, area ex-closure, forest plantation (Emiru Birhane *et al.*, 2006). There are two major types of area ex-closures practiced in general in Ethiopia, particularly in Tigray. The one most common type was closing off an area from livestock and people to regeneration of new vegetation. The second option is closing off degraded land with simultaneously implementing additional measures enrichment planting with exotic and indigenous seedling species to enhance the regeneration process (Eshetu Yirdaw *et al.*, 2017).

Exclosure was started during Derg regime although activities were mainly planned and implemented using a top-down approach without community participation and resource utilization which in turn adversely affected the sense of ownership (Eshetu Yirdaw *et al.*, 2017). Exclosures are a type of land management, implemented on degraded land for above and below ground carbon biomass restoration(Amit Kumar and Sharma, 2015). Ex-closures play significant roles in carbon sequestration and mitigation of climate change, soil and water conservation, watershed protection, soil organic nutrient recycling, the creation of microclimate and biodiversity conservation (Emiru Birhane et al., 2006).

Ex-closures are usually established in a steep slope, eroded and degraded areas that have been used for grazing and other illegal tree cutting in the past. Establishing ex-closures are the cheapest and suitable methods employed to restore, manage and conserve woody species(Tsegay Gebregergs et al., 2018).

The area is identified and closed by Wereda and Kebelle forest protection experts, and user groups who agreed to protect them from any form of grazing, manual harvesting of grass and tree cutting. The most important criterion for site selection was the extent of land degradation, implying that the more an area is degraded and the more likely it is to be exclosure for regeneration (Wolde Mekuria et al., 2009).

1.1 Problem Statement and Justification

In Tigray, before many years it had large woodland, and high forests resource coverage (Tesfay Atsbha et al., 2018). Because of political, economic and ecological mismanagement woodland plant areas degraded and gradual decline of the area coverage during and after the Derg regime or war. Due to this, it increases bare land, climate warming and depletion of above and belowground carbon biomass (Emiru Birhane et al., 2017).

Another challenge is the establishment of exclosure, not sharing and communicating scientific data, lack of clarity of land tenure and public land use policy, lack of real ground community decision making in the management and resource utilization and lack of knowledge about the actual amount of benefits (Wolde Mekuria et al., 2009).

Ex-closures in Ahferom Woreda have been implemented for about many years, the empirical data on the effectiveness of these community controlled areas of ex-closures are lack organizing data (Cleemput *et al.*, 2002). however, there is less information on the effects of long-term exclusion of grazing area on carbon biomass accumulation (Mengesteab Hailu et al., 2018).

In the Woreda to reduced the land degradation; different rehabilitation measures have been launched by government and non- governmental organizations jointly (Abeje Eshete et al., 2011) for instance, natural regeneration by exclosure the areas. Even though the Woreda and the local government declared these forest areas as protected, from human activity and livestock grazing are still active and common (Kibruyesfa Sisay et al., 2017).

1.2. Objectives

1.2.1. The general objective

The overall objective of the study is to estimate the potential of exclosure and open grazing land on aboveground, below ground biomass and soil carbon stock of Ahferom Woreda, Gundi-etki district study site.

1.2.2. Specific objective

I. To estimate the aboveground, below ground biomass and soil carbon stock potential of the ex-closure area and the adjacent open grazing land.

II. To compare the total ecosystem and Soil carbon stock potential between ex closure and the open free grazing adjacent area.

III. To estimate the total ecosystem carbon stock biomass and soil carbon stock of the area ex-closure and adjacent free grazing land.

1.3. Hypothesis

i. The total biomass and carbon stock of the ex-closure area are not greater than the open free access adjacent land.

ii. There is no difference in biomass and carbon stocks along the two land use systems.

1.4. Significance of the study

In Tigray, there are a number of studies on the best practice of area exclosure vegetation restoration of ecosystem service. But there is still limited information on the above and below ground carbon stocks of the protected area exclosure and the comparison with the adjacent communal free land. Estimating the carbon stock of a given exclosure is essential for the development of management plans significant to climate change and evaluates the effectiveness of the exclosure intervention for improvement of carbon stocks after rehabilitation of the given degraded area.

In the same, this study can generate the biomass and soil carbon stock baseline information of the ex-closures in planning and developing scientific research for academic students, government and non-government institutions, sustainable land management projects, and Woreda Agricultural office. It can also create better awareness of the community to enhance their efforts of land rehabilitation. Besides its importance for policymakers to make decisions, the study will help future studies on carbon stock change through time.

1.5. Research process

In order to meet the requirement of the objectives mentioned in the above and to collect sound and accurate data the following process was carried out.

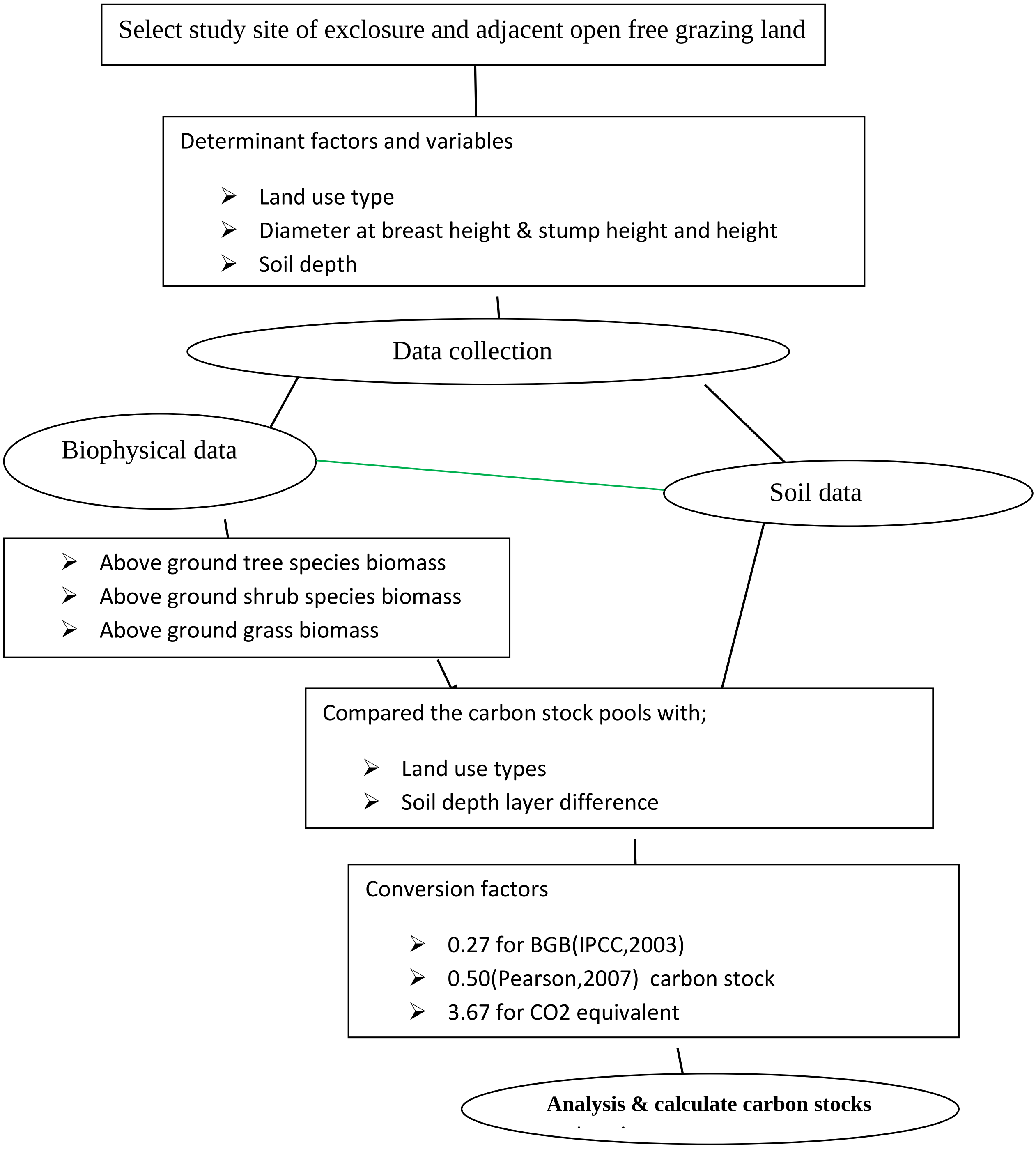

Figure 1 Research process of the study

1.5. Definition of terms and concepts

Exclosure; are a method of rehabilitation and re-generation of degraded land in arid and semi-arid environment by excluding land from human and livestock animal interference. For the purpose of regeneration of native vegetation and reduce soil erosion and keeping animals out of the given area(Aerts et al., 2008).

Enclosure; is the action of areas surrounding or making walls with a fence or boundary for keeps things inside a given area(Aerts et al., 2008).

Aboveground biomass: is the dry mass of all woody stems, branches and leaves of living trees/shrubs and includes all trees/shrubs >2.5cm diameter.

Belowground biomass: it comprises living and dead roots, soil fauna and microbial community and all coarse living roots greater than 2mm diameter.

Allometric equation: equation used for estimating tree/shrub species weight from independent variables such as diameter and height which are measured in the field.

1.6. Organization of the thesis research

This thesis research consists of five main sections. Section one served as general introduction to the research. It includes the thesis research problem and justification, significance of the study, objectives and research hypothesis test. Section two defines a literature review about the concepts of different carbon stock pools, and relevant with the thesis research titles review from published journals, articles, and reports of organization like IPCC, Pearson, Chave. The third one is the research methodology i.e. sampling procedure; research methods in data collection and analysis are discussed. Section four covers the result and discussion of findings of the study. Section five deals with about the conclusion.

1.7. Scope and limitation of the study

This research thesis is focused on area exclosure effects on aboveground, belowground and soil organic carbon stock. It was include from the above ground carbon stock biomass; tree, shrub and grass species and belowground carbon stock biomass was estimated based on root shoot ratio.

The major limitation of this study was not included the biodiversity and regeneration condition of the two land uses. The belowground carbon stock biomass was not detailed field experimental data estimation and used by root shoot ratio default factor conversion. The main reason there was not includes because of the time, financial and labor limitation and in exclosure area not allowed to harvest woody and non-woody vegetation because the area was excluded for the purpose of carbon biomass restoration and re-vegetation.

2. LITERATURE REVIEW

2.1 Forest land Degradation and deforestation

Forest degradation is the major source of carbon emission. It shrinks; forest sequestration capacity, above ground forest coverage, soil organic carbon depletion, reduce indigenous biodiversity species (Birdsey *et al.*, 2013). It is also complex to identify the carbon stock changes because of different land cover types; such as species, age, soil types, and altitudinal or shape of topographic variation (IPCC *et al*., 2003). Forest degradation loss of more greenhouse gases than deforestation and accounts for at least 5% of carbon emission according to the IPCC report (Ravindranath *et al.*, 2012).

According to the IPCC and FAO definition deforestation is the ‘' permanent removal of forest cover and withdrawal of land from forest use and conversion of forest to another land use (FAO, 2012). Global net loss of forest area has been estimated at 5.2Mha/yr between 2000 and 2010 (IPCC, 2014). Tropical deforestation is a major contributor to GHG emissions and climate change impacts because of the extent of forest being cleared each year and contain high carbon stock per unit area (IPCC *et al.*, 2003). In East Africa over 200,000 ha per year or 0.78% tropical forest area was lost (FAO, 2010).

Ethiopia is endowed with natural resource particularly in forest resource. But due to unwise use and mismanagement of the forest resource, huge of natural resource is degraded (Mulugeta Lemenih *et al.*, 2007). The current rate of deforestation and forest degradation is estimated to be 160,000-200,000 hectare per year and rapid decreasing percentage of the forest cover of the country from 40% in 1900 to 3.2% in 1980 and now it is estimated to be less than 3% that is agreed by most research scholars (Amit Kumar and Sharma, 2015). Today dry Afromontane forests, CombretumTerminalia woodlands and Acacia-Commiphora woodlands of Ethiopia have faced vast exploitation and large forest area have been converted to another land system (Tesfay Atsbha, 2016).

Deforestation and forest degradation, accelerated soil erosion, and land degradation are problems in Ethiopia. To overcome these problems, efforts have been made to launch the afforestation and exclosure program; however, success to date has been limited (Cleemput *et al.*, 2002). In Tigray there are two causes of deforestation and degradation: direct deforestation such as direct causes (wars and military, air pollution, urbanization and infra-structure development, mining, wildfires, overgrazing, illegal logging and fuel wood collection and expansions of farming land). Indirect causes (land right and tenure inequitable distribution, economical cause, undervaluing the forest, political cause, illegal forest contract of privet investor, overpopulation and poverty) (Mulugeta Lemenih *et al.,* 2007).

