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*Article*

# Carbon stock and climate change mitigation potential of Godebe National Park, North West Ethiopia

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## Abstract

Forest plays a crucial role in climate change mitigation by sequestering and retaining carbon in above and below-ground biomass of trees, dead tree and deadwood biomass, litter biomass, and soil. Thus, the study was conducted to estimate the carbon stock potential of Godebe National Park, North Western Ethiopia. The field data were collected through systematic random sampling techniques from the 20 m × 20 m area of 44 sample plots. The above-ground biomass, below-ground biomass, deadwood biomass of the study area was collected from 20 m × 20 m area of the main plot, while the soil sample and litter biomass were collected from 1 m × 1 m area of subplots, which located at the four corners and one at the center of the main plot. The carbon stock of different carbon pools was estimated using different selective allometric and mathematical models and analyzed by statistical package for social science (SPSS) software version 23. The result showed that the mean carbon stock of each carbon pool such as above-ground carbon, below-ground carbon, deadwood carbon, litter carbon, and soil organic carbon accounted for about 338.893, 67.779, 5.43, 2.56 and 109.34 t/ha, respectively. The carbon stock variation along different strata (Acacia Woodland, Combretum Terminalia woodland and Riverine Forest) indicated that statistically significant effect was observed on carbon pools of the study area at α (0.05). The ultimate result showed that the study area stored and sequestered 523.948 ton of carbon per ha and 1922.887 tone $CO_2$ equivalents per ha respectively. Although the national park is newly established it has a great potential on carbon sequestration and such biodiversity conservation effort should be strengthened.

**Keywords** carbon stock; Godebe National Park; Allometric equation; above ground; soil organic carbon; below ground.

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## 1 Introduction

Climate change has been proved by scientific evidences and unequivocally accepted by the global community as a common issue of interest. Since the industrial revolution, the burning of fossil fuels and the destruction of forests have caused the concentrations of heat-trapping Green House Gases (GHGs) to increase significantly in our atmosphere, at a speed and magnitude much greater than natural fluctuations would dictate. If concentrations of GHGs in the atmosphere continue to increase, the average temperature at the Earth’s surface will increase by 1.8 to 4°C by the end of the century (IPCC, 2007). Thus, the rapid increase in global surface temperature is mainly due to the rise in the amount of carbon dioxide in the atmosphere primarily due to anthropogenic activities (Petit et al., 1999). As a result of change in global climate there has been a wide spread and growing concern that has led to extensive international discussions and negotiations. In seeking solutions for this, the overwhelming priority is to reduce emissions of GHGs and to increase rates of carbon sequestration. The concerns have led to efforts of reducing emissions of GHGs, especially $CO_2$, and measuring carbon absorbed by and stored in forests, soils, and oceans. To slowdown the rise of GHGs concentrations in the atmosphere, and thus possible climate change, is to increase the amount of carbon removed by and stored in forests (Broadmeadow, 2003; IPCC, 2007b).

As a natural solution, the role of trees and forests in the process of carbon cycle is quite significant as it stores more carbon among the terrestrial ecosystems (Jandl, 2006; Pan, 2011; Sundquist, 2008). This will make forest ecosystems to be the largest terrestrial carbon pool. Protected areas, with their all and diverse ecosystems including forests are vital systems to capture and store carbon from the atmosphere and to help people and ecosystems adapt to the impacts of climate change (Dudley, 2010). Ethiopia, being party to the United Nations Environmental Program and signatory to its treaties and protocols, is striving to contribute to the international effort of climate change adaptation and mitigation. It has adjusted its development strategy aiming at meeting net zero emissions by 2030 and developed climate resilient green economy (CRGE) strategy. Conserving and enriching existing forests, establishing new forests, enhancing of the existing protected areas and establishing new ones are some of the measures undertaken by the government. The role of forests to capture and store carbon from the atmosphere has been studied by several researchers (Abel, 2014; Adugna, 2013; Tibebu et al., 2014; Tulu, 2011; Habtamu and Zerihun, 2016; Andargie et al., 2018). However, studies on carbon storage process at a landscape level for instance in a protected area like Godebe National Park with different land covers are lacking.

Deforestation is taken place in the Godebe National Park for the purpose of investments like commercial farming and collection of fuel wood by the local communities. At the same time most of low land National parks are affected by Livestock pressure. This National Park should require sustainable management plan for the carbon storage sustainably and conserve the biodiversity. It has no information about the carbon potential for further carry out research or financing by carbon trading according to REDD+ mechanism. Therefore, this study was undertaken to assess the carbon storage potential of Godebe National Park to develop sustainable management plan and baseline to incentive REED+ system of the national park.

## 2 Methodology

### 2.1 Site description

‘Godebe’ national park is found in West Gondar Administrative Zone, West Armachiho District in Amhara Region, North west of Ethiopia. The National Park is 390 km far from Bahir Dar, the Capital city of Amhara region.Godebe national park is bordered with six rural kebeles from West Armachiho and Metema districts (on the East the park is bordered with ‘Dirmaga’ kebele, on the North with ‘Girarwuha’ and ‘Korhumer 01’ kebeles; on the West it is bordered with ‘Metema yohanes 01’ and ‘Zebachi Bahir’ kebeles, and on the South it is bordered with ‘Meshaha’ and ‘Shimelegara’ kebeles of Metema District. Geographically, it is located on $13^0$12’20.51’’ to $13^0$23’18.10’’ N latitude and $36^0$13’56.73’’ to $36^0$28’04.63’’ East longitudes with an altitudinal range of 718 m to 1229 m above sea level.

