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Carbon Sock of Gambella National Park: Implication for Climate Change Mitigation

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Abstract
Recent attempts to mitigate global climatic change have brought forestry based carbon sequestration into sharp focus due to its potential to absorb CO_2 from the atmosphere. Although a number of studies have been done on carbon stock estimation, the National Park carbon stock has not been properly addressed. This paper was conducted to estimate the carbon stock in forest of the Gambella National Park with 76 plots in the categories of riverine and terrestrial forest. The total mean carbon stock in forest part of the National Park was 394.85±24.34ton/ha. The carbon stocks in each pool exhibited distinct patterns between the forest Stratum (riverine and terrestrial). The total carbon stock in the riverine forest and forest land/wood land was 454.51±26.01ton/ha and 324.89±17.25 ton/ha respectively. The results of LULCC analysis indicated that the forest and woodland decreasing at an average rate of 120,470.6ha. This study concluded that despite the rapid decline in the forest land and woodland coverage, the existing forest/wood land has a huge potential sequestration of carbon for mitigation of climate change.
Keywords: Carbon sequestration, Land use and land cover change, Gambella National Park, Terrestrial forest, Riverine forest.

INTRODUCTION

Background

The global carbon cycle has received the most attention in recent years as it has become evident that increased levels of CO_2 in the atmosphere are causing changes in our climate at an alarming and accelerating rate [1]. Worldwide concern for natural and biological resources is higher than ever before. Issues such as loss of biodiversity, ozone layer depletion, desertification etc. have taken the center stage in the global discourse. Anthropogenic factors are identified as the main drivers [2]. Humankind increasingly influences carbon cycle through the burning of ever-greater quantities of oil, gasoline and coal and the cutting down of forests. The largest source of greenhouse gas emissions in most tropical countries is from deforestation and forest degradation. In Africa, for example, deforestation accounts for nearly 70% of total emissions [3]. Moreover, clearing tropical forests also destroys globally important carbon sinks that are currently sequestering CO_2 from the atmosphere and are critical to future climate stabilization [4] Despite the importance of avoiding deforestation and associated emissions, developing countries have had few economic or policy incentives to reduce emissions from land use change [5]. The United Nation Framework Conference On Climate Change (UNFCCC) recently agreed to study and consider a new initiative, led by forest-rich developing countries, that calls for economic incentives to help facilitate reductions in emissions from deforestation in developing countries (REDD). Mitigation and Adaptation measures are needed in order to maintain household food security in the face of the threat of desertification exacerbated by climate change [6]. Hence, developing long-term financing systems and achieving the requisite level of funding is a key element for protected areas sustainability. Gambella National Park is one of the largest parks in Africa and in Ethiopia but not well protected for provision of ecosystem services to the region and the country. Gambella National Park land use and land cover change is studied for the purpose of observing the deforestation rate pertained to carbon stock potential in the Park. The Park is proposed to protect the diverse and abundant wildlife but there is high deforestation. The park is a potential area for biodiversity conservation of endemic plants and animals. Therefore, estimation the carbon stock potential of the National Park is important to provide its role for mitigation of climate change. The objective of the study is to determine the total carbon stock potential of Gambella National Park in order to show its role for mitigation of climate change and land use land cover change.

MATERIALS AND METHODS

Description of the Study Area

Location

This study was conducted in Anuak zone, Gambella National Regional State, in the Gambella National Park and located at 850 km west of Addis Ababa and 80km from Gambella town to the south. Its Coordinates is 34^O 0.00' East 7^O 52.00' North. The existing Park area is situated in six woredas namely Jikawo, Gambella, Itang, Gog, Abobo and Jor. The Park area is home to the Nuer and the Anuak people and it is the largest National

Park in Ethiopia and the second largest Park in Africa.

Fig. 1 Map of Gambella National Park

Climate

Agro-climatically, it is classified as Kolla and the climate is hot and humid high temperatures are recorded just before the onset of rains in May. Annual mean temperature is with a minimum and maximum of 18.09 and 39.34 ^{0}C respectively. The lowest rain fall is recorded in November to April whereas highest rainfall is May to October. Annual rainfall is estimated to around 120.45mm in the plains.