2.2 Communal free grazing land

Open grazing land is the area former forest areas that had been converted into communal grazing lands through the year (Negasi Solomon *et al.*, 2017). Although unrestricted access to such resources can result in overexploitation and degradation of the resource (Tesfay Atsbha, 2016). Grazing lands occupy about half of the world's land area and contain more than 33% of the above and below-ground carbon reserves (Timothy R. H. Pearson *et al.,* 2017). Soil carbon change can occur in response to a wide range of management and environmental factors (Belachew Gizachew et al., 2016).

The open land cover is estimated to be 61-65% of the land mass of Ethiopia and it is classified under the highland part of the country. Grazing common land exclusion from livestock and human impacts has become a common practice in Ethiopia for reversing and recovering of forest degradation and minimizing the negative effect of overgrazing

(Mengesteab Hailu *et al.*, 2018). The lowland of Tigray is occupied by farm, which employs a communal resource system for livestock production and grazing exclosure (Negasi Solomon *et al.,* 2018). Livestock grazing is a vital common issue affecting plant growth, plant species diversity, and soil carbon accumulation (Zelalem Teshager *et al.*, 2018).

2.3 Role of ex-closure in land rehabilitation

Area exclosure is the areas closed from the interference of human and domestic animals with a goal of promoting natural vegetation regeneration of degraded grazing, eroded and bare land (Tesfay Atsbha, 2016). Area exclosure in Ethiopia was established by the massive efforts made to reverse land degradation process; such as soil organic carbon, aboveground carbon biomass, and belowground carbon stocks (Zelalem Teshager *et al.*, 2018). It is important to promote regeneration of indigenous species and mitigate the effect of increasing CO_2 concentration in the atmosphere due to fast vegetation recovery at the younger stage with a minimum and cheap cost. This practice enhances vegetation area coverage faster and with better coverage than planted seedlings without human and financial investment. Area closure is also important to restore sufficient number of seedlings, sapling, mature trees and the new species regeneration potential improvement in the short time (Wolde Mekuria *et al.,* 2018).

In Highlands of Ethiopia the rate of deforestation and degradation is estimated at least 160,000-200,000 ha/yr and the average soil organic carbon losses or erosion for all land uses was approximately 35 tons/yr per hectare (Tashi *et al.*, 2017). The practice of exclosure has been traditionally exercised for a long time around church boundaries by restricting the use of forests around churches as a symbol of reverence for the religious sites (Wairore *et al.*, 2015). The above and below ground biomass and diversity ex-closures increases with time after establishment and species diversity is more in exclosure than in continuously grazed open areas. Until 2017 about 143,000 ha closed areas have been established in Tigray region and to be successfully (Samson Shimelse *et al.*, 2017).

Exclosure, areas protected for natural regeneration are found within the boundaries of a community (the kebele) and communally utilized by the local people by developing local bylaws of the specific site (Kibruyesfa Sisay *et al.,* 2017).The process area exclosure delineation; First DA's, and local administration committees identify the site protection based on set criteria. Final discussion and general meeting with local community members; Based on the interests of the local people, methods of protection area of grazing and exclosure impacts on carbon sequestration of degraded lands and show the cause of overgrazing for increase the bare land and decrease the carbon reservation of soil-plant system (Tesfay Atsbha, 2016)

2.4. Impacts of ex-closures on climate change mitigation

Area closure is important for reducing of greenhouse gas emission, increase removal of deforestation and degradation, enhance and conserve forest carbon pools (Tsegay Gebregergs *et al.*, 2018). Carbon sequestration is the process of removing CO_2 from the atmosphere and storing carbon pools in the forest area through carbon sink by store and photosynthesis of CO_2 in living and sequestration carbon in soil (Wolde Mekuria *et al.*, 2009). Climate change is a focus of global climate change policy and international climate treaties even if at watershed level to reduce greenhouse gas (GHG) emissions (IPCC *et al.*, 2003).

Carbon emissions from deforestation and forest degradation are the second largest source of anthropogenic carbon emissions (Gibbs *et al.*, 2007). Exclosure significantly increases carbon stock in the aboveground biomass and soil organic carbon (Tesfay Atsbha *et al.*, 2018). Also changes in land cover from non-forest to forest through exclosure; afforestation and reforestation activities increase the carbon sequestration potential of an area (Beyene Belay *et al.,* 2018). Closed forest areas provide as well ground water regulation, flood controlled, soil erosion prevention or increased soil organic carbon and climate change mitigate (Negasi Solomon *et al.,* 2018). By increasing the restoration of aboveground biomass and soil carbon stock, afforestation and sustainable managing the area from any interfere (Negasi Solomon *et al.,* 2017). The mean aboveground biomass measured inside the ex-closures was more than twice that of the adjacent grazed areas (Kibruyesfa Sisay *et al.,* 2017).

2.5. Carbon Stock Pools

2.5.1. Aboveground Biomass Carbon Stock

Biomass and carbon content are generally high in tropical forest, reflecting their influence on the global carbon cycle. Tropical forests have great potential for the mitigation of CO_2 through the appropriate conservation and management (Abeje Eshete *et al.*, 2011). Rehabilitation and regeneration status of natural vegetation successfully improve the micro-climate, biodiversity of the area closed, provide soil organic fertility, improve degraded ecological conditions, and remove the CO_2 concentration in the atmosphere (Ekoungoulou *et al.*, 2014).

Above ground biomass is defined as all the woody stems, branches and leaves of living trees and the carbon pools are expressed as tonnes of carbon stock per hectare. It is the most and more visible and dominant carbon pool in the closed forest (Ravindranath *et al.*, 2012). For instance, the living above biomass in Africa is 59.5% carbon stored in the above ground. Carbon dioxide (CO_2) and global warming is the most important cause of anthropogenic climate change (Ekoungoulou *et al.*, 2014) by deforesting and loss of forest aboveground biomass. The aboveground living biomass (AGLB) of trees generally forms the largest carbon pool and is the one that receives the biggest impact from deforestation. It is generally assumed that 50% of the overall total biomass is made up of actual carbon stock of above ground (IPCC *et al.,* 2003).

Above ground (AGB) carbon stocks of exclosure were significantly higher than the adjacent open grazing land (Gibbs *et al.*, 2007). For example, the lowlands of Tigray Regional state; the average difference in AGB carbon stock of ex-closures and adjacent open grazing land ranges between 2.3 and 5.6 tons of C/ ha, in the highlands of Tigray; in northern Ethiopia also the AGB carbon stock varied between 2.0 and 7.0 tons of C/ ha (Tesfay Atsbha *et al.,* 2018)**.**

Land cover change is a key factor in above soil carbon stock changes. There was high variability in total carbon stocks among land cover types for instance in dense closed forest area have high carbon stocks while the low carbon stocks in open communal land and bare land (Negasi Solomon *et al.,* 2017)**.** The aboveground vegetation properties could be useful in the estimation of the soil organic carbon stock in the dry Afromontane forests. Dry Afromontane forests have the potential to store large amounts of carbon in its aboveground biomass (Abyot Dibaba *et al.,* 2019). The exclosure has a sound type of regeneration, represented both by the community structure and individual species population structure (Emiru Birhane *et al.,* 2017).

2.5.2. Belowground carbon stock

Below ground biomass included all the living roots that play an important on carbon cycle transferring and storing carbon in the soil (Pearson, Brown and Birdsey, 2007). Roots are an important part of the carbon balance because they transfer a large amount of carbon into soil and sequestered or stored carbon (Gibbs *et al.*, 2007). Through, the increasing soil organic carbon accumulation following root decomposition in soil. Large trees tend to have large roots and stored large amount of carbon for long time. The biomass of root systems is difficult, take time and expensive to measure accurately in forest trees(Ch *et al.*, 2016).

Root biomass in ecosystems is often estimated from root-to-shoot ratios, thus, it makes a significant contribution to SOC (IPCC *et al.*, 2003). About 50% of the carbon fixed in photosynthesis is transported to belowground and partitioned among root growth, and assimilation to soil organic matter (Ch *et al.*, 2016).

2.5.3. Soil carbon stock

Improved management of free grazing land due to controlled grazing and limited fuel-wood stock rate of using were important to enhance and conserve soil organic carbon by reducing the soil disturbance(Liu *et al.*, 2014). Soil is the largest terrestrial reservoir of carbon and can stored about three times as much as atmosphere, sequester mainly in decomposed plant and residues. Soil organic carbon losses due to livestock and agricultural uses, however if well managed may have high potential to stored soil organic carbon in the soil (Pearson, Brown and Birdsey, 2007).

Soil organic matter is increased through the increase of above ground carbon biomass after the establishment of exclosure area by improves the soil organic matter accumulation (Negasi Solomon *et al.*, 2018). About three times more carbon is contained in soils than the above ground vegetation carbon stocks (Mehari A Tesfaye *et al.*, 2016). The soil carbon stock affected by environmental factors; such as topography, soil depth, and anthropogenic activity. The national soil carbon stock of Ethiopia was estimated and ranges from 101MgC/ha to 200MgC/ha (Gebeyaw Tilahun, 2015).

Soil organic carbon stocks are the amount of organic carbon found in soil and half of SOC is carbon. The soil organic carbon is different from location to location, slope or altitudinal variation, management practice and depth of the soil layer. Soil affects the vegetation of rangelands since it influences water availability, soil temperature regime, elemental balance, microbial biomass carbon, and the activity and species diversity of soil flora and fauna (Ouyang *et al.,* 2017). Then there is increased the loss of topsoil carbon and to reduce soil carbon loss established area exclosure by integrating a government institution with different NGO'S donors (Tesfay Atsbha *et al.*, 2018).

Soil degradation management of the SOC concentration is very important to improving and enhances the soil physical, chemical, and biological qualities. Exclosure land use type has shown an improvement in soil organic carbon even in the highly degraded steep slope grazing land have a positive result at the current time (Wairore *et al.,* 2015).

According to the IPCC, (2002) the concentration of organic carbon in soil is highest in the topsoil and decreases as soil depth increases (Brown, 2004). The soil organic carbon is estimated to a depth of 0-30cm since most of nutrient content is high in the top layers and root activity is concentrated in this horizon. Soil organic carbon was determined through samples collected from the default depth prescribed by the (Pearson *et al.*, 2017). According the Wolde Mekuria *et al.*, (2009) report the natural vegetation restoration in exclosure increased due to increase soil organic matter in the soil depth of 0-15cm and higher SOC in the topsoil deth than the lower depth.

3. MATERIALS AND METHODS

3.1. Site description

3.1.1. Location

The study area was conducted in the Gundi-etki Exclosure and adjacent open grazing land in Ahferom district in the Northern highland of Ethiopia, central zone of the National Regional State of Tigray at about 140 km North West of Mekelle. The two land use systems are lies between 14º16'26"N to 14º16'59"N and 39º7'39"E to 39º8'27"E with an elevation range from 2041 to 2250 m.a.s.l. The topography of the study site is characterized as steep slope (30 to 50%), moderate slope (15 to 30%) and the flat (0-15%) of the slope gradient and the climate as tropical semi-arid (source; NRM & forest sector, 2017).

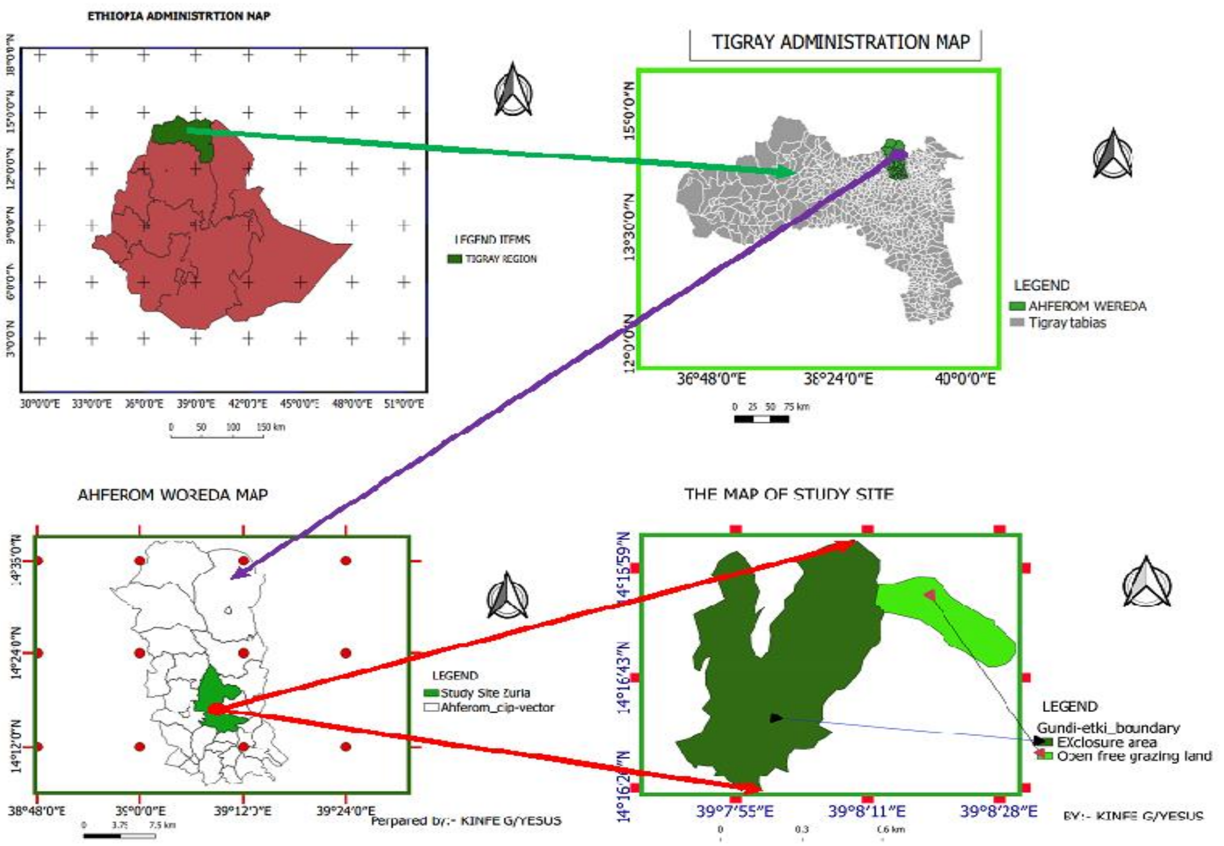

Figure 2 Location map of the study area

3.1.2. Land use types

The total area of the Woreda is covering an area of 139,979 hectare from the total 19,112 hectare is grazing land. The total ex-closure area of the Woreda was 15,813 hectare that is approximately 45% of the total forest coverage of the 34,925 hectare (source; NRM and forest sector, 2017). The specific study site of ex-closure and the adjacent rangeland of “Gundi-etki” areas are 48.54 ha and 11.01 hectare respectively (source from high resolution Google Earth image, 2018).