Godebe National Park is situated under ‘Kolla’ agro ecological zones. The area is hotter throughout the year having annual temperature range of 25-48$^o$C with mean annual temperature of 27.1°C and the area receives 600-1100 mm annual rain fall stayed from June – August (Hurni, 1998). Based on the long-term weather variable records of Global weather data records (1979-2013) calibrated with ground truth data from the nearest Abraha Jira Station, the mean annual rainfall is 780 mm with a monomodal rainfall season ranges from June to August, which contributes about 82% of the annual rainfall of the study area (https://globalweather.tamu.edu).

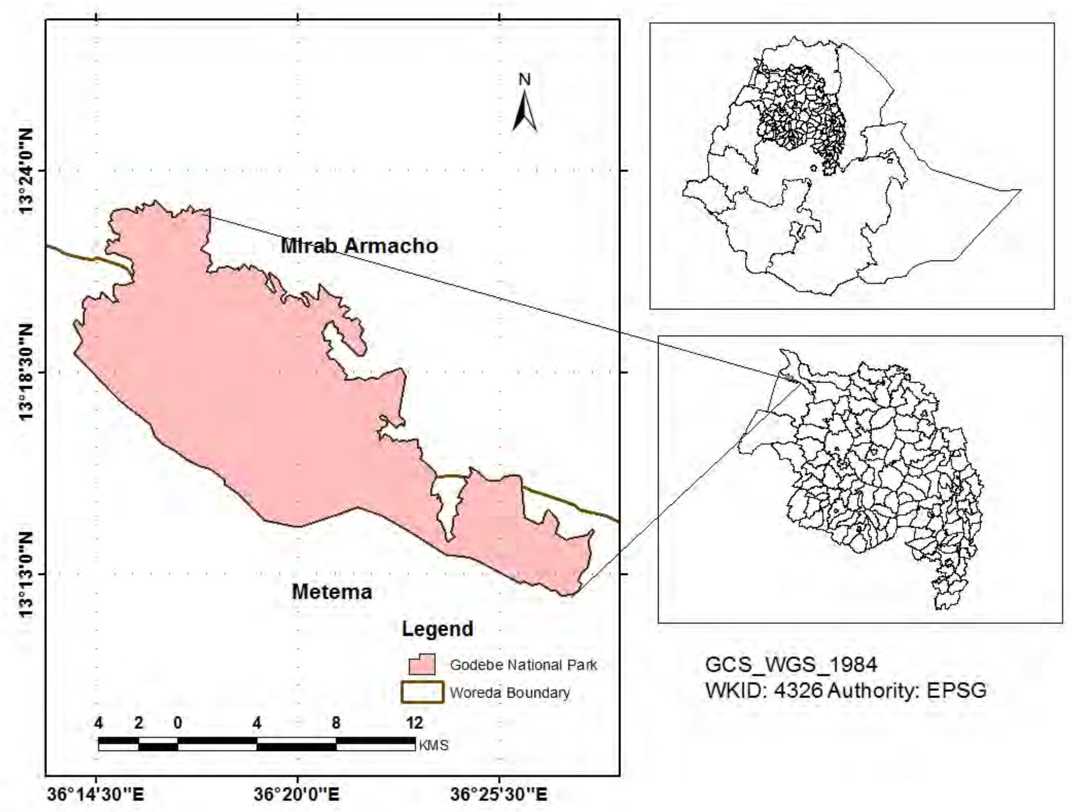

**Fig. 1** Map of the study area.

Based on vegetation classification of Ethiopia IbFriis (2010), Godebe National Park Forest communities are broadly categorized as Combretum-Terminalia woodland and wooded grassland with *Terminalia brownii*, *Anogeissus leiocarrpa* and *Dalbergia melanoxylon* as frequent species; Acacia-Commiphora woodland and bushland proper with dominant *Acacia seyal*, and *Acacia polycantha* species; and riparian/riverine forest with *Adansonia digitata*, *Diospyros mespiliformis* and *Tamarindus indica* as dominant woody species.

The topography of Godebe National Park wood land forest is: 54.52% plain, 31.87% is sloppy, and 13.61% is gorgy lands. The major soil types of the area are *Eutric nitisols*, *Chromic vertisol*, and *Orthic luvisols*. The land use of Godebe national park is demarcated by the district land administrative office as protected area. But, still now there are some illegal encroachments on the area which has negative influence on the regeneration status of the existing vegetation.