The Park Flora

The natural vegetation of Gambella varies much with the rainfall and temperature, which shows wide variation. Thus, in different studies, often different classification is used in defining the natural vegetation. Vegetation in Gambella Region has affinity to two phytogeographical regions, which have been described by White [1983], in his classification of African vegetation and phytogeography. The regions are the Sudanian and the Guineo-Congolian centers of endemism which make the area very rich in terms of biodiversity. In the dry season, the vegetation is susceptible to fire. Riverine forests (*Tamarindus indica-Anogeissus leiocarpa* community) are also parts of the park flora and found along the Baro, Alwero and Gilo Rivers and their tributaries.

The Park Fauna

The Gambella plain is one of the few places not only in Ethiopia and the African continent, but also in the whole world where the original and rich fauna and flora. At present, in Ethiopia 277 mammal species occurred. From this, 69 species of mammals are in the National Park [8]. Larger mammalian species such as White-eared kob, Nile Lechwe, Nile Buffalo, Elephants, and Roan Antelope are important species of the area. The migration of White –eared Kob between Gambella National Park and Boma National park of Southern Sudan makes the park to be the second migratory route in the World (i.e., next to the migration of Wildebeest between Masai Mara and Serengeti National Parks of Kenya and Tanzania)[9].

Methodology

Stratification of the Study Area

The study area should be stratified in to different land cover/forest stratum or strata based on analysis and interpretation of aerial photos or satellite images, review of historical classifications and field sampling. The stratification for this study was vegetation and drainage used. The forest of the National Park was taken to determine the carbon stock potential by classifying in to forest stratum (riverine and terrestrials forest). One of unique features of the National Park is availability of water resources such as rivers and wetland that flow in the National Park. Due to water resource, there is variation of tree species and growth of trees. The forest density and Species composition of the forest stratum has been described after analysis of the data collected during this assessment.

Sampling Design

A transect is a line along which samples of vegetation is taken. It is set up deliberately across areas where there are rapid changes in vegetation and marked environmental gradients [10]. If some parts of the strata have higher carbon content than others, systematic selection usually results in greater precision than random selection. Systematic sampling also may appear more credible [11]. Sampling sites from the forest was arranged by the line transects from the starting of forest to all directions covering the whole range of the area (20 m right and left of the river) that encompass for the study. Transect line was made along the riverine forest and wood land forest/land forest using the GPS navigation system. A plot of 10 x 20 m (200 m^2) was placed at 200 m distance drop between each plot because the environmental variables were similar in the study area. The number of plots (number of plot reverine vegetation was 38 plots and wood land forest or land forest was 38 plots), totally 76 samples/plots was taken. To collect riverine forest data, set quadrant of 20m to the right and to the left from the tip of the river and the necessary data were collected. Even though, both rectangular and circular plots are applied in most of the forest carbon measurements, rectangular samples is more advantageous and recommended for the study area. This is because rectangular plots tend to include more of within-plot heterogeneity, and thus be more representative than the circular plots of the same area [12; 13] Therefore, for the study preferred a more precise method rectangular plot was taken.

Data Collection and Identification

Currently 5 carbon pools have to be reported under the UNFCCC; Above-ground Biomass, Below-ground Biomass, Dead Organic Matter, Soil Organic Matter and litter biomass. Diameter and height was measured for every individual tree having DBH greater than 5cm using Haga hypsometer, caliper, clinometers and linear tape. Tree with multiple stems at 1.3 m height was treated as a single individual and DBH≥ 5 of stem were taken. A complete list of trees by classified them riverine and wood land forest/ forest land/ in each plot was done. Litter included in the study area such as shrubs/bushes, leaves and small fell wood. Plant specimens were collected, pressed, dried and identified their scientific name, species and vernacular name in the Gambella National Park office and the dry litter and soil was brought for analyzing in the laboratory. During collecting plant and vegetation data, local people (Anuak, Nuer) were involved, and asked the local names and the uses of the plants encountered in the survey. The botanic names of the plants were identified using Hedberg and Edwards [1989] manual which is located in the Gambella National Park Office. Generally, at each plots the following data were collected for providing information of the study area. Altitude was recorded from a handheld GPS unit, DBH and height of the tree was measured by using clinometers, direction was obtained by compass, collecting all litters (leaves, shrubs and wood) on the ground, soil sample was taken in each plots, measure height of dead wood (stand), and mark the tree whether it is riverine and terrestrials.