In the area ex-closure, there was no livestock grazing, nor any other agricultural activity. Except for yearly grass cutting and carry by the community, same times there were illegal human and livestock interference or encroachment with vegetation regeneration especially in the edge of the closed area. However, in the open grazing land was having livestock grazing, illegal cutting and settlement (source; AO and NRM sector 2018).

3.1.3. Climate

The mean annual rain fall and temperature of the study site ranges from 450 to 750 mm and 18^{o}c to 27^{o}c in respectively. The area is characterized by a bimodal rainfall regime with peak rainfall from late June to early September and a short and less intense or distribution rain season from late March to early May. It is vary from year to year in amounts and distributions rainfall. The study Gundi-etki sites of the closed and non-closed area lie in Weyna-dega agro-ecology.

3.1.4. Vegetation types

Vegetation type of the study area of Woreda Ahferom consists of natural forest, bushland, shrubland and mixed or enrichment secondary forest. The study area is located in the most degraded part of the region and almost devoid of vegetation coverage or biomass for decades. Dispersed trees, and shrubs in ex-closures, trees, and Acacia species are the dominant woody species found in the study Woreda. The dominant naturally regeneration trees and shrubs species of the sites are *Acacia lahay, Acacia etbaica, Acacia senegal, Acacia seyal, Carissa edulis, Euclea schimper, Acacia aska Mytenus senegalensis, Rhus natalensis, Euphorbia abyssinica, Cupparis micrautha and Dodonea angustifolia(*source: AO and NRM sector, 2018).

3.1.5. Farming Systems and livelihood strategy

Woreda Ahferom was the first one populated and food unsecured area from the Tigray region. The total populations of the Woreda are 209,025. From the total population male and female are 101,153 and 107,872 respectively and 47,040 household populations. From the total population more than 92% are dependent on agriculture (source; WBOPF, 2012). There is fast population growth and settlement in forest area and cause forest degradation and deforestation.

The dominant farming system is a highland mixed farming system; heavily depending on the variable rainfall, traditional livestock husbandry and illegal tree harvesting. Due to these conditions the farming system is very low in productivity capacity and low soil organic matter. The major crops grown in the area are teff, wheat, barley, finger millet, sorghum, pulses, maize and beans. The most serious problem for the agricultural production is the shortage of land holding (ranges from 0.25 to 0.75 ha per household) and the land tenure distribution inequality, loss of fertility of the soil and unpredictable rainfall. As a result, the yield per hectare and per household is very low.

3.1.6. **Soil types**

The study area soil condition is characterized by coarse or dry rocky, low infiltration rate and high runoff. The nature of Enticho sandstone and limestone is affecting for the rate of erosion and infiltration rate of the soil in the study area. The dominant soil types of the Woreda are chronic luvisols 7,754.22 ha (6.36%), lithosols 65,581.73ha (53.86%) and eutric cambisols 48,418.84 ha (39%) from the total area (Source: AO and NRM sector 2018). The dominant soil textures of the specific study site of the two land uses were sand soil 27.976 ha (46.98%), silt 18.804 ha (31.57%) and clay soil 12.77 ha (21.44%) (Source: AO and NRM sector 2018).

3.2. Data collection techniques

3.2.1. Field survey

Reconnaissance field survey and direct field observation have been conducted. To an overview the physical condition of the area before an actual field work starts to identify the two land types; species composition, species diversity, shape or topographical features and forest stock. To facilitate the distribution of sample plots, determined sampling size and design in the study area.

The primary and secondary data were used in order to collect the important data and to meet the objectives of the study. Primary data were obtained through field measurement in the study and the secondary data were collected from different resources like published and unpublished research articles, journals, reports, books and electronic web sites related to exclosure management practice.

Follow standard procedures and techniques in the fieldwork data collection to collect rigorous and sound data. Data collection formats were developed after the data collection in the field starting.

3.2.2. Material and tools used for research data collection

Different field measurement techniques were used to measure the total carbon stock of the exclosure and adjacent common grazing land. Qgis and GPS are used for delineated the boundary of the study area and to distributed sample plots and navigated in the ground using GPS.

The diameter and height of the trees and shrubs of the study area were measured by linear tape meter, ranging pole, diameter tape, caliper and clinometers. Soil core sampler and soil auger are used to collected soil bulk density and soil organic carbon. Plastic bag is used for soil and grass sample stored and transport to laboratory shows as follows;

Table 1 the materials and equipment used in the field during data collection

S.N.	Materials and software	Purpose of use	Remarks
1	GPS receiver	For Boundary delineation and Navigating the center point of the sample plot in the field	Garmin 72
2	Linear tape and rope	To fix the nested plots for sampling purpose	
3	Diameter tape and caliper	To measure of the diameter of trees/shrubs	
4	Clinometers and 5m poles	To measure the total height of trees and shrubs	
5	Weight machine	To weight soil and grass sample that collected from field	
6	MS word and excel	To summarized and prepare overall report	2013
7	IBM SPSS version 20	To statistical analysis of the thesis research	V.20
8	Qgis	To mapping the study area and sample plots	V. 3.4.0
9	Sample soil core	To sampled the undisturbed soil sample data	
10	Soil auger	To collect sample soil carbon from four position of the plot	
11	plastic and paper bags	collect and labeled soil and grass field samples	
12	Chalk	For marking the trees/shrubs to avoid double counting	

3.3.Sampling design

3.3.1. Study site Selection and delineation

According to the objective of the research thesis, the study site was selected purposely based on the adjacent location of the two land use systems and in order to compare the above and below ground biomass and soil carbon content of free grazing land from the area exclosure. The two lands uses having similar biophysical condition before establishing ex-closures and best known exclosure practices.

For measurement of the carbon stocks delineation of the study boundaries was the first step (IPCC, 2014). The boundary of the study exclosure and adjacent opened land was delineated by taking geographic coordinates with GPS at each turning point and Qgis software. The X, Y, Z GPS reading points that were taken from the study site to indicate each sample plots were recorded, and fed to GPS to navigate the sample points distributed in systematical sampling method.

3.3.2. Plot types and lay out

A systematic transect sampling method and laying ten grids lines were employed to collected field data from the sample plots and reduce variability of distance (K. Giday et al., 2013). The sample plots were distributed at uniform interval spacing of 100m*100m along the horizontal and vertical position of the study area (Tsegay Gebregergs *et al.,* 2018). The first sample unit was selected randomly.

3.3.3. Shape and size of the sample plots

Circular nested plots sampling design were conducted to collect all necessarily data from the field. Because of it needs minimizing time and cost, simple to apply in the field, to get accurate and precise data from the multi-layer plots (Mulugeta Mokria *et al.,* 2018). Also was not need marked around the plot boundary.

All plots have a fixed size of 100m^2 (5.64 radius) area sizes were systematically taken for all data collection from each of 51 main sample plots. From the center of the each points were recorded the coordinate points using high precision GPS unit of GARMIN 72. Within each plot five sub-plot of 1m*1m or 0.56m radius (small circular plots) sizes were taken one at the center and four along the radius of 2.82m mark half way from the center.

The one sample at the center of each plot was measured grass biomass and soil bulk density data in the field. The other four samples of each plot estimated for soil organic carbon stock biomass (Mehari A Tesfaye *et al*., 2016).

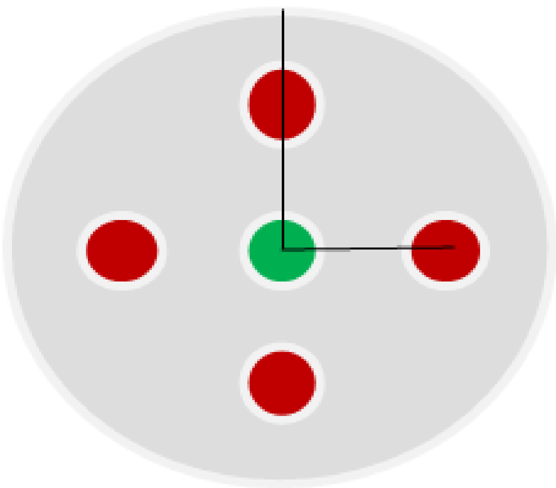

Figure 3 The arrangement and shape of the sample plots

3.3.4. Stratification of the study area

To facilitated the field work and to increase the accuracy and precision of measuring field data of the study area were sub-divided into relatively homogenous units strata (Pearson, Brown and Birdsey, 2007). The study site was stratified into exclosure and adjacent open grazing land. These strata were stratified from high resolution satellite image of Google earth using Qgis software and GPS based on the field observation of vegetation composition and management practices difference. The stratification was necessarily to collected sound and rigorous data from the field and easily to compare the ecosystem carbon stock of the two land uses.

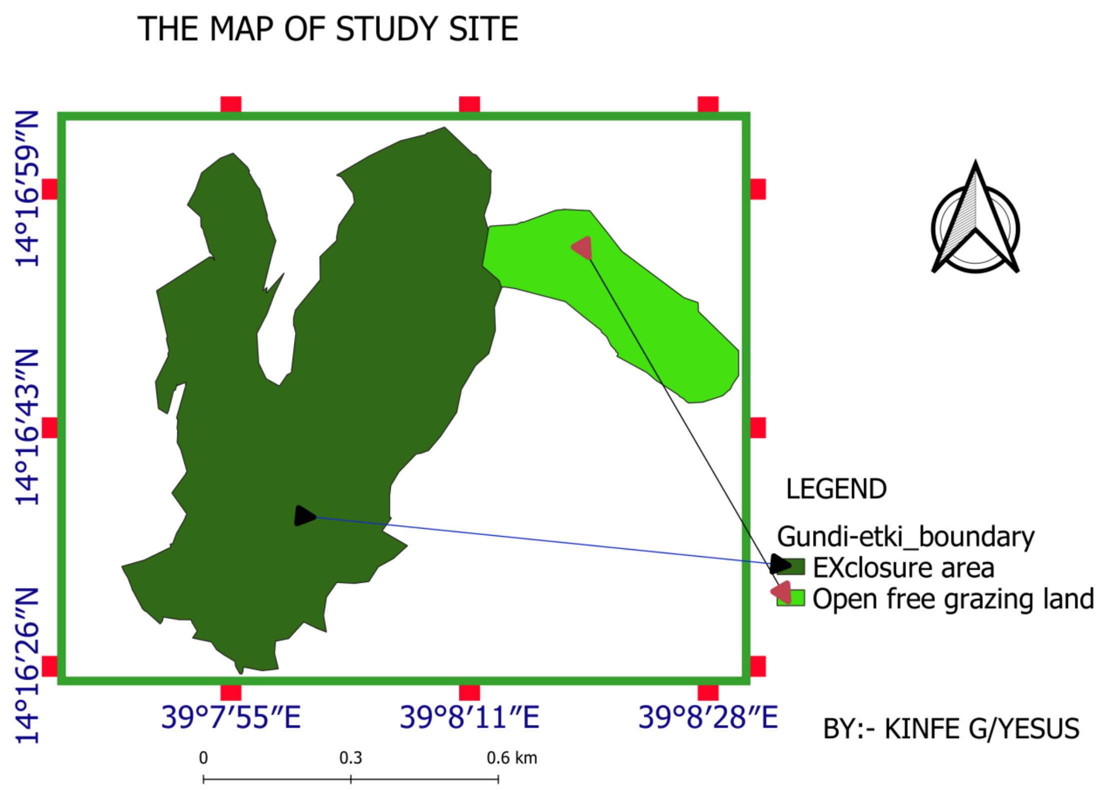

Figure 4 Gundi-etki study site area's stratification

3.3.5. Number of Sample plots

The sample point was distributed systematically along the two land uses to collect all necessarily parameters in the field such as diameter, height, grass and soil sample.