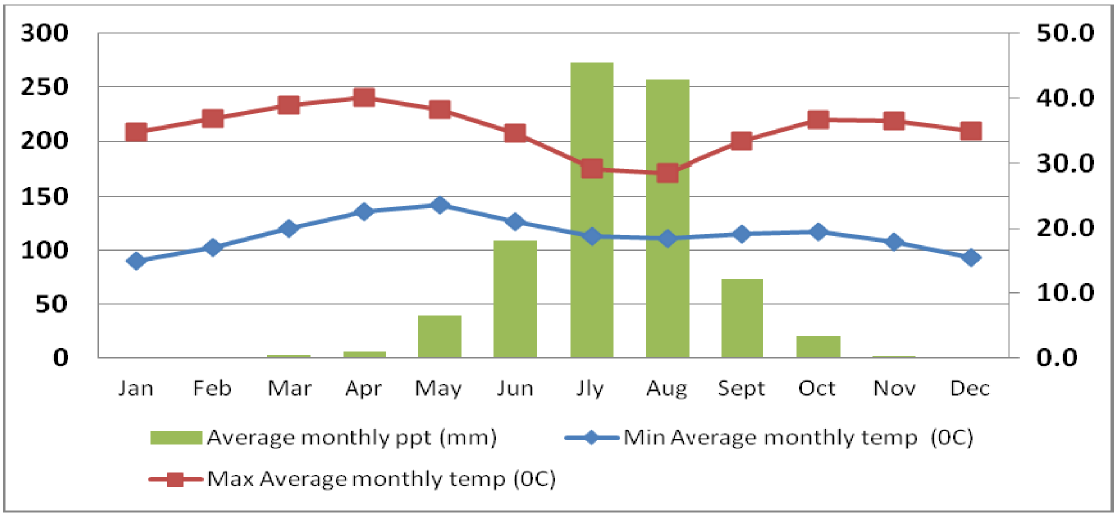

**Fig. 2** Graphical representation of local meteorological data of the study area. Source: Global waether data for SWAT (https://globalweather.tamu.edu) and Calibrated with the mean annual ranfall of the nearest Abraha Jira Station.

### 2.2 Procedures of data collection

#### 2.2.1 Sampling design and sample size

The study area is selected purposively having extensive coverage of Combretum-Terminalia and acacia Commiphora wood land vegetation which is one of the very important vegetation in combating desertification, and having considerable number of wild life resources and its potential to ecotourism and socio-economic benefits. Moreover, it is a newly established national park and its immense potential is not yet explored. Reconnaissance survey was done in the third week of November 2020, to collect some preliminary information, to have a mental picture and visual information on the study area in relation to its ecological attributes and to identify the possible sampling sites and the number of transect lines to be laid down across the Forest. This preliminary survey aimed to identify the distribution and abundance of the forest and to have a better familiarization with the study area. During the surveying period, supportive information was collected from the park administrative office and local households living near the National Park.

The sampling design employed was, systematic random sampling. Systematic sampling was employed for vegetation data collection to ensure that sufficient representative samples of vegetation from all gradient levels (Krebs, 1999; Kent, 2012). Following the procedure used in Senbeta and Teketay (2001), Fisaha et al. (2013), and Temesgen (2020). Eight transect lines were laid in the forest following vegetation distribution that may include the Combretum-Terminalia woodland community, the Acacia-Commiphora woodland and bushland community, and the Riparian/ riverine vegetation community following the methodology used by Temesgen (2020). Based on the above principles 44 square sample quadrats with a size of 20 m × 20 m and 1 m × 1 m for mature tree/shrubs and litter, respectively, were laid down alternatively along the line transects at 500 m intervals along the linear transects using GPS and Compass. The first sampling plot was located randomly, and the subsequent plots were established at fixed intervals systematically.

Carbon in the AGB was assessed through measurement of standing trees and shrubs using proper mensuration techniques. Diameter at breast height (DBH) and height of trees were measured according to their size class in the respective subplots. Therefore, species type, diameter at breast height (DBH) and height of trees (H) were the interest of measurement for trees. GPS was used to identify exact location of plots. DBH was measured with calliper/diameter tape depending on the size of the tree. Tree height was measured using haga hypsometer and graduated stick, and slope was measured with suunto clinometer to adjust the size of the plots to proper size.

Flora of Ethiopia and Eritrea Volume 1-8 (Inga Hedberg, 1989; Edwards and Demissew, 1997; Inga Hedberg, 2003; Inga Hedberg et al., 2006) and Natural Database for Africa (NDA) version 2.0, August 2011 CD-Rom was also used for species identification. For species that was difficult to identify in the field, their local names were recorded, herbarium specimens were collected, pressed and dried properly using plant presses and identified in the office helped by botanists.

Litter samples were collected manually from each of the five 1 m × 1 m areas of subplots, which located at the four corners and one at the center of the main plot as it is recommended by (Pearson et al., 2005). Composite samples were obtained by mixing litter from the five sub-plots of the main plot. About 100 g of 44 composite samples were collected from five sub-plots of the main plot. Then after the composite samples were placed in a plastic bag and all samples were labeled to which sample plot, they belong and taken to the regional soil laboratory of 'Gondar'. Then the litter samples were oven-dried to a constant weight at 105°C for 12 hours. Finally, the carbon fraction of litter samples was determined in the laboratory using Walkley–Black method (1934).