Determination Carbon in Different Carbon Pools

Above Ground Biomass (AGB)

In plot size of 10x20m, marking each tree to prevent accidentally counting it twice and each tree recorded individually, together with its species name, local name and field ID. During collecting the data, identifying the tree species occurrence in the riverine and terrestrials land were the activities to determine the above ground biomass and carbon stock. There are different allometric equations have been developed by many researchers to estimate the above ground biomass. These equations are different depending on the types of species, geographical locations, forest stand types, climate and others [15]. Therefore, the application of appropriate equations to the study area is advantageous in a view of cost (time). From the different available allometric equations to estimate the above ground biomass, the model was developed by Brown *et al.* [1989] and this formula was selected for the study site. This formula is used for dry climate and its rainfall is <1500 mm with diameter of tree ≥5cm. The general equation that was used to calculate the above ground biomass is given below.

$$Y = 34.4703 - 8.0671(DBH) + 0.6589(DBH^2) \quad \text{(equ….1)}$$

Where,

Y is above ground biomass, DBH is diameter at breast height.

Below Ground Biomass (AGB)

The estimation of root biomass is difficult and time consuming and the methods are not standardized (14). Pearson *et al.* [2005] described as it is more efficient and effective to apply a regression model to determine belowground biomass from knowledge of biomass aboveground. Thus, the equation developed by MacDicken [1997] to estimate below ground biomass was used.

$$BGB = AGB \times 0.2 \quad \text{… (equ…2)}$$

Where BGB is below ground biomass, AGB is above ground biomass

For both AGB and BGB the biomass stock density was attained in $k/g/m^2$ by means of dividing the sum of all individual weights (in kg) of a sampling plot by the area of sampling plot. The value was converted to ton/ha by multiplying it by 10. Total carbon content was estimated from aboveground biomass by converted from biomass to carbon stock. From the reports [17], carbon content would be about fifty percent of the amount of aboveground biomass while multiplication factor 3.67 needs to be used to estimate CO_2 equivalent [Pearson *et al*., 2005].

Estimation of Carbon Stocks in Dead Wood Biomass (DWB)
Standing dead trees are important carbon sinks and also carbon sources which need to be accounted for. Thus, within plots delineated for live trees, standing dead trees also measured. There were tree species in the forest Nation Park which was died but alive, simply leaf was not available. Therefore, to determine the carbon stocks in dead wood, calculate the above ground biomass of the trees following subtracts 3% from above ground biomass of the tree. The dead wood were occurred in terrestrials land such as woodland forest and land forest whereas riverine forests were green throughout the year (species occurred at river side are obtained water throughout the year).

Carbon stocks in the litter biomass (LB)
One rectangular sub plot of $1m^2$ in size was established at the center of each nested plot. The litter within the $1m^2$ sub plots needs to be collected and weighed [18]. The procedure for collect the litter in the measurement plot were weight the litter which is fresh then exposed for air dry and weigh the dry-weight of the litter by using dry matter; conduct organic carbon analysis in the laboratory to examine the carbon content. Where, multiplying by 100 converts the units to metric t/ha. Multiplying by 0.5 gives the amount of carbon (person *et al*., 2007). According to Pearson *et al.,* (2005), estimation of the amount of biomass in the litter can be calculated by:

$$LB = \frac{Wfield}{A} \times \frac{Wsub\_sample(dry)}{Wsub\_sample(fresh)} \times \frac{1}{10{,}000} \ldots\ldots\ldots \qquad (equ\ldots3)$$

Where;
LB = Litter (biomass of litter ton/ha)
W_{field} = weight of wet field sample of litter sampled within an area of size 1 m^2 (g) A = size of the area in which litter were collected (ha)
W sub-sample, dry = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), and
W sub-sample, fresh = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g).