To calculate the number of the sample plots of the study area of Gundi-etki site, the following steps were employed:

- identify the desired precision level
- Identify pilot plots to collect the mean carbon stock of the two land use. Determined three pilot plots from each land use.
- Estimate mean carbon stock, standard deviation, and variance of each the three plots
- Based on the above data calculated the number of plots of the study sites.

The number of main sampling size (number of plots was calculated and estimated using the (Pearson and Brown, 2005) equation. This formula was used for the main plot of the area closure and adjacent open grazing land systematically distributed in uniform position to calculate the carbon stocks of each land use stands of the study sites.

$$\boldsymbol{n} = \left[\frac{\frac{(\sum \boldsymbol{Ni} * \mathrm{si})^2}{\mathrm{N}^2 * \mathrm{E}^2}}{\mathrm{t}^2} + \left(\sum \mathrm{Ni} * \mathrm{si}^2\right) \right] \text{.......................... (Equation 1)}$$

Where, n= number of plots to measure,

Ni= the number of sample plot i stratum (strata area unit in hectare)

T= student t value distribution for the 95% of confidence level set 2 because population variance is not known

Si= standard deviation of each stratum i and

E= the desired precision is calculated mean carbon stock biomass by 10% precision.

Based on the above equation 51 sample plots were determined. 41 plot from exclosure area and 10 plots where from open free grazing land of the Gundi-etki study site area.

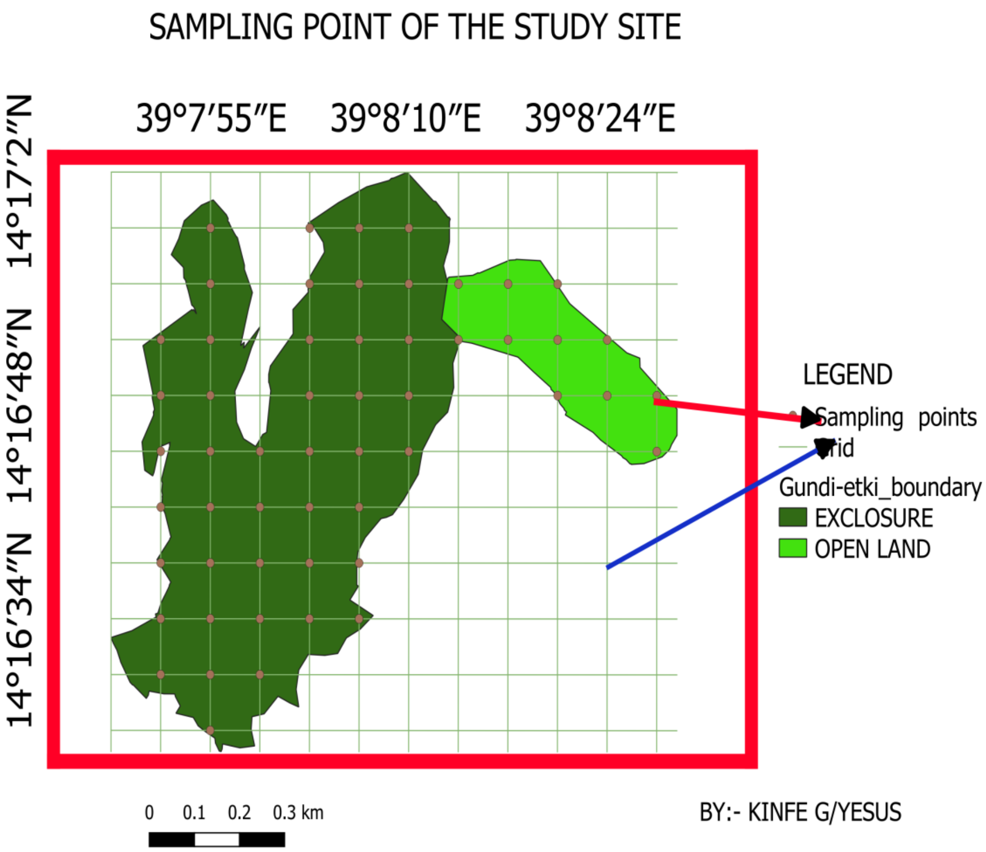

Figure 5 Sample point distribution

The red arrow represents the sample points of the two land uses and blue arrows also represents the grid line was lies along the two land uses of Gundi-etki study area. The above figure is shown that 10 grid lines has 111.28 meter to 1.113 kilometer length ranges. The sample plots were leis along the grid lines in 100*100 meter spacing in uniform interval of horizontally and vertically gradient lines.

3.4. Data collection method

3.4.1. Species identification methods

The living woody vegetation species $\geq$ 2.5cm diameter was identified in the field by recording the local name by asking the people living around the study area. The identified plant name in local names were changed to their corresponding scientific species and family names using the useful trees and shrubs of Ethiopia and Eritrea (Azene Bekele, 2007). All the tree/shrub species inside a sample plot of the closed and adjacent grazing lands were identified and their conditions were recorded: tree species (local and scientific name), species status (live standing, dead wood, tree or shrub).

3.4.2. Above ground living Woody species sampling

The estimation of above and below ground carbon depends on the above ground living woody biomass species (IPCC, 2014). Non-destructive allometric equation methods were selected that applied in semi-arid Africa tropical forest particularly in highland of Ethiopia. The carbon stock in the AGB woody living vegetation was estimated based on the easily measurable parameter of diameter and height in the fixed sample plots or sample points. From each sample plots of 5.64 radiuses or $100m^2$ circular plot's area of each woody species were measured at diameter of $\geq$2.5cm at breast of 1.3m and at 30cm stump height (Mengesteab Hailu *et al.,* 2018).

The diameter was measured separately and considered as single shrubs when the stem was branched below 30cm height. However, in the cases where trees boles buttressed, DBH was measured at normal the bole above and below the buttressed.

3.4.3. Grass data collection

The grass samples were collected from the center of each 30 sample plots of the exclosure of Gundi-etki study site to estimate the above ground grass carbon stocks' and biomasses. The sample data were collected from thirty sample plots of exclosure of study site but has no grass sample was collected from the open grazing land because it did not have grass cover due to overgrazing by livestock animals.

In each plot the total grass cover was harvested and collected in the field and the fresh weight from each sample plot size of 1m^2. 100 gram grass samples per plot were Oven dried at 105ºc for 24 hours to a constant weight to determine the grass dry biomass carbon stock(Bhattarai *et al.*, 2016).

3.4.4. Soil Sampling

The soil sample were collected from (2 depth*2 soil sample*51 sample plot) for soil organic carbon stock and bulk density analysis. To reduce variability, Soil sample were taken from four directions (south, east, north and west) of 1m2 quadrants of the circular sample plots were analysis soil organic carbon stock using soil auger (Kenye *et al.*, 2019). One soil sample was collected from the center of plots using a core sampler with a diameter and height of 5cm from center of each transects line sampling unit area to analyzed bulk density. The soil core sampler was inserted to the desired soil depth ranges 0-15cm and 15-30cm in total 30cm depth (Ashenafi Manaye *et al*., 2019). All the soil material in the core sampler was placed into appropriately labeled sample bags.

After soil samples were collected and mixed properly by taking equal amount of soil from each quadrants and sample plot corresponding to their depth in order to make composite. Before a physical and chemical analysis in a laboratory the soil samples were sieved by 2mm mesh size and at 105 ºC in the oven for 24 hour to determine dry weight of each soil sample (Ouyang *et al*., 2017). The carbon fraction of each sample was measured in laboratory by using Walkley-Black method(Gelman *et al*., 2011)

3.5. Data Analysis

3.5.1. Allometric equation selection

To estimate the above ground living trees/shrubs of the study sites before data collection in field were identified the independent variables such as diameter at breast height, diameter at stump height, the total height and wood density from the woody biomass inventory and planning strategy program WBISPP (2000) (Bastin *et al.*, 2015).

The identification of independent variables was based on a cause and effective relationships between dependent and independent variables (Pearson, Brown and Birdsey, 2007). Based on the name of the woody trees/shrubs species five equations were selected. From those the best fitted equation with the collected independent variables was select.

Table 2 the allometric equation of aboveground woody biomass selection

Spp. type	Reference	variables	R^2	F	P - value	Diameter
Dry tropical forest	(Chave *et al.*, 2014)	Dbh, Ht, Wd	0.868	256.73	<0.001	>5cm
Dry tropical forest	(Mugasha *et al.*, 2016)	Dbh, Ht, Wd	0.861	240.94	<0.001	>5cm
Acacia abyssinica	(Solomon *et al.*, 2017)	Dbh	0.966	3421.8	<0.001	≥2cm
Acacia etbaica	(Ubuy *et al.*, 2018)	DSH	0.967	3525.1	<0.001	≥2.5cm
Mixed trees Spp.	(Mokria *et al.*, 2018)	DSH and Ht	0.955	2074.0	<0.001	≥2.5cm

Whereas; Dbh=diameter at 1.3m, DSH=diameter at 30cm, Ht total height and Wd =wood density of individual tree/shrubs.

These models were selected based on the high value coefficient of determination or relationships, correlation, accuracy measured, species specific, site specific and least mean square error(Marshall *et al.*, 2012). The recommended application of semi-arid of degraded exclosure forest area AGB allometric equation (Mengesteab Hailu *et al.*, 2018) of shrub/tree species with DBH and DSH ≥2.5cm as predicated variables was shows better results (higher R^2 =0.967, p<0.0001 and lower mean standard errors) and developed for acacia species and exclosure specific site in Tigray region.

3.5.2. Aboveground Carbon Biomass Estimation

3.5.2.1. Woody Tree/shrub Species Estimation

Most researchers employed and recommended destructive (direct) measurement method to estimate trees or shrubs biomass (Cleemput *et al.*, 2002). However, destructive methods have many limitations in practical application such as not cost effective, more laborious for large forest area and require many sample plots, difficult to apply for endangered and rare tree species and create the opportunity for illegal forest harvest by the local people and the land designed for rehabilitation purposes.

In most of the case, DBH were used for the estimation of AGB using allometric equations because it saves time, cost and energy. Allometric models using the diameter and height of trees are rare since height measure in the field is difficult for large area and very larger trees (Aneseyee *et al*., 2018). However, in this study there were not very large trees because area closure mostly covered by shrubs, small trees and other non-woody understory vegetation. The allometric regression equation was selected necessary to estimate the above-ground biomass of individual woody trees species for tropical forests as a function of diameter at breast height and diameter at stump height *(*Mengesteab Hailu *et al.,* 2018). Individual tree or shrub species' AGB (kg) was calculated in each plot.

All the shrubs/trees from each the plots were measured or estimated using the woody species allometric equation that was applied in Tigray exclosure and degraded areas with diameter of ≥2.5cm for Acacia spp. The multi stemmed diameter plant species were calculated using a diameter equivalent as follows (Tsegay Gebregergs *et al.,* 2018*)*

$$\boldsymbol{de = \sqrt{\quad \sum_{1}^{n} di\hat{}2}} \text{ ……………………… (eq.2)}$$

Where: de=diameter equivalent, di= diameter of i^{th} stem of shrubs/trees

Generally the following steps and the parameters are included for calculating biomass carbon stock in exclosure and adjacent study sites(Brown *et al.,* 2014):

- In the fixed area sample plots the tree's height and diameter was measured
- All the data collected from the field inventory was recorded in excel spread sheet
- Select an allometric equation function for the individual tree biomass based on species and family.
- Calculate and summarize of the individual tree biomass to estimate plot level AGB.
- Calculate the total biomass and carbon stock using appropriate allometric equation for each land use areas.
- Analyzed the difference between area ex-closure and adjacent open access area of AGB of the total sample plots.

$AGB = 0.3098 * D^{\wedge}1.8761$…………………….. (eq.3)(Mengesteab Hailu *et al.*, 2018)

Where,

AGB = Aboveground biomass (kg or tons of carbon per hectare)

D = Diameter of trees/shrubs ≥2.5 (cm)

Converted trees/shrubs in to Carbon= AGB*0.5 carbon factor(Pearson, Brown and Birdsey, 2007)

CO2e absorption calculates by

CO_2 equ= C*3.67 or 44/12 (Timothy R. H. Pearson *et al., 2017)*

3.5.2.2.Grass Biomass Estimation

The fresh weight of grass collected and recorded in the field from each sample plot size of 1m^^{2} was oven dried at 105^{o}c for 24hrs to a constant weight. After oven dry the grass sample, grass biomass of each sample plot was calculated and converted to carbon by 0.5 default value factor (Pearson, Brown and Birdsey, 2007).