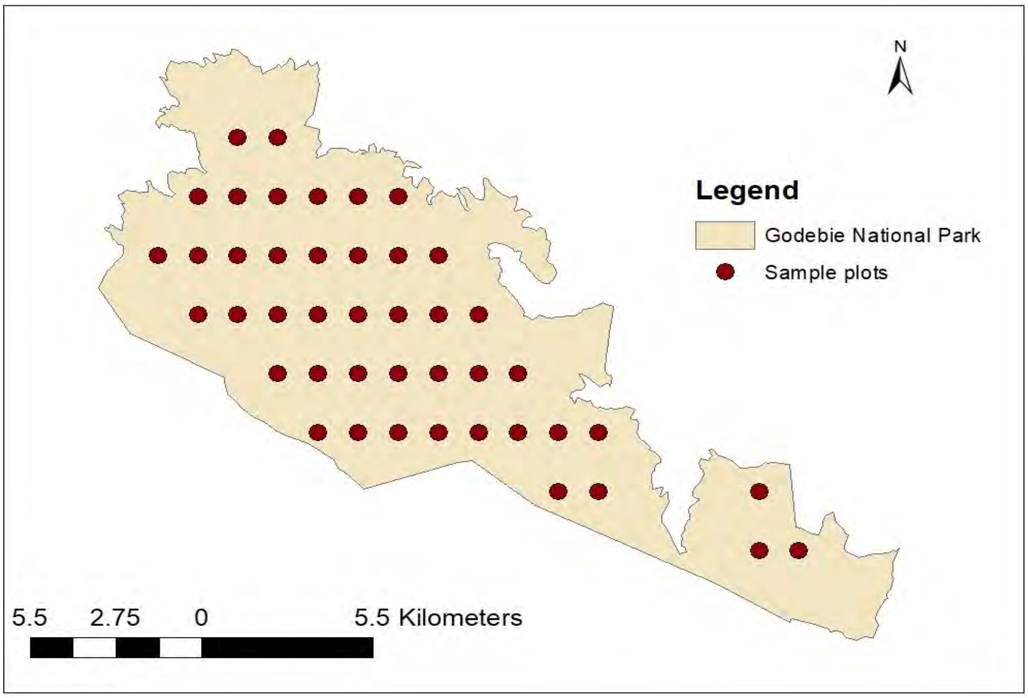

**Fig. 3** Distribution of sample plots.

### 2.2.2 Estimation of biomass and carbon stocks

Carbon stock has been assessed in five forest carbon pools, which is in accordance with the IPCC 2006 guideline. Hence, the major activities of carbon measurement during the field data collection were focused on above-ground biomass, below-ground biomass, dead wood, litter, and soil organic carbon as stated here below.

(1) Aboveground and below ground biomass and carbon

Carbon stock assessments in Africa are highly variable and have high degree of uncertainty due to lack of consistency in techniques of inventory and lack of site and species specific allometric equations. There are few species specific allometric equations developed in Africa, and most of the carbon stock assessments used general allometric equations. But this causes the high degree of variability in site growth conditions and growth characteristics of species as well as it cannot estimate the correct biomass and carbon. Therefore, Species-specific allometric equations are very important and, in this regard, there are allometric models (Andargie et al., 2018) which are appropriate for improving aboveground biomass (AGB) and carbon (AGC) estimations in woodland ecosystems in Ethiopia and near to study area in particular. Thus, this study used the following equation developed by Andargie et al. (2018) as follows

$$\ln(AGB) = -2.965 + 1.820\ln(DBH) + 1.157\ln(H) \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where H is total height; DBH is diameter at breast height; AGB is aboveground biomass; and ln is natural logarithm.

The above-ground carbon (AGC) and above-ground biomass $CO_2$ equivalent (AGB CO2eq) sequestrated in the study area was calculated by the principles of Pearson et al. (2005) and (2007) as follows

$$AGC = AGB * 0.5) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$
$$AGB\ CO2eq = AGC \times 3.67 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

According to Mac Dicken (1997) and Pearson et al. (2005) standard methods of estimating belowground biomass (BGB) and belowground carbon (BGC) can be obtained as 20% (AGB*0.2) and 10% (AGC*0.5) of above-ground tree biomass, respectively.

(2) Dead wood carbon

The biomass of lying dead wood (BLDW) was also calculated using the volume and density of wood as recommended by Pearson et al. (2005)

$$BLDW = V \times \rho \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$V = \pi^2 \left[\frac{d1+d2+dn}{8L}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where BLDW = biomass of lying dead wood, V = volume of lying dead woods ($m^3$/ha), ρ = density of the wood (0.5 g/$cm^3$) as recommended by Hairiah et al. (2001). d1, d2, dn = diameter of intersecting pieces of dead wood (cm), L = length of the dead lying wood (m).

(3) Litter carbon

The biomass of litter found in the study area was calculated using litter biomass formula of Pearson et al. (2005) as follows

$$LB = \frac{Wfeild}{A} * \frac{Wsub-sample\ (dry)}{Wsub-sample\ (fresh)} * \frac{1}{10000} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where LB = biomass of litter (t/ha), Wfeild = weight of wet feild sample of litter in gram from an area of 1 $m^2$, A = size of the area in which litter was collected, Wsub-sample (dry) = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content, Wsub-sample (fresh) = weight of the fresh sub sample of litter taken to the laboratory to determine the moisture content (g)

LC=LBM*%C ………………………………………….…(7)

where LC = is total carbon stocks in the litter in t/ha, LBM = is oven-dry biomass of leaf and %C = carbon fraction determined in the laboratory.