Once the litter biomass is obtained then carbon stock in dead litter biomass was calculated by using the following formula given below.

$$C_L = LB \times \% C \ldots\ldots \quad (eq\ldots.4)$$

Where, C_L is total carbon stocks in the dead litter in ton/ha, % C is carbon fraction determined in the laboratory (Pearson *et al*., 2005). The concentration of carbon (fraction carbon) in litter biomass was determined by loss of ignition method by using 55^0C.

Soil Organic Carbon (SOC)
In order to obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables must be measured: (1) depth, (2) bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material), and (3) the concentrations of organic carbon within the sample. For convenience and cost-efficiency, it is recommended a sample constant depth, maintaining a constant sample volume rather than mass and 30cm probe is an effective measurement tool (Pearson *et al.,* 2007). Soil samples were also analyzed following [19] procedure and it was conducted at Zeway research center of soil laboratory. Soil sample was taken at riverine forest and wood land forest/forest land/ of the study area from five points in the rectangular plot followed soil sampling is done using a composite method (mixed depth of 0 cm -5 cm, 5 cm - 10 cm, 10 cm - 20 cm, and 20 cm - 30 cm). For the study area the soil samples for soil carbon determination was collected at the same sampling sub-quadrates recommended for litter sampling (1mx1m). From the center of each plot and/or sub-plot a pits of up to 30 cm in depth was dug to best represent of the forest in the national park. Bulk density was determined after air drying of soil and the weight of the soil was divided by the volume of the core sampler. The procedure for Measurement of organic soil carbon content in the forest area of the national park was done as follows. The carbon stock density can be calculated as recommended by Pearson *et al.* (2005) from the volume and bulk density of the soil.

$$V = h \times \pi r^{2)} \ldots\ldots \qquad (equ\ldots5)$$

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 (Pearson *et al*., 2005).
In the study area the radius for soil sample was 2.5cm and height core sampler 30cm. More over the bulk density of a soil sample can be calculated as follows.

$$BD = \frac{Wav,\ dry}{V} \quad \text{(equ… 6)}$$

Where, BD is bulk density of the soil sample per, Wav, dry is average air dry weight of soil sample per the quadrant, V is volume of the soil sample in the core sampler auger in cm3 (**Pearson** et al., 2005).

$$SOC = BD * d * \% C \quad \text{(equ... 7)}$$

Where, SOC= soil organic carbon stock per unit area (t ha-1),
BD = soil bulk density (g cm-3),
D = the total depth at which the sample is taken (30 cm), and
%C = Carbon concentration (%)

(According To Walkley and Black, 1934) % Easily Oxidizable Organic Carbon was calculated by:

$$\%C = \frac{(B-S)\times M\ of\ Fe2+\times 12\times 100}{g\ of\ soil\times 4000} \quad \text{(equ….8)}$$

Where:
B = mL of Fe_2+ solution used to titrate blank
S = mL of Fe_2+ solution used to titrate sample
12/4000 = mill equivalent weight of C in g.
Note: To convert easily oxidizable organic C to total C, divide by 0.77 (or multiply by 1.30).

Total carbon stock in the study area

There was forest classification in to riverine and wood/forest land for this study. Therefore, calculating the carbon pools in each forest stratum following the carbon sock summing of the two forest stratum in the study area was necessary. The carbon stock density was calculated by summing the carbon stock densities of the individual carbon pools of the stratum using the Pearson *et al*. (2005) formula. Carbon stock density of a study area:

$$C_{plot} = C_{AGB} + C_{BGB} + C_{LB} + C_{DWB} + SOC \quad \text{(eq…9)}$$

Where;
C_{plot} = Carbon stock density for all pools (ton/ha)
C_{AGB} = Carbon in above -ground tree biomass (ton/ha)
C_{BGB} CBG= Carbon in below-ground biomass (ton/ha)
C_{LB} = Carbon in dead litter (ton/ha)
C_{DWB} = Carbon in dead wood biomass (ton/ha)
SOC = Soil organic carbon (ton/ha)

The total carbon stock was then converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 (Pearson *et al.*, 2007).