The harvested grass from each sample plot was estimated based on the following steps;

- Place the sampling frame in the two land uses by systematic method
- Collected all the grass biomass inside the frame sample by labeling and coding
- The fresh weight of the grass biomass was determine and recorded and transported to shire soil laboratory center
- The samples are oven dried at 105^{o}c for 24 hours to determine the dry weight biomass
- Finally the total oven dry weight of grass sample biomass was calculated using the following equation;

$$\boldsymbol{Biomass}\left(\frac{\boldsymbol{t}}{\boldsymbol{ha}}\right) \frac{\textbf{=total fresh weight(kg)} \quad * \quad \textbf{sub-sample dry weight(kg)}}{\textbf{sub-sample fresh weight(kg)*sample areas(m2)}} \text{.... Eq.4)}$$

(Huy et al., 2016)

Carbon= dry grass biomass***50%** of the biomass of grass(Holly K Gibbs *et al*., 2007)

3.5.3. Below Ground Biomass (BGB) and Carbon Stock

Below ground carbon biomass was directly measured or estimated from the above ground living biomass of the woody vegetation (IPCC *et al*., 2003). The below ground carbon stock was estimated using the Root: Shoot ratio of semi-dry tropical forest model. The root-shoot ratio (R: S) or belowground-aboveground (BG: AG) biomass ratio was used for estimating belowground carbon stock. The ratio expresses a general relationship between root biomass and shoot biomass (IPCC *et al.,* 2003). The allometric equation for the ratio of BGB: AGB for dry tropical forest range from 0.28 to 0.56 for <20tonns AGB per hectare, from 0.27 to 0.28 for >20tons AGB per hectare (Kumar and Sharma, 2015).

Biomass of roots was difficult and time consuming to measured and estimated in any forest ecosystem and methods. The below ground biomass was estimated from the AGB trees biomass for each plots, for each land uses and sample points by multiplying it with a default factor of 0.27 (root/shoot ratio)(IPCC *et al*., 2003) (FAO, 2012).

$$BGB = AGB * 0.27\ carbon\ factor \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(eq.5)$$

According the IPCC, (2003) for estimating the below ground biomass was expressed by

$BGC\ =\ BGB\ x\ 0.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(eq.6)$,(Pearson, Brown and Birdsey, 2007)

Where, BGC = carbon content of below ground

BGB= below ground biomass

3.5.4. Soil Organic Carbon Estimation

Soil organic carbon contributes to more than 50% of forest carbon stock in some forest types (Gselman *et al*., 2011). To calculate the soil organic carbon content the three types of soil organic variable; soil depth, soil bulk density and concentration of organic carbon within the sample unit to obtained an accurate soil organic carbon stocks as suggested by (Pearson and Brown, 2005). Was used as following;

The carbon stock density of the soil organic carbon was calculated based on the Pearson *et al.*, (2017) from the volume and bulk density of the soil.

$$V = h * \pi r^2 \text{ ……………………………………… (eq. 7)}$$

Where, V is volume of the soil in the core sampler augur in cm^^{3}, H is the height of core sampler augur in cm, and r is the radius of core sampler augur in cm.

More over the bulk density was calculated as follows:

$$BD = (OWD - RF)/CV \text{…………………(eq.8) (Pearson et al., 2007)}$$

Where, BD is bulk density of the sample per unit sample of <2mm fraction in g/cm^3, OWD is average air dry weight of soil sample per quadrant or oven dry mass total sample in grams, CV is volume of the soil sample in the core sampler in cm^^{3} and RF mass of coarse fragments (>2mm in grams) (Pearson and Brown, 2005). Concentration of soil chemicals generally are measured in air-dried soils, while bulk density was measured in oven-dried soils to 105ºC for 24 hr the fragmented soil was sieved and weighted and recorded.

Finally the determination for the organic carbon stocks(t C/ha) in the 0-15cm and 15-30 cm depths were calculated according to Pearson, Brown and Birdsey, (2007), employing the following equations.

$SOC\left(\frac{t}{ha}\right) = [\text{depth} * \text{BD} * \%OC\ ]$ …………..(eq.7)

Where, BD= soil bulk density (gcm^^{3}),

Depth= total depth at which the sample was taken (30cm),

SOC= soil organic carbon stock per unit area (t /ha) and

%OC= carbon concentration (%).

The percent of soil organic matter was calculated by multiplying the percent of organic carbon by a factor of 1.72 (Tsegay Gebregergs *et al*., 2018).The mass of coarse fragments is not carbon stored because of occupy space in soil profile, then if not distinguish the coarse soil the soil organic carbon calculation is overestimate(Wolde Mekuria *et al*., 2009). The soil sample collected from the different plot unit was calculated the mass of carbon stocks and volume per one hectare and total soil organic carbon of the total exclosure and adjacent open land.

3.5.5. Estimation of total carbon stocks

There were calculated the total biomass and the biomass per hectare of living woody, grass and belowground biomass. After this converted to the same unit of measurement and calculated the total biomass by summing each plot biomass and average overall plots as follows.

$$(\mathrm{T - Biomass = AGB - woody + AGB - grass + BGB}) \ldots\ldots\ldots\ldots\ldots\ldots \text{(eq.8)}$$

The total carbon stock from various carbon pools was calculated by aggregating of all carbon pools by (Pearson and Brown, 2005).

$$\mathrm{T}_{\mathrm{Carbon}(\frac{\mathrm{tones}}{\mathrm{ha}})} = \mathrm{AGC}_{\mathrm{Woody}} + \mathrm{AGC}_{\mathrm{grass}} + \mathrm{BGC} + \mathrm{SOC} \ldots\ldots\ldots\ldots \text{(eq.9)}$$

Whereas:

Tcarbon= total carbon stocks in tones per hectare

AGC-woody= the carbon stocks of living woody tree/shrub species (t/ha)

BGC= the belowground carbon stocks (t/ha),

AGC-grass= the grass carbon stock (t/ha),

SOC= is soil carbon stock (t/ha)

CO_2 equivalent= carbon*44/12 or 3.67 (Pearson *et al.*, 2017).

3.6.Statistical Analysis

After the data collection was completed, data analysis of various carbon pools measured in the Exclosure and adjacent open grazing land were recorded, organized and fed into the excel sheet and Microsoft (MS) sheet.

Soil and living woody vegetation biomass (belowground, aboveground of carbon stocks) data's from ex-closure was analyzed using one ways ANOVA with post hoc test to find out the variation and statistically significant difference with land use types and soil depth. In addition, exclosure carbon data was compared with open grazing lands to know significant differences and relationships between different parameters of above ground, below ground and soil carbon stocks using SPSS 20 software packages.

The aboveground woody trees/shrubs were analysis using an allometric regression equation depend on some easily measurable inventory data such as DBH, Dsh and height of exclosure and open free grazing forest area. Also between the Parameters or factors affecting the soil, above and below ground carbon stock of the exclosure and open access forest area was analyzed by simple linear regression equation how close the data were to the fitted regression line and relationship among the necessary parameters of the result analysis.

4. RESULTS AND DISCUSSION

4.1. Aboveground woody carbon stocks versus land uses

The total mean above ground tree/shrub species in exclosure area and free grazing land was estimated 4.87±0.406 and 1.20±0.20 tons of biomass per hectare respectively. The mean above ground carbon stock also 2.44±0.22 and 0.60±0.10 tons of carbon per hectare respectively in the two land uses shows in (table3).

Exclosure had higher total mean aboveground biomass and carbon stocks than the adjacent open free grazing land because it had a significant potential to regeneration or restored degraded grazing land, high species stock biomass and large carbon stocks potential due to the area was excluded from any anthropogenic impacts. Four times higher aboveground carbon stocks and biomass in exclosure area compared to adjacent free grazing land of Gundi-etki study site due to the grazing land dominated by very small number of large trees, low new vegetation regeneration and low plant biomass. According Mulugeta Mokria *et al*., (2018) report exclosure had greater carbon stock biomass than grazing lands in Ethiopia.

According the Mengesteab Hailu *et al.*, (2018), Cleemput *et al.*, (2002), more than two times aboveground biomass has produced under exclosure than the adjacent free grazing lands in the highlands of Tigray region. In other ways above ground living woody vegetation biomass declined with degraded grazing land, reduction of basal area cover and root biomass, tree/shrub species composition, leading to a less aboveground biomass production at higher pressure compared to exclosure areas. The carbon stocks biomass were statistical significant higher in exclosure than the adjacent open free grazing land at 0.01confidence interval ($p \leq 0.001$) show in table (3).

Table 3 The mean biomass and carbon stock content (Mean±SE) of the two land uses

Activity	unit	Land uses		Total mean
		Exclosure	Free grazing land	
AGB	Tons per hectare	4.87±043	1.20±020	4.54±0.406
AGC	Tons per hectare	2.44±0.22	0.60±0.10	2.27±0.20
Number of stem	Per total area	28900	2500	31400
CO2 equivalent	Tons per hectare	8.94±0.79	2.2±0.37	8.33±0.74

Whereas; AGB is aboveground biomass per hectare

AGC is aboveground carbon per hectare

CO_2eq is carbon dioxide equivalent per hectare.

4.2. Grass biomass and carbon stock in respect to land uses

Grass biomass was significantly varied between open grazing land and area closure. Accordingly, the highest grass biomass was obtained from the ex-closure, whereas no grass biomass was under the open grazing land. In the closed area the total average aboveground biomass, carbon and carbon dioxide of equivalent accounts about 0.058±0.003, 0.029±0.001 and 0.106±0.005 tonnes in respectively but in open free grazing was zero figure(6). Area exclosure of Gundi-etki study site is highly and significantly stored and sequestered carbon dioxide equivalent than free grazing land at (t= 21.347, P-value <0.001).

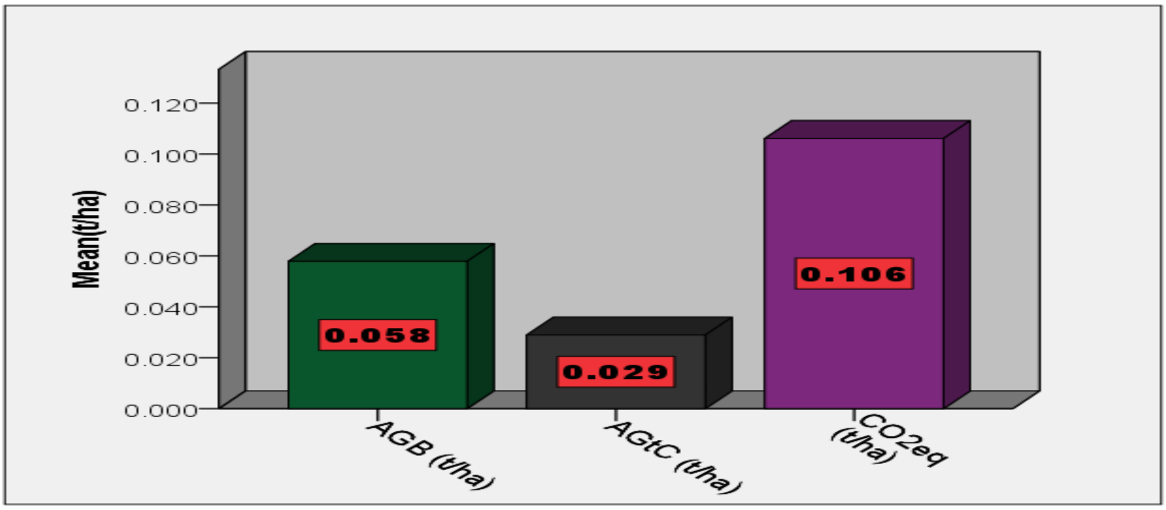

Figure 6 the carbon stock, CO_2eq and biomass across exclosure area

Whereas; AGB (t/ha) is above ground biomass of grass tonnes per hectare

AGC (t/ha) is above ground carbon of grass tonnes per hectare

CO2eq (t/ha) is carbon dioxide equivalent stock of grass tonnes per hectare

4.3.**Belowground carbon stock biomass across the two land uses**

The total average belowground carbon stock and biomass were found 34.79±0.09 and 69.58±0.18 tonnes in the two lands use respectively. The mean average belowground biomass of living trees/shrubs of the two land use system of the study area is shown in the (table4). The mean average below ground biomass was 1.62±0.20 tons per hectare and 0.35±0.06 tons per hectare were estimated in the ex-closures and open grazing land respectively.

The total average carbon dioxide equivalent also 267.92±0.21 and 0.86±0.001tonnes were stored and sequestered from woody living carbon biomass. It was significantly different between the two land-use systems because large living tree/shrub species, deep soil, high aboveground biomass, large root biomass and greater soil moisture content in exclosure area shown in (table4). In other way the belowground carbon stock of open free grazing land was significantly lower than ex-closures area because it had low carbon stock biomass store, shallow soil depth and very small and scattered living woody and non-woody vegetation regeneration.