(4) Soil organic carbon

The soil organic carbon stock of the study area was estimated as follows

$SOC = BD * d * \%C$ ……………………………………….(8)

where SOC = soil organic carbon stock per unit area (t/ha), BD = soil bulk density (g/cm$^3$), D = the total depth at which the samples were taken (30 cm), %C=carbon concentration. The total carbon stock density of the study area was calculated using the equation of Subedi et al. (2010), by summing up the carbon stock densities of the individual carbon pools of the study area

$TC = AGC + BGC + LC + DWC + SOC$ ………………..…(9)

where TC = carbon stock density for all carbon pools (t/ha), AGC = carbon in above-ground tree and shrub biomass (t/ha), BGC = carbon in below-ground tree and shrub biomass (t/ha), LC = carbon stock in litter biomass (t/ha), DWC = carbon stock in dead tree and dead wood biomass(t/ha), SOC = soil organic carbon (t/ha).

### 2.3 Data analysis

SPSS V.23 software was used to analyze all the statistical data. Descriptive statistics was used to summarize the data, including the mean, maximum, minimum and standard deviations of carbon stock of each carbon pool of the study area, while one-way ANOVA was used to determine the statistical significance difference of carbon stocks of each carbon pool along forest strata of the study area.

## 3 Results and discussion

### 3.1 DBH and height distribution

Fig 4 illustrated that about 55.5% and 36.7% of the measured DBH falls between 5-10 Cm diameter and between 10-29 cm diameter respectively. About half percent (.5%) had DBH of above 90 Cm. The minimum recorded DBH was 5.0 and the maximum recorded DBH was 227 cm. The maximum DBH was recorded on Riverine Forest. Generally, the DBH distribution is said to be inverted ‘J’ shape. Some studies also agreed with this idea Emiru et al. (2020) revealed that an inverted ‘J’ shape on the study conducted with the title Woody Plant Species Composition, Population Structure and Carbon Sequestration Potential of the *Acacia senegal* (L.) Wild Woodland Along a Distance Gradient in North-Western Tigray, Ethiopia.

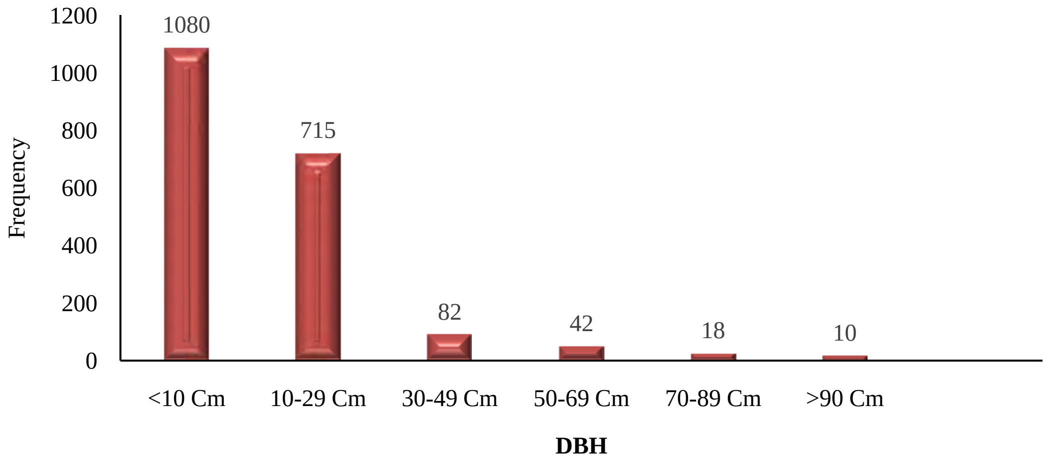

**Fig. 4** Distribution of Diameter at breast height (1.3 meter).

Fig. 5 illustrated that about 31% of the measured height falls below 4 meter and similarly, about 57% of the measured samples had a height class between 5-14 meters respectively. Moreover, the height class from 15-24 meter was found to be 7.7%. And lastly, about 3.2% of measured samples had height of above 35-meter height.