Land Use and Land Cover Change Analysis

Remote Sensing Data Acquisition

A comprehensive geographic information system (GIS) and remote sensing was one of the tools used by this study to integrate different sources of data by means of satellite image interpretation. For this study, three year dates (1986, 2000 and 2011) of LANDSAT satellite images were acquired from different source such as GLCF (Global land cover facility) down loading from Google web, ILIRI (International Live Stock Research Institute) and EMA (Ethiopia Mapping Agency). The downloaded satellite images were in tiff format and stacked in ARC GIS map software and developing function in it to stack each layer to produce one single layer composing of each band and Google earth is used for reference of the study area. The stacked band of the study area was extracted based on the shape file of the area. The sensor was LANDSAT ETM with path 171 rows 54 & 55, path 172 rows 54 & 55. The band was 7 with pixel size/ Ground Resolution of 30m/. To differentiate crop land and grazing land was impossible in this image resolution. The processing of the images has been geometrically corrected with road and river intersection and the topographic map of the study area with scale of 1:250,000 and appropriate coordinate was located, after the raw data are georeferenced, image enhancement is to improve the visual interpretability of an image by increasing the apparent distinction between features in the scene (20) and it is used to increase the details of the image by assigning the image maximum and minimum brightness values, and this makes visual interpretation easier and assists the human analyst. Supervised image classification was a method for the study area by gathering appropriate data that representative of each desired land cover category. Assessment of the accuracy was done based on the data that collected in the field work.

RESULTS

Carbon Stock in the Different Carbon Pools

Carbon Stock in Above (AGB) and below Ground Biomass (BGB)

The mean above ground biomass of the study area was 384.35±25.67 ton/ha. The above ground biomass was the base for obtaining the carbon stock and carbon sequestration of the trees. Therefore, the mean above ground carbon stock in the study area was 192.17±12.83t/ha. Therefore, the mean carbon sequestration of the above ground biomass was 705.29±47.01 ton/ha (Table 1).

Table 1: Mean, maximum, minimum value of above and below ground carbon stock and carbon dioxide equivalent

	AGB /plot	AGB (Kg/m^2)	AGB (ton/ha)	AGC (ton/ha)	CO_2e (ton/ha)	BGB/ Plot	BGB (ton/ha)	BGC (ton/ha)	CO_2e ton/ha
Mean	7687.15	38.44	384.36	192.18	705.30	1537.4	76.87	15.37	56.42
Max.	25714.32	128.6	1285.72	642.86	2359.3	5142.9	257.14	51.43	188.74
Min.	1191.48	5.96	59.57	29.79	109.32	238.30	11.91	2.38	8.75

The largest carbon stock per species was observed in *Acacia seyal, Grewia mollis, Crateva adansonii* and *Terminalia macroptera,* their carbon stock value for each tree species 452.94, 413.51, 399.94, 388.39 tons respectively. The least above ground carbon stock per tree species were recorded for *Lannea welwitschii, Acacia hockii*, *Combretum adenogonium* and *Sarcocephalus latifolius* value of 135, 98.74 and 51.37, 30.86 ton respectively. The minimum and maximum carbon stock per tree was 0.41 and 6.84 ton recorded for *Combretum adenogonium* and *Bridelia scleroneura*, respectively. The current result showed that the mean below ground biomass was 76.87±5.13 ton/ha. The mean below ground carbon stock was 15.37±1.02ton/ha. The mean of below ground carbon dioxide sequestration is 56.42 ± 3.76 ton/ ha.

Carbon stock in dead wood

The mean dead wood biomass and carbon stock was 13.97±1.26 ton/ha and 29.66±2.69 t/ha respectively. The highest and the lowest carbon stock was 35.91 ton/ha and 0.24 ton/ha respectively. The mean carbon dioxide sequestration was 51.71±32.31 ton/ha. The result showed that more dead wood carbon stock was occurred in terrestrial forest than reverine forest (Table 2).

Table 2: Mean, maximum and minimum biomass of dead wood, carbon stock and carbon sequestration.