Table 4 Belowground carbon stock biomass (Mean±SE) across the two land uses

land use system		BGB (tons/ha)	BGC(t/ha)	CO2 equivalent(t/ha)
Exclosure	Mean	1.62±0.20	0.81±0.10	2.97±0.37
	Sum	66.46	33.23	121.95
open land	Mean	0.35±0.06	0.17±0.03	0.64±0.11
	Sum	3.12	1.56	5.73
Total	Mean	1.39±0.18	0.70±0.09	2.55±0.33
	Sum	69.58	34.79	127.68
		Significant at 95% confidence interval (P –value=0.006)		

Whereas; BGB (tons/ha) is belowground biomass in tonnes per hectare

BGC (t/ha) is belowground carbon stock in tonnes per hectare

CO_{2eq} (t/ha) belowground carbon dioxide equivalent in tonnes per hectare

Deeper soils allowed a larger rooting volume in different lands use type of terrestrial ecosystem (IPCC *et al*., 2003). The current result indicated that exclosure contained four times greater than the open free grazing land because it had deep soil and root biomass than open grazing land. According Negasi Solomon *et al*., (2018), report exclosure has high below ground biomass carbon stock than free grazing land. This result is having similarity with the current result.

Also the lowest above and belowground carbon stocks were record in open grazing land could be due to loss of carbon stocks by overcutting and trimming living woody vegetation plants. In general the result shows that exclusion of the eroded and degraded grazing land from livestock and human activity have a positive effect on the increasing and restoring of above and belowground carbon stocks.

4.4. Soil organic carbon concentration along soil depths

According Tesfay Berihu *et al*., (2017) results soil organic carbon concentrations across the soil depth down to 30 cm depth in different land-use types in northern Ethiopia was consistently decreased. The exception to this pattern is obtained in Gundi-etki of ex-closure and adjacent open grazing lands. The SOC concentration content in the 0- 15 cm were larger than in 15-30cm depth layer.

The soil organic carbon concentration of the top and lower soil depths were 1.60%±0.04 and 1.39%±0.035 with the total of 1.50±0.028% in 0-30cm soil depth show in (table 5). The soil organic carbon concentration and soil organic matter in top soil depth was significantly higher than the lower soil depth by about 0.20% at 0.01 confidence interval (F-value= 14.70 and p-value≤0.001). Thus SOM concentration showed a negatively relationship and correlation as the soil depth increased.

The organic carbon matter were recorded 2.75%±0.08 and 2.375%±0.07 in the depth of 0-15cm and 15-30cm respectively and it is highly significant at the lower soil depth than the upper depth (F-value= 11.569, P-value= 0.001) because of high soil organic matter, soil moisture, microbial activity and nutrient fixation, low compaction soil and litter decomposition at the top of the soil surface layer shows in (table 5).

Table 5 Percentage of organic carbon concentration (Mean±SE) in the two soil layers

Soil depths	Soil OC (%)	Soil OM (%)
0-15	1.60055±.040	2.75±0.08
15-30	1.39437±.035	2.375±0.07
mean average of 0-30cm soil depth	1.49746±.028	2.56±0.057
P –value	<0.001	0.001
Correlation coefficient value (Pearson)	-0.393**	-0.325**

**Correlation is significant at 0.01 levels (2-tailed)

4.5.Soil organic carbon stock versus the soil depths

Soil depth is one of the main factors of soil organic carbon density influencing in forest areas with the same land and climatic condition (Pearson *et al.*, 2017). According to Pearson (2007) observations as soil depth increases the soil organic carbon stock density decreases. Because higher accumulation of soil organic carbon content and organic matter at the top soil surface, less soil bulk density compaction and highest litter accumulation and decomposition.

The mean SOC stock was stored in the 0-15cm soil depth was 17.40±0.58 and 15.34±0.50 tones carbon per hectare in the soil depth of 15-30cm. The soil mass of 0-15cm soil depth 1087.59 tons per hectare and 15-30cm soil depth 1101.82 tons per hectare. The study result shows that the mean soil organic carbon stock is highly significance in the top soil depth than lower soil depth ($F = 7.253$, P-value= 0.008 and $r = -0.262$) but negative correlation or relationships with soil depth difference. The result is shows similarity report with the Wondimagegn Amanuel *et al.*, (2018) and Pearson *et al.*, (2007) show (figure 7).

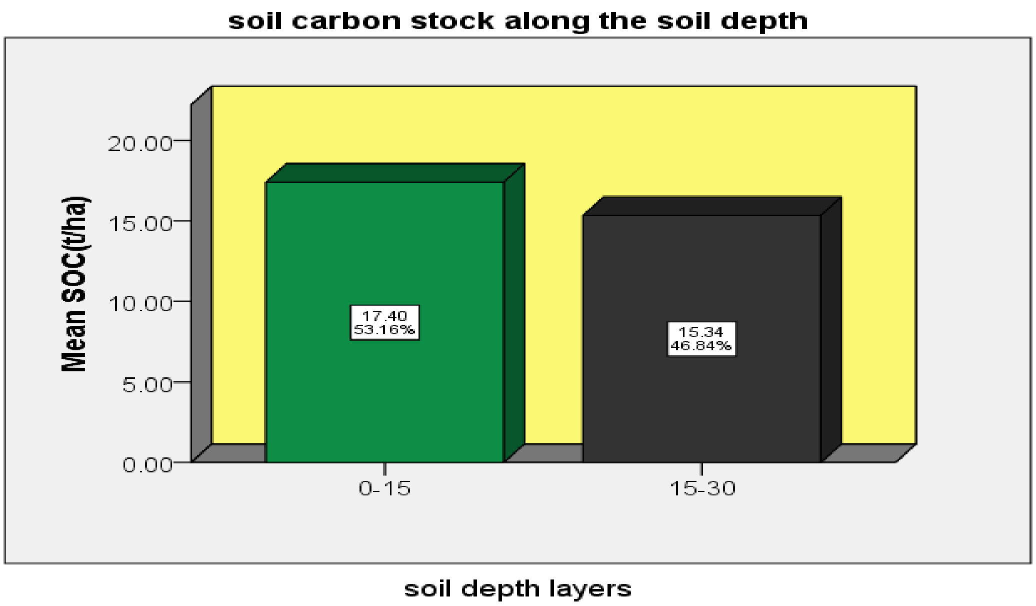

Figure 7 Soil carbon stock in respect to the two soil layers

4.6.Soil organic carbon concentration variation across the land use systems

Soil organic carbon concentration was varied with land use-land cover type that ranges from 1.57±0.03% and 1.40±0.059% respectively in exclosure and open free grazing land of the study area. The highest mean value was recorded on the ex-closure area, while the lowest was on adjacent open grazing land use type and statically significant at 95% confidence level (t=2.574, p=0.012) and inverse correlation.

Soil organic matter concentration also varied with land use type it was recorded 2.69±0.06% in exclosure and 2.46±0.12% in the adjacent free grazing area. This finding supports the report of Ashenafi Manaye *et al*., (2019) result.

Table 6 Soil organic matter and carbon concentration (Mean±SE) versus land uses

Land use type		% OC	% OM
Exclosure	Mean	1.57±0.029	2.69±0.0655
Open land	Mean	1.40±0.059	2.46±0.12
Total	Mean	1.53±0.027	2.78±0.05
P- value		0.012	0.012

4.7.Soil organic carbon stock along the land uses

Ex-closure had consistently higher SOC stocks (16.88 ±0.44 tons of carbon per hectare) than the adjacent open grazing land (14.33 ±0.73 tons of carbon per hectare) statically significant at 0.01 confidence interval (F= 10.692, p-value= 0.009) and inverse relationship. Because of area closure there was high vegetation restoration, soil moisture content, high decomposition, different vegetation species and high understory vegetation regeneration. Moreover, area is free from any livestock animal and human impacts.

Woldu Mekuria and E. Aynekulu, (2013) finding showed that ex-closures had a high potential to rehabilitate degraded and grazing lands given the higher SOC recovery than that observed in open grazing land. On the other hand, the topographic location of the ex-closures could hinder the SOC stock accumulation due to slope steepness, shallowness of the soil, and high content of rock fragments.

A significant difference in the SOC concentration of the ex-closures and open grazing lands in Tigray was previously observed by (Tsegay Gebregergs *et al*., 2018) who explained this finding by favorable conditions created through improved land management in the ex-closures that facilitated plant growth, plant nutrient uptake, and decomposition and turnover rate of soil organic matter potential.

The amount of carbon dioxide storage was significantly differing between exclosure and open grazing land area. In exclosure a significantly higher CO2 equivalent result was recorded (61.95±1.63 t CO2e/ha) than open free grazing land (52.58±2.68). In general the current study result is having similarity with the Tsegay Gebregergs *et al.*, (2018) and Woldu Mekuria and E. Aynekulu, (2013) reports.

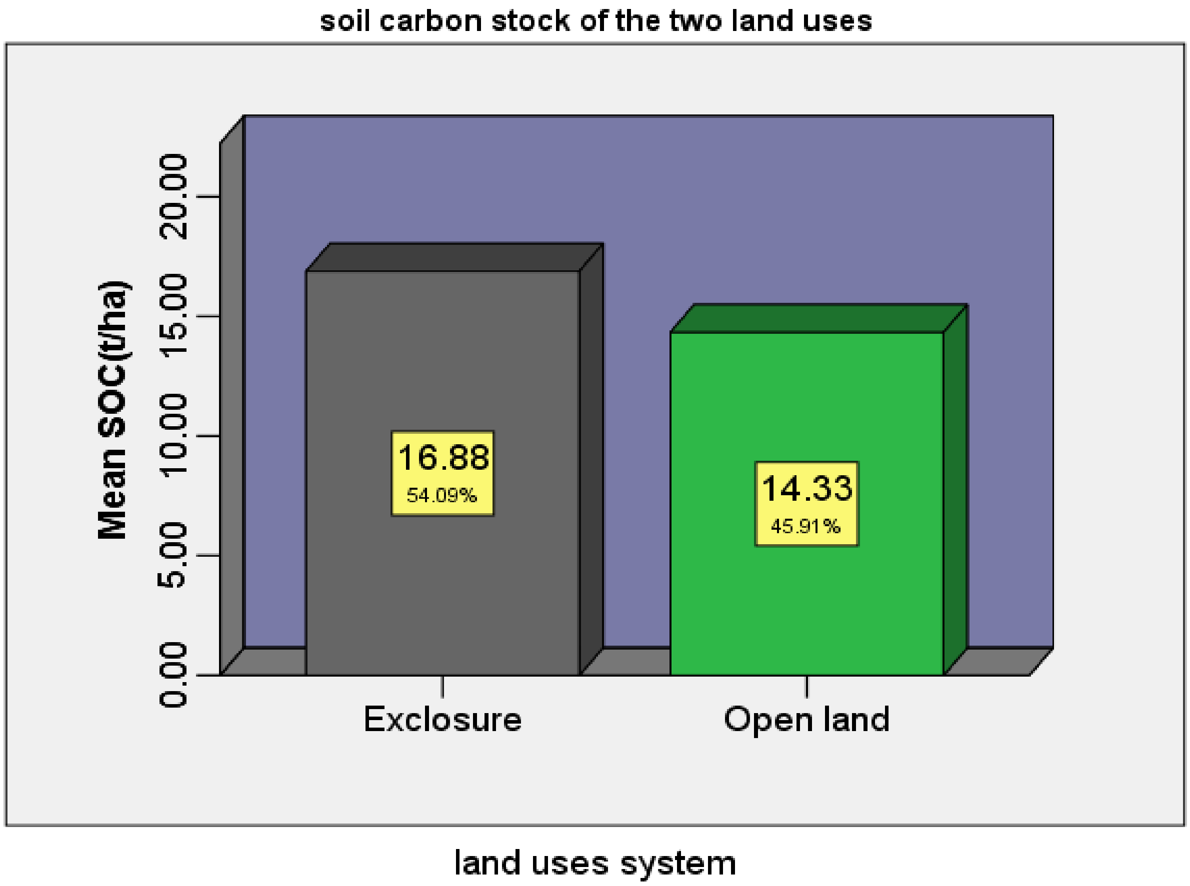

Figure 8 mean soil carbon stock (tonnes per hectare) versus land uses

4.8. Total carbon stocks of the study area

4.8.1. Total carbon stocks in the two land uses

The total mean carbon storage of ex-closure and the adjacent open free grazing land was 20.48±0.72 ton carbon per hectare and 15.38 ±0.94 ton carbon per hectare respectively. The aboveground carbon comprised 2.56±0.33 ton carbon per hectare, belowground biomass comprised 0.69±0.09 ton carbon per hectare and Soil organic carbon stock comprised 16.37±0.498 ton Carbon per hectare.

The largest carbon stock was estimated in soil carbon pool followed by aboveground biomass carbon stocks, belowground biomass carbon, and grasses biomass carbon showed in figure (8). The total carbon stock of the two land uses were very small amount because of young forest area, very shallow soil depth and steep slope, less large vegetation coverage.