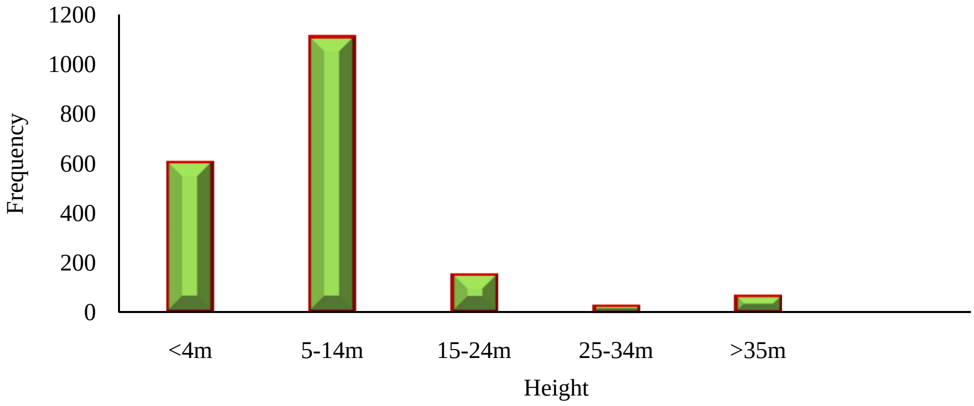

**Fig. 5** Height Class distribution.

## 3.2 Carbon stock in different carbon pools

### 3.2.1 Carbon stock in above-ground and below-ground biomass

The maximum and minimum above-ground carbon of the study area was found to be 2835.519 and 4.902 t/ha. The maximum and minimum above-ground biomass $CO_2$ eq sequestered in trees and shrubs of the study area was also estimated to be 10406.345 and 17.989 t/ha. The mean above-ground and below ground carbon stock in trees and shrub species of the study area was estimated to be 338.893±45.9 t/ha and 67.779±15.5 t/ha, respectively. This is due to high density of biomass in reverine area. Andargie et al. (2018) revealed more or less similar carbon stock in above and below ground biomass of Alitash National Park, North West Ethiopia, which have similar agroecology like Godebe National Park (this study) Accordingly, a mean of 1243.74±107.99 and 248.747±32.59 t/ha $CO_2$ eq was sequestrated in the above-ground and below ground biomass of trees and shrubs of the study area respectively. The variation in the amount of $CO_2$ sequestered and stored in the species within the forest stand was affected greatly by the stand density of trees of their total population (Pascua et al., 2021).

**Table 1** Descriptive statistics of above and below ground carbon stock and carbon dioxide equivalent.

| | **Above ground** | | | **Below ground** | | |
|---|---|---|---|---|---|---|
| | **AGB (t/ha)** | **AGC (t/ha)** | **$CO_2$ eq (t/ha)** | **BGB (t/ha)** | **BGC (t/ha)** | **$CO_2$ eq (t/ha)** |
| N of plots | 44 | 44 | 44 | 44 | 44 | 44 |
| Mean | 721.048 | 338.893 | 1243.735 | 144.210 | 67.779 | 248.747 |
| Max | 6033.020 | 2835.519 | 10406.345 | 1206.604 | 567.104 | 2081.269 |
| Min | 10.429 | 4.902 | 17.989 | 2.086 | 0.980 | 3.598 |
| Median | 129.781 | 60.997 | 223.859 | 25.956 | 12.199 | 44.772 |
| SD | 1465.871 | 293.174 | 688.959 | 137.792 | 826.751 | 3091.958 |
| Skewness | 2.856 | 2.856 | 2.856 | 2.856 | 2.856 | 2.856 |
| Kurtosis | 7.611 | 7.611 | 7.611 | 7.611 | 7.611 | 7.611 |

### 3.2.2 Deadwood carbon and litter carbon

The maximum and minimum value of dead wood carbon was 8.225 t/ha and 0.909 t/ha respectively. Since the biomass of dead wood was sequestered a maximum of 30.184 t/ha of $CO_2$ equivalent and a minimum of 3.336 t/ha of $CO_2$ eq. The mean biomass and carbon stock of dead woods in the study area was estimated to be 5.376094 t/ha and 3.43. Accordingly, a mean of 19.730 t/ha $CO_2$ eq was sequestered in dead trees and dead wood biomass of the study area. On the other hand, the park had a total litter carbon of 2.56 t/ha. At the same time, litter in Godebe National Park sequestered 9.395 t/ha of $CO_2$ equivalent.Generally, the lower amount of litter carbon in the study area might be related with high turnover rate of litter. That means due to high temperature and rainfall the litters may decompose faster.

**Table 2** Descriptive statistics of dead wood carbon stock and carbon dioxide equivalent.

| | **DWC (t/ha)** | **$CO^2$ eq (t/ha)** |
|---|---|---|
| Mean | 5.376094 | 19.730 |
| Max | 8.22467 | 30.18451 |
| Min | 0.909043 | 3.336182 |
| Median | 1.738396 | 6.379907 |
| SD | 1.204859 | 4.421828 |
| Skewness | 2.792907 | 2.792907 |
| Kurtosis | 11.156 | 11.156 |

### 3.2.3 Soil organic carbon

The soil organic carbon stock of Godebe National Park was ranged from 55.03 (plot 26, Fig. 6) to 242.53 t/ha (plot 14, Fig. 6). At the same time, this Park sequestered a maximum of 809.10 t/ha $CO_2$ equivalent and a minimum of 201.96 t/ha $CO_2$ equivalent respectively (Table 3).

**Table 3** Descriptive statistics of soil organic carbon and carbon dioxide equivalent.

| | **Min** | **Max** | **Mean** | **Median** | **Mode** | **SD** | **Skewness** | **Kurtosis** |
|---|---|---|---|---|---|---|---|---|
| SOC | 55.03 | 242.53 | 109.34 | 99.85 | 84.67 | 36.58 | 1.45 | 2.88 |
| $CO_2$ eq | 201.96 | 890.10 | 401.29 | 366.44 | 310.72 | 134.26 | 1.45 | 2.88 |