Descriptive	**BMDW (ton/ha)**	**DWC (ton/ha)**	**CO_2e (ton/ha)**
Mean	29.67	13.97	51.71
Max	76.41	35.91	131.81
Min	0.51	0.24	0.89

Carbon Stock in Litter Biomass (LB)

To obtain carbon stock in litter biomass two parameters are important. These are percent carbon concentration that obtain from laboratory analysis and litter biomass from field data collection. The result of laboratory analysis for litter carbon concentration showed that the highest value was 54.99 % and the lowest value was 47.04%. The mean litter carbon concentration that determine in the laboratory sample plots of the study area was 52.04±0.24% .The litter biomass of the sample plots showed relatively different value. The mean litter biomass was 18.68±0.35 ton/ha. Mean total carbon stock of litter of the study site was 8.75±0.17 ton/ha (Table 3).

Table 3: Mean, maximum and minimum carbon concentration, litter biomass, litter carbon stock and carbon sequestration.

Descriptive	**Carbon %**	**LB (ton/ha)**	**LC (ton/ha)**	**CO2e (ton/ha)**
Mean	52.01	18.68	8.78	32.23
Max.	47.04	13.57	12.09	44.37
min.	54.99	25.72	6.38	23.41

Carbon Stock in the Soil

The study of the result showed that the soil bulk density ranged from 0.12 g/cm^{-3} of minimum to 0.25 g/cm^{-3} of maximum value. The mean soil bulk density was 0.19 g/cm^3±0.004. The largest soil organic matter was 67.0% whereas lowest soil organic matter was 5.40% and its mean was 31.34% ±1.97%. The carbon stock in soil as carbon pool minimum storage was 29.55 ton/ha and maximum was 873.51 ton/ha per plot of the study site. The mean soil carbon stock was 164.55±9.56 ton/ha. This soil carbon pool sequestered a minimum and maximum CO_2e value of 108 ton/ha and 1554 ton/ha, respectively with a mean of 603±56.34 ton/ha. It is showing a large amount of CO_2 captured in soil comparing to the other carbon pools except above ground biomass.

Total Carbon Stock of the study area

According to the result, the maximum total carbon stock was 837.08 ton/ha and the minimum was 118.27 ton/ha with mean carbon stock of 394.85 ±24.34 ton/ha. In the forest area of the Gambella National Park the sequestration potential was 1445.98 ton/ha carbon dioxide equivalent (see Table 4).

Table 4: Total mean carbon stock in the study area

Plots	**Carbon pools**					
76	AGC	BGC	DWC	LC	SOC	Total
Mean (ton/ha)	192.18±12.83	15.37±1.03	13.97±1.27	8.78±0.16	164.552±9.56	394.85±24.34

Carbon stock along forest stratum (Riverine, Terrestrials forest)

Above ground biomass in the forest stratum

The carbon stock value of the study site in different carbon pool showed different storage of carbon and also there was a variation of carbon stock in each carbon pool of the forest stratum (AGB of riverine forest has different carbon stock with land forest/wood land). From the Table 5 showed that the mean above ground biomass of riverine forest was 442.22±43.36 ton/ha and its mean carbon stock was 221.11 ±21.67 ton/ha. The mean above ground biomass of wood land forest was 326.48±24.70 ton/ha and its mean carbon stock was 163.24±12.35 ton/ha. The maximum carbon stock in riverine forest and land forest was 642.86 ton/ha, 335.76 ton/ha respectively. The minimum amount of carbon stock in the riverine forest and wood land/forest land was 54.77 and 29.78 ton/ha respectively. The mean sequestration potential of riverine forest was 811.48±79.56 ton/ha and the wood land /forest land sequestration was 599.10±45.33 ton/ha. From the result conclude that above ground biomass of the riverine forest contained higher amount of carbon stock than land forest/wood land. In other words, as go to riverine forest there was higher carbon sequestration potential than wood land forest. The statistical analysis was significant which is $p= 0.004<0.005$, therefore, an overall increasing carbon stock trend toward riverine forest (Table 5).

Table 5: Mean above ground biomass, carbon stock and carbon sequestration in the forest stratum.