In order to know their relation, correlation can be mostly applied statistical analysis method. It shows significant, extent and direction of the relationship. The total carbon stocks along the land uses were statistically significant higher in exclosure area than open free grazing land. The total AGC and BGC shows significant relation with the two land use systems (p=0.006) at α =0.01 confidence interval.

The total mean carbon stocks of the study area of land uses have statistical significance different at 0.01 correlation coefficient level (p=0.007). The total mean CO_2 equivalent of the exclosure and adjacent free grazing lands in respectively were 75.48±2.63 tons of CO_2 equivalent and 56.44±3.45 tons of CO_2 equivalent.

This indicated that, there is vegetation regeneration and restoring difference, soil moisture content and litter decomposition because of illegal livestock and human disturbance, topographical factors, and management difference of the two land uses.

The result indicated that there is having similarity with Tsegay Gebregergs *et al*., (2018) and Ashenafi Manaye *et al*., (2019) reports. In general the total carbon stocks and carbon dioxide equivalent storage exclosure area is greater than four times exceeded from open free grazing land area. It estimated 122.21±0.37 tonnes of carbon and 5.78±0.37 tonnes of carbon and 3094.49±2.63 and 507.99 tonnes of CO_2eq stored in exclosure and free grazing land in respectively and significantly difference at 0.01 confidence level along the two land uses of the study site.

Table 7 Total carbon stocks (Mean±SE) across the two land uses

land use system		AGC (t/ha)	BGC (t/ha)	SOC (t/ha)	Carbon (t/ha)	CO_2eq (t/ha)
Exclosure	Mean	2.98±0.37	0.80±0.10	16.88±0.44	20.54±0.72	75.48±2.63
	Total sum	122.21	33	684.60	839.81	3094.49
open land	Mean	0.64±0.116	0.17±.03	14.33±0.73	15.38±0.94	56.44±3.45
	Total sum	5.78	1.56	131.08	138.42	507.99
Total	Mean	2.56±0.33	0.69±.09	16.37±0.40	19.61±0.67	72.05±2.47
	Total sum	127.99	34.56	817.96	980.51	3602.50
P -value		0.006	0.006	0.009	0.007	0.007

Whereas; AGC (t/ha) is above ground carbon stock in tonnes per hectare

BGC (t/ha) is below ground carbon stock in tonnes per hectare

SOC (t/ha) is soil organic carbon stock in tonnes per hectare

Carbon (t/ha) the total mean summation of the carbon pools of the two land uses

CO_2eq (t/ha) the total carbon dioxide equivalent in tonnes per hectare of the two land uses

4.8.2. Total carbon stock pools and carbon dioxide equivalent in the study area

The total carbon stock was higher in exclosure than the adjacent open grazing land of “Gundi-etki” exclosure and adjacent open grazing lands. In exclosure areas have higher carbon stocks was stored in soil than the above ground and below ground carbon stocks (figure9). More than 80% of the total carbon stocks of Gundi-etki exclosure and open grazing land were contributed by soil organic carbon stocks. The ratio between exclosure to open free grazing land of total average carbon stocks were 85.6% to 14.12 %.

According report made by to Mehari A Tesfaye *et al.*, (2016) soil carbon contained and contributed about three times more organic carbon than the above ground living woody vegetation carbon stocks. similarly soil organic carbon stocks contributed about 80% of the total terrestrial carbon stocks (Ravindranath *et al.*, 2012). The finding supports the result of Mehari A Tesfay (2016) and Ravindranath (2012) findings.

In the study area 127.99±0.33 above ground carbon, 815.68±0.40 soil carbon and 34.56±0.09 tonnes of below ground carbon mean stocks biomass mean per total areas was quantified Gundi-etki study area. The total average carbon stocks and carbon dioxide equivalent storage in the exclosure and free grazing land of Gundi-etki were estimated 980.51±0.67 and 3602.50±2.47 tonnes in respectively.

In general above ground, below ground and soil carbon stock storage and sequestrations of the Gundi-etki exclosure and adjacent open grazing land has been highly difference between the two land uses of the study area (figure 10).

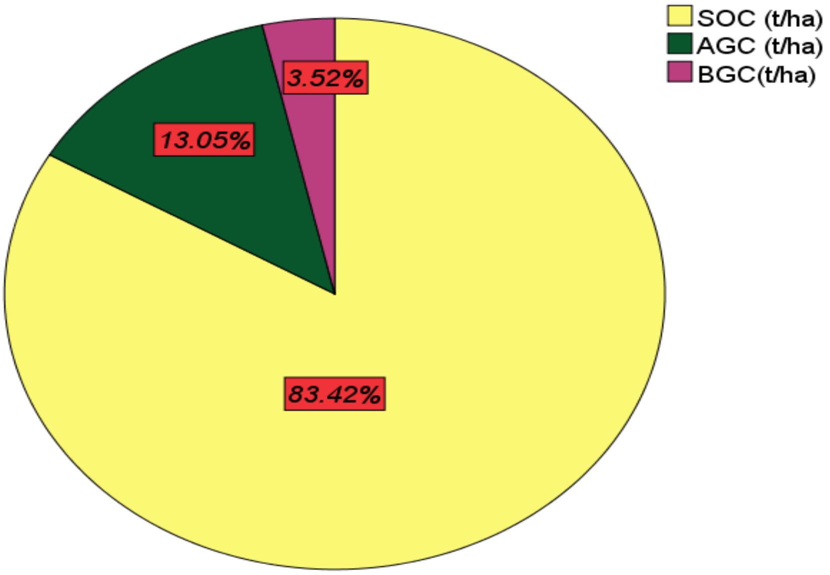

Figure 9 carbon stock proportion of individual along the land uses by percent

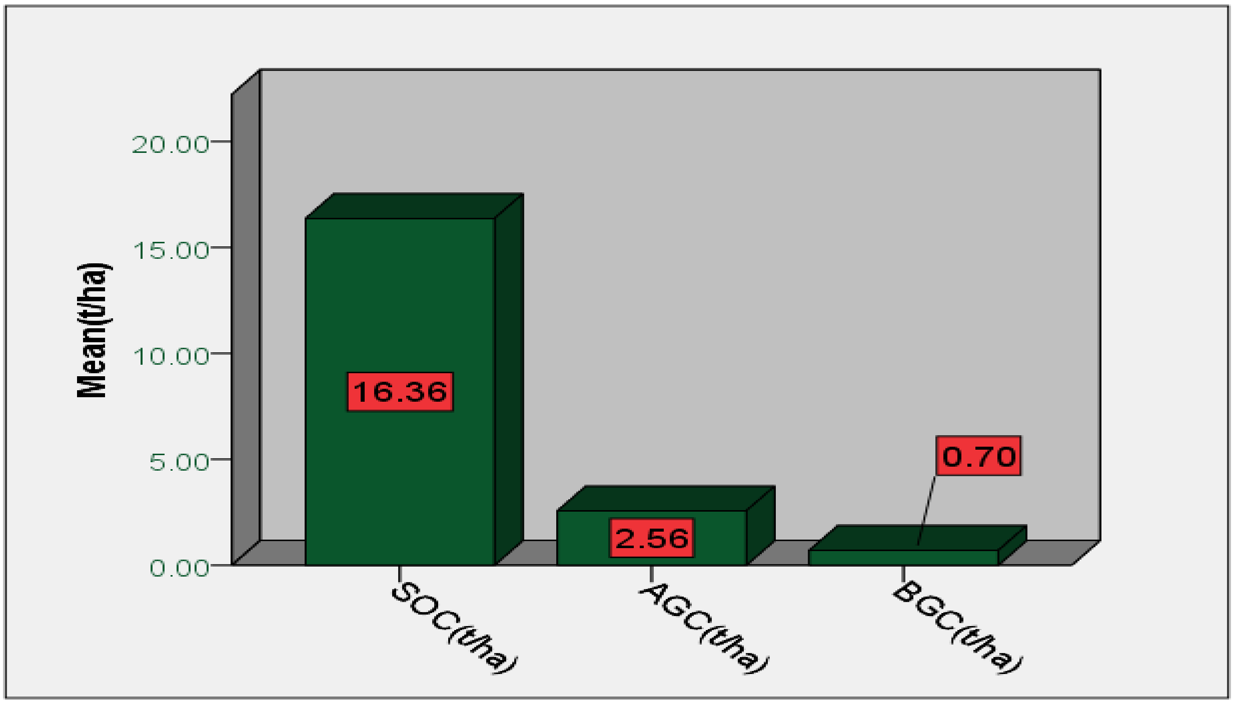

Figure 10 proportion of individual carbon pools of the study area by mean of amount

5. CONCLUSIONS AND RECOMMENDATION

5.1.Conclusions

The result indicated that, the effect of exclosure on above ground, below ground and SOC stocks along the two land uses in Ahferom Wereda, Tigray region of Gundi-etki exclosure better than free grazing land. Before establishing of the exclosure shrub/tree plants were highly browsed and low exhibiting species diversity and had small scattered number of living woody trees and shrubs.

The study result showed a significantly increase of above ground living woody vegetation biomass and aboveground grass biomass in the exclosure area. Area exclosure is very important to restoration of above and belowground carbon stock biomass in degraded land.

Exclosure is significantly higher soil organic carbon, organic matter and fertile soil than the open free grazing land. However, bulk density and soil biomass is grater in open free grazing land than exclosure. Due to in exclosure had higher soil decomposition, humus soil, deep soil layer, large root biomass and more microbial activities.

The top soil layer is having significantly higher soil organic matter and soil organic carbon stocks store than the lower soil depth layer. Because of at the upper part of the soil layer have higher litter accumulation, organic matter and humus soil. More than 83% of the total ecosystem carbon stock of the study area is covered by soil organic carbon stock.

The ecosystem carbon stock is significantly higher in exclosure area than the open free grazing land. The result showed that the conversion of open free grazing land to exclosure has significantly higher potential to increase carbon restoration and sequestration of carbon dioxide from the atmosphere. In general the establishment of exclosure areas on eroded and degraded communal grazing land has a positive effect in restoring woody living trees and shrubs vegetation biomass, increase carbon sequestration and CO_2 sink and soil organic matter and nutrient of the eroded soil lands.

5.2. Recommendations

Based on the current result of the study site of Gundi-etki exclosure and open free grazing land, the following recommendations have been forwarded.

- Establishment of area exclosure is a widely needed practice in semi-arid areas of Tigray region and Ahferom Woreda to enhance vegetation biomass; carbon stocks restoration potentials, minimizing soil erosion and improved soil nutrient. However not much more higher results from other exclosure studies because of less management. It should be manage in sustainability way and other simultaneous activities such as afforestation and soil conservation.
- Open free grazing land had low above ground and below ground biomass and soil organic matter than exclosure. Therefore, it should be a strong attention and follow up to change the open free grazing land to exclosure area with integrating the local community with concerned sectors.
- It is better to expanded exclosure area practice to other non-closed area of the Woreda because it provide a positive result on above ground and below ground biomass and carbon stocks.

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Appendices

Table 1.Number of individual species of the study site

Spp.name	Family name	number/hectare	Total number	percent
Acacia lahay	FABACEAE	280	7000	22.3%
Acacia etbaica	FABACEAE	297.14	10400	33.1%
Acacia seyal	FABACEAE	166.67	500	1.6%
Capparis micrautha	CAPORAIDACEAE	175	1400	4.5%
Carissa edulis	APOCYNACEAE	300	1800	5.7%
Mytenus senegalensis	CELASTERACEAE	170	1700	5.4%
Euclea schimperina	EBENACEAE	256.25	4100	13.1%
Acacia aska	FABACEAE	262.5	2100	6.7%
Acacia senegal	FABACEAE	300	600	1.9%
Rhus natalensis	ACARDIACEAE	216.67	1300	4.1%
Dodonea angustifolia	SAPINDACEAE	150	300	1.0%
Erthrina brucei	FABACEAE	200	200	.6%
Total		257.38	31400	100.0%

Table 2 Aboveground biomass carbon stocks of individual species of the study site

Spp.name		DBH (cm)	DSH (cm)	Height (m)	AGB (t/ha)	AGC (t/ha)	BGC (t/ha)	CO2eq (t/ha)
Acacia lahay	Mean	10.25	6.22	4.14	6.78	3.39	0.92	12.45
Acacia etbaica	Mean	9.70	7.91	3.72	6.95	3.47	0.94	12.75
Acacia seyal	Mean	9.28		4.32	3.36	1.68	0.45	6.17
Capparis micrautha	Mean	9.11	6.97	3.18	3.12	1.56	0.42	5.73
Carissa edulis	Mean	6.21	5.35	2.62	2.32	1.16	0.31	4.27
Mytenus senegalensis	Mean	8.28	5.51	1.99	1.38	0.69	0.19	2.53
Euclea schimperina	Mean		6.00	2.09	2.10	1.05	0.28	3.86
Acacia aska	Mean	7.49	5.35	2.39	2.26	1.13	0.31	4.15
Acacia senegal	Mean	8.06		4.08	4.98	2.49	0.67	9.13
Rhus natalensis	Mean	6.53	6.03	2.78	1.88	0.94	0.25	3.45
Dodonea angustifolia	Mean		6.40	1.60	1.47	0.73	0.20	2.70
Erthrina brucei	Mean		7.02	2.75	2.40	1.20	0.32	4.40
Total	Mean	9.46	6.09	3.20	4.54	2.27	0.61	8.33
	Sum	661.94	322.81	390.88	553.9	276.97	74.78	1016.4