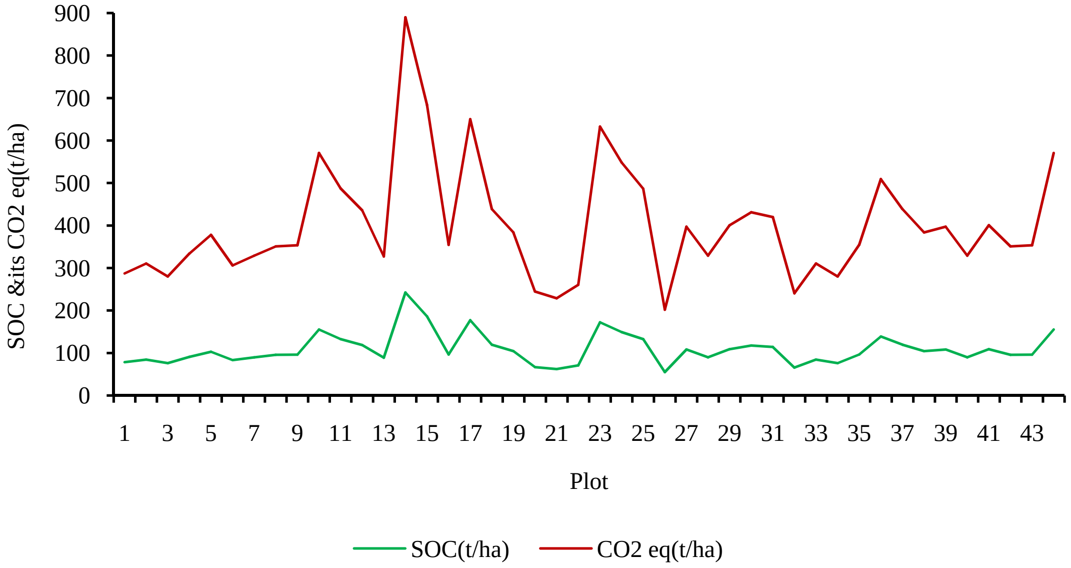

**Fig. 6** Soil organic carbon and its $CO_2$ equivalent.

The result showed that, the mean organic carbon of the soil within the study area was estimated to be 109.34 t/ha with a standard deviation of 36.58. The study area is vertisol dominated and therefore that is why the mean soil organic carbon of the study area is significantly high. At the same time, Karlin Zapata Coirini (2021)revealed similar result in Monte region (Argentina) by studying the soil organic carbon and dead biomass pools in woodlands. Moreover, the average $CO_2$ equivalent sequestered by the soil of Godebe National Park was estimated to be 401.29 $CO_2$ equivalent.

### 3.3 The total carbon stock and climate change mitigation potential of Godebe National Park

The total mean carbon stock potential of Godebe National Park was calculated by summing up all the carbon Pools of the study area namely: AGC, BGC, DWC, LC and SOC with 338.893, 67.779, 5.376, 2.560 and 109.34 t/ha, respectively (Fig. 7). Then which gave a total carbon stock potential of 523.948 t/ha. Compared with other studies with similar forest structure, this study area comes up with high carbon estimation. This is because using site specific allometric equation developed by Andangie et al. (2018) rather than other generic equation. The carbon pools of above-ground biomass, belowground biomass, dead wood biomass, Litter biomass, and Soil organic carbon had a capacity of removing 1243.735, 248.749, 19.730, 9.395, and 401.29 t/ha $CO_2$ equivalent, respectively. This reveals that Godebe National Park has a total global climate change mitigation potential of 1922.887 t/ha $CO_2$ equivalents.

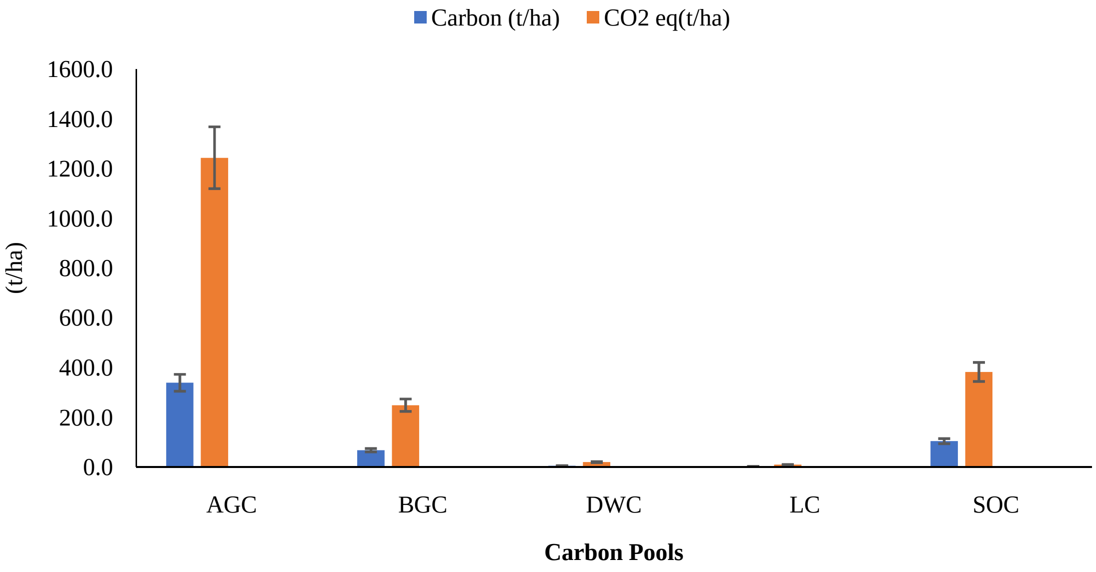

**Fig. 7** The total carbon stockof Godebe National Park.

### 3.4 Variation of carbon stock along Forest Stratum (Combretum Terminalia woodland, Riverine Forest and Acacia woodland)