Table 3 Grass AGB, AGC and CO2eq along the land use

LU		Field-data	Fresh-weight	oven.dry	AGB (t/ha)	AGC(t/ha)	CO2eq(t/ha)
exclosure	Mean	64.36	49.27	37.70	0.05	0.02	0.09
	Sum	321.79	246.36	188.51	0.25	0.12	0.45
	Mean	81.94	65.93	49.35	0.06	0.03	0.11
	Sum	1147.12	923.06	690.85	0.85	0.43	1.56
	Mean	78.21	58.40	43.74	0.06	0.03	0.11
	Sum	860.29	642.40	481.14	0.64	0.32	1.17
	Mean	77.64	60.39	45.35	0.06	0.03	0.11
	Sum	2329.20	1811.82	1360.50	1.74	0.87	3.18
	Mean	77.64	60.39	45.35	0.06	0.03	0.11
	Sum	2329.20	1811.82	1360.50	1.74	0.87	3.18

Table 4 the total carbon stock of the study site of Gundi-etki

Land uses		AGC(t/ha)	BGC(t/ha)	SOC(t/ha)	total carbon(t/ha)	CO2eq(t/ha)
Exclosure	Mean	2.98±0.37	0.80±0.10	16.75±0.55	20.54±0.72	75.48±2.63
	Sum	122.21	33	686.88	842.09	3094.49
open land	Mean	0.64±0.12	0.17±0.03	14.56±0.93	15.38±0.94	56.44±3.45
	Sum	5.78	1.56	131.08	138.42	508
Total	Mean	2.56±0.33	0.69±0.09	16.36±0.49	19.61±0.67	72.05±2.47
	Sum	127.99	34.56	817.96	980.51	3602.5

Table 5 statistical analysis of carbon stock biomass of study site

a) Aboveground biomass of woody trees/shrubs with the two land uses

		t-test for Equality of Means				
		t	df	Sig.	Mean Difference	Std. Error
AGB	Equal variances assumed	3.528	120	.001	12.56	3.56

b) Soil organic carbon, organic carbon content and mass with land uses

		t-test for Equality of Means				
		t	df	Sig.	Mean Difference	Std. Error
% OC	Equal variances assumed	2.574	98	.012	.17	.06
SOC	Equal variances assumed	2.656	98	.009	2.55	.96
Mass	Equal variances assumed	2.140	98	.035	90.04	42.07

c) Samples Test between SOC, %OC and mass with soil depth

		t-test for Equality of Means				
		t	df	Sig.	Mean Difference	Std. Error
% OC	Equal variances assumed	4.228	98	.000	.21	.05
SOC	Equal variances assumed	2.693	98	.008	2.07	.77
Mass	Equal variances assumed	-.414	98	.680	-14.23	34.40

d) Statistical test between the total carbon stock pools and land uses

		t-test for Equality of Means				
		t	df	Sig.	Mean Difference	Std. Error
Total sum carbon	Equal variances assumed	2.825	48	.007	4.93	1.75
	Equal variances not assumed	4.020	21.051	.001	4.93	1.23

e) the individual carbon pools along the land uses, altitudinal gradient

Land use	Carbon pool biomasses	Correlation coefficient value	P- value
Exclosure and Open free grazing land	AGB of woody & grass	0.307**	0.001
	BGC	0.385**	0.006
Altitudinal gradient			
	SOC	0.208*	0.037

Whereas; AGC/AGB is the aboveground woody and grass biomass and carbon stock, BGC is the belowground carbon stock and SOC is soil organic carbon stock.

Table 6 Soil organic carbon along the soil depth and land uses

<table>
<tr><th colspan="2">the soil depth</th><th>%OC</th><th>%OM</th><th>BD</th><th>SOC (t/ha)</th><th>Mass(t/ha</th><th>CO2e(t/ha)</th></tr>
<tr><td rowspan="4">0-15</td><td rowspan="4">Total</td><td>1.52</td><td>2.64</td><td>0.72</td><td>16.35</td><td>1080.63</td><td>60.01</td></tr>
<tr><td>1.62</td><td>2.69</td><td>0.74</td><td>17.92</td><td>1110.11</td><td>65.78</td></tr>
<tr><td>1.71</td><td>3.04</td><td>0.71</td><td>18.28</td><td>1058.68</td><td>67.09</td></tr>
<tr><td>1.60</td><td>2.75</td><td>0.73</td><td>17.40</td><td>1087.59</td><td>63.88</td></tr>
<tr><td rowspan="4">15-30</td><td rowspan="4">Total</td><td>1.31</td><td>2.27</td><td>0.71</td><td>13.76</td><td>1058.34</td><td>50.49</td></tr>
<tr><td>1.43</td><td>2.44</td><td>0.78</td><td>16.71</td><td>1172.94</td><td>61.31</td></tr>
<tr><td>1.48</td><td>2.45</td><td>0.70</td><td>15.57</td><td>1047.63</td><td>57.15</td></tr>
<tr><td>1.39</td><td>2.38</td><td>0.73</td><td>15.34</td><td>1101.82</td><td>56.28</td></tr>
<tr><td rowspan="10">Total</td><td rowspan="4">Exclosure</td><td>1.43</td><td>2.44</td><td>0.75</td><td>15.86</td><td>1121.49</td><td>58.21</td></tr>
<tr><td>1.52</td><td>2.56</td><td>0.76</td><td>17.31</td><td>1141.52</td><td>63.54</td></tr>
<tr><td>1.60</td><td>2.75</td><td>0.70</td><td>16.93</td><td>1053.16</td><td>62.12</td></tr>
<tr><td>1.52</td><td>2.59</td><td>0.74</td><td>16.88</td><td>1112.72</td><td>61.95</td></tr>
<tr><td rowspan="2">Open land</td><td>1.40</td><td>2.46</td><td>0.68</td><td>14.33</td><td>1022.68</td><td>52.58</td></tr>
<tr><td>1.40</td><td>2.46</td><td>0.68</td><td>14.33</td><td>1022.68</td><td>52.58</td></tr>
<tr><td rowspan="4">Total</td><td>1.41</td><td>2.45</td><td>0.71</td><td>15.05</td><td>1069.48</td><td>55.25</td></tr>
<tr><td>1.52</td><td>2.56</td><td>0.76</td><td>17.31</td><td>1141.52</td><td>63.54</td></tr>
<tr><td>1.60</td><td>2.75</td><td>0.70</td><td>16.93</td><td>1053.16</td><td>62.12</td></tr>
<tr><td>1.50</td><td>2.56</td><td>0.73</td><td>16.37</td><td>1094.71</td><td>60.08</td></tr>
</table>

Whereas; %OC and %OM are organic carbon and matter content, SOC (t/ha) is soil organic carbon stocks in tonnes per hectare, BD is bulk density, mass is mass or volume of soil in 30cm soil depth and CO2eq (t/ha) is carbon dioxide equivalent in tonnes per hectare

Table 7 Geographical location of sample points

Plots code	X	Y	Z	Plots code	X	Y	Z
1	514143	1578851	2202	41	514913	1578851	2061
3	514363	1578851	2220	42	515023	1578851	2080
4	514473	1578851	2198	43	515133	1578521	2092
5	514583	1578851	2163	44	514033	1578411	2118
12	514143	1578741	2177	45	514143	1578411	2174
14	514363	1578741	2212	46	514253	1578411	2198
15			2168	47	514363	1578411	2152
16	514583	1578741	2120	48	514473	1578411	2101
17	514693	1578741	2103	49	514583	1578411	2069
18	514803	1578741	2100	54	515133	1578411	2063
22	514033	1578631	2115	55	514033	1578301	2122
23	514143	1578631	2162	56	514033	1578301	2175
25	514363	1578631	2191	57	514253	1578301	2190
26	514473	1578631	2135	58	514363	1578301	2140
27	514583	1578631	2095	59	514473	1578301	2093
28	514693	1578631	2075	66	514033	1578301	2112
29	514803	1578631	2073	67	514033	1578191	2158
30	514913	1578631	2086	68	514143	1578191	2199
31	515023	1578631		69	514253	1578191	2127
33	514033	1578521	2113	77	514363	1578191	2090
34	514143	1578521	2169	78	514033	1578081	2120
36	514363	1578521	2169	79	514143	1578081	2166
37	514473	1578521	2116	80	514253	1578081	2150
38	514583	1578521	2079	81	514363	1578081	2080
90	514253	1577971	2166	88	514473	1578081	2066
100	514143	1577861	2077	89	514143	1577971	2091

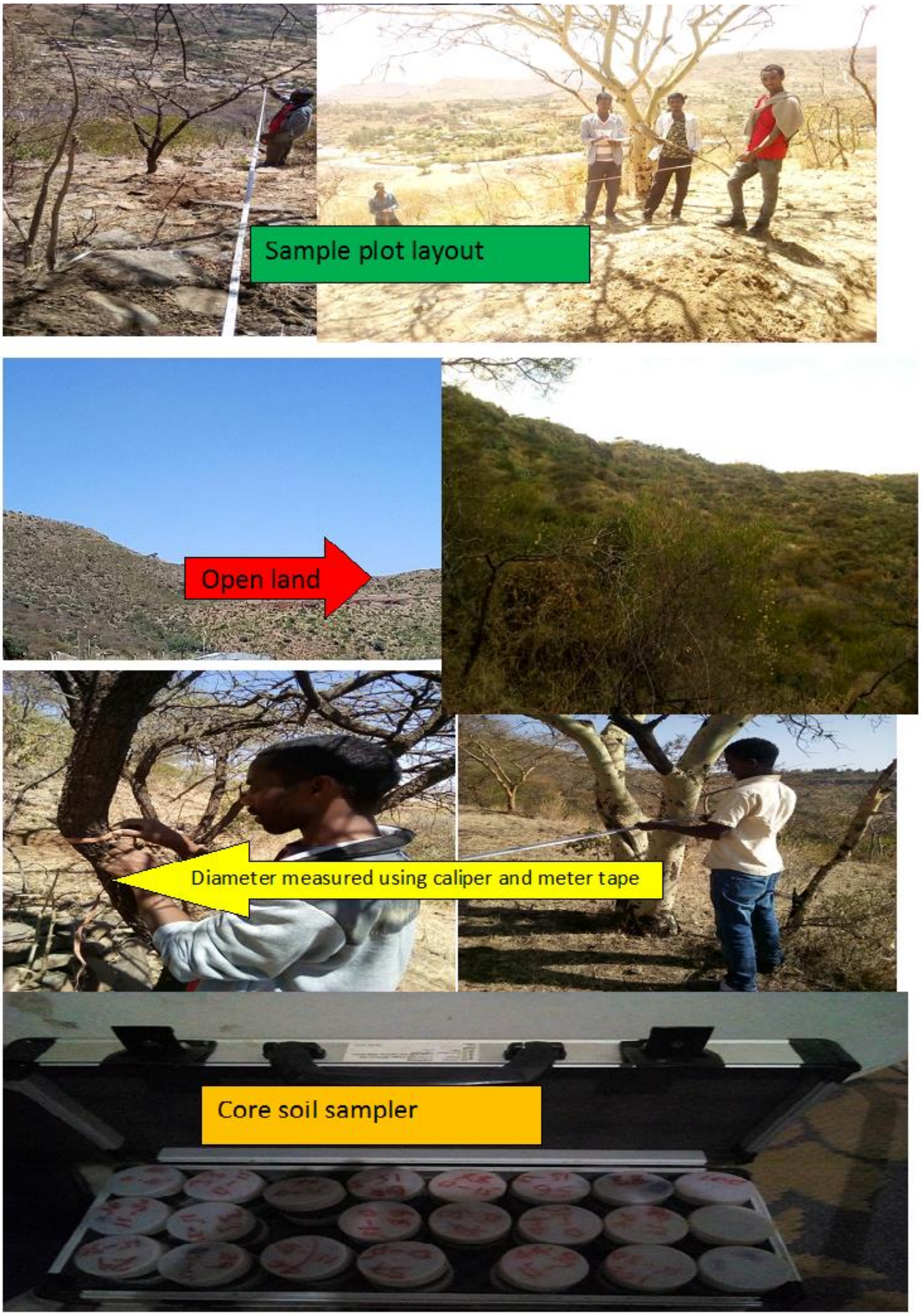
Sample plot layout
Open land
Diameter measured using caliper and meter tape
Core soil sampler

Figure 11. Photo gallery during the data collection and laboratory analysis