The mean carbon stock of each carbon pools was changed along altitudinal class of the study area. The largest mean above- and below-ground carbon stock was found within the Riverine Forest (947.67 t/ha) followed by Combretum Terminalia woodland (201.24 t/ha) and the lowest mean above and below-ground carbon stock was showed in Acacia woodland (71.10 t/ha) as shown in (Table 4). The statistical analysis showed that there was a significant variation among the stratum (F = 4.30, P = 0.020) (Table 3). Generally, the riverine forest was the largest in carbon stock and Acacia woodland was the least. In lowland riverine areas the species richness of plants and large size (high DBH) of tree family were dominant than the two remaining class (Combretum Terminalia woodland and Acacia woodland). This might be due to multitude factors mainly hydrology and other geomorphologic factors like soil, moisture and humidity. Some scholars like Emiru et al. (2021) and Suarez et al. (2021) evidenced with similar findings. For instance, Emiru et al. (2020) proved that the variation of biomass carbon stock across each distance gradients may imply the impact of the past and ongoing anthropogenic disturbance associated with microclimatic conditions declined the current and future carbon stock potential that needs protection, conservation and rehabilitation of the native woody plant species of the *Acacia senegal* woodland in North West Ethiopia.

**Table 4** Variation of carbon stock along Forest Stratum.

| **Class** | **AGB** | **BGB** | **AGC** | **BGC** | **AGC+BGC** | **F-value** | **P-Value** |
|---|---|---|---|---|---|---|---|
| Combretum Terminalia woodland | 356.81 | 71.36 | 167.70 | 33.54 | 201.24 | 65.009 | 0.0001 |
| Riverine Forest | 1680.27 | 336.05 | 789.73 | 157.95 | 947.67 | | |
| Acacia woodland | 126.06 | 25.21 | 59.25 | 11.85 | 71.10 | | |
| **Mean** | **721.05** | **144.21** | **338.89** | **67.78** | **406.67** | | |

All units are in ton/hectare (t/ha).

The mean soil organic carbon stock of Riverine Forest, Combretum Terminalia woodland, Acacia Woodland were 101.845 t/ha, 133.532 t/ha and 86.931 t/ha respectively (Table 5). Similarly, about 319.037 t/ha of $CO_2$ equivalent, 490.061 t/ha $CO_2$ equivalent and 373.771 t/ha $CO_2$ equivalent were sequestered in the soil of Acacia Woodland, Combretum Terminalia woodland and Riverine Forest respectively. Therefore, the highest soil organic carbon stock was found in Combretum Terminalia woodland (this is due to high forest density) and the lowest were in Acacia Woodland. Oneway ANOVA showed that there was a significant variation among the stratum (F = 8.82, P = 0.0007) (Table 6). The variation in soil organic carbon is due to soil type, forest density and geomorphological factors.

**Table 5** The mean soil carbon stock (SOC) of forest at different strata.

| | **Acacia Woodland** | | **Combretum Terminalia woodland** | | **Riverine Forest** | |
|---|---|---|---|---|---|---|
| | **SOC (t/ha)** | **$CO_2$ eq (t/ha)** | **SOC (t/ha)** | **$CO_2$ eq (t/ha)** | **SOC (t/ha)** | **$CO_2$ eq (t/ha)** |
| Mean | 86.931 | 319.037 | 133.532 | 490.061 | 101.845 | 373.771 |
| Max | 103.077 | 378.292 | 242.534 | 890.098 | 172.482 | 633.009 |
| Min | 65.513 | 240.433 | 89.149 | 327.177 | 55.030 | 201.960 |
| Median | 87.177 | 319.938 | 119.560 | 438.785 | 108.296 | 397.448 |
| SD | 9.978 | 36.620 | 38.471 | 141.188 | 33.534 | 123.071 |
| Skewness | -0.455 | -0.455 | 1.466 | 1.466 | 0.579 | 0.579 |
| kurtosis | -0.256 | -0.256 | 2.321 | 2.321 | -0.153 | -0.153 |

**Table 6** Analysis of variance of soil organic carbon (Oneway ANOVA).

| **Source** | **SS** | **df** | **MS** | **F** | **Prob>F** |
|---|---|---|---|---|---|
| Between groups | 17709.4882 | 2 | 8854.74412 | 8.82 | 0.0007 |
| Within groups | 41173.1396 | 41 | 1004.22292 | | |
| Total | 58882.6278 | 43 | 1369.36344 | | |

SS=sum square, df=dgree of freedom, MS=mean square.

## 4 Conclusions

Forest can sequester and mitigate the atmospheric concentration of carbon dioxide. The studied carbon pools of the forest especially the above-ground carbon pool and soil organic carbon had the largest carbon stock potential, which accounted for about 333.8 t/ha and 109.68 t/ha, respectively. But also, below-ground carbon pool, deadwood carbon pool and litter carbon pool had about 72.55±44.21 t/ha, 3.43±0.46 t/ha, and 2.01±0.04 t/ha, respectively.

There was the statistically significant difference in stand carbon pools and soil organic carbon in different forest. The ultimate result showed that the study area stored and sequestered 523.948 carbon t/ha and 1922.887 $CO_2$ equivalents per ha, respectively. This could be a good opportunity regarding the carbon financing in the future. Climate change mitigation through carbon sequestration by forests is the low-cost method and it will open a door for development activities because it is a very easy and simple way of receiving funds for carbon sequestration. Having observed the above result Godebe national park has a good carbon sequestrating potential and hence the ongoing protection and conservation effort has to be promoted.

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