Reverine forest (ton/ha			**Wood land forest (ton/ha)**		
AGB	**AGC**	**Co₂e**	**AGB**	**AGC**	**Co₂e**
442.22 ±43.36	221.11 ±21.67	811.48 ±79.56	326.48 ±24.70	163.24 ±12.35	599.10 ±45.33

Below Ground Biomass in the forest stratum

Below ground biomass and its carbon stock showed similar pattern to that observed carbon stock in the above ground biomass. Thus, the result showed that riverine forest has higher below ground carbon stock than land forest/wood land forest/. The maximum below ground biomass was recorded in the riverine forest which was 88.45 ton/ha (Table 6) and the maximum carbon stock was 64.92 ton/ha and the minimum carbon stock is 47.93 ton/ha in the study area. The mean carbon stock in the riverine forest is 17.69±1.73 ton/ha. Whereas, in the forest land, maximum below ground biomass was 65.30 ton/ha then the maximum carbon stock in the forest land was 47.93 ton/ha. The mean carbon stock in the forest land was 13.06±.99 ton/ha. The statically analysis indicate that significant difference above ground carbon stock and below ground carbon in the forest stratum ($p= 0.004<0.005$).

Table 6. Mean below carbon stock difference between riverine and wood land forest in the study area.

Riverine forest			Wood/ forest land		
BGB (ton/ha)	BGC (ton/ha)	CO_2e (ton/ha)	BGB (ton/ha)	BGC (ton/ha)	CO_2e (ton/ha)
88.45±8.67	17.69±1.73	64.92±6.34	65.30±4.94	13.06±.99	47.93±3.63

Dead wood along the forest stratum

The mean dead wood carbon stock in the riverine forest was 7.71±1.96 ton/ha and the forestland/wood land was 15.61±1.41ton/ha and they were statistically significant (p= 0.000). The lowest litter biomass and carbon were recorded in riverine forest as compared to other carbon pools. The mean carbon stock in the riverine forest was 7.71±1.96/ha whereas the mean carbon stock in the woodland forest was 15.61±1.41ton/ha (Table 7).

Table 7 : The dead wood carbon stock in the forest stratum (ton/ha)

	Riverine Forest			**Wood/land forest**	
DWB	DWC	CO_2e	DWB	DWC	CO_2e
16.42±4.18	7.71±1.96	28.32±7.21	33.15±2.99	15.61±1.41	57.86±5.16

Litter biomass in the forest stratum

It is similar trend with dead wood carbon stock but contrast to above and below ground biomass. The mean litter carbon stock in the riverine and forest land/wood land was 8.40± and 9.17±ton/ha respectively. When go to the riverine forest and land forest/wood land/ more litter carbon stock was occurred in the forest land (land which is free of river). However, analyzing the data it was not statistically significant (p= 0.24>0.005). The laboratory analysis of carbon result for the litter biomass was higher in the riverine forest which was 52.22±.36% than the forest land/wood land forest 51.84±.32%. The result indicated that Litter biomass of carbon in the riverine vegetation was lower than the wood land forest (Table 8).

Table 8: Mean litter biomass, litter carbon and carbon dioxide equivalent

	Riverine forest (ton/ha)				**Woodland/ Land forest (ton/ha)**		
% OM	LB	LC	CO_2e	% OM	LB	LC	CO_2e
52.22 ±.36	33.85 ±.44	8.21 ±.21	30.11 ±.76	51.84 ±.32	19.62 ±.48	9.22 ±.23	17.46 ±.83

Soil carbon in the forest stratum

As Table 9 shows that the mean carbon stock in the riverine and forest land /wood land forest/ were 205.2897±13.53 and 123.81±9.89ton/ha respectively. The result indicated that more soil carbon stock was available in the riverine forest than forest land /wood land. Statically it was significant (p=0.000<0.005). Bulk density of the soil was important indicators of the physical properties of the soil (it is inversely proportional to organic matter). The bulk density of the riverine forest was 0.2116±.01 g/cm^3 and the wood land/forest land was 0.33±.01g/cm^3. Therefore, more soil organic matter was occurred in the riverine forest than wood land forest. The mean soil organic matter in the woodland forest/forest land was 42.79±2.4% and the riverine forest was 19.8750±1.66%.

Table 9: The mean carbon stock of the soil in the riverine and wood/forest land

Forest types	BD (g/cm^3)	SOM %	SOC (ton/ ha)	CO_2e (ton/ha)
Riverine forest	0.33 ±.01	19.87 ±1.66	123.81 ±9.89	753.41 ±49.66
	BD (g/cm^3)	SOM %	SOC (ton/ ha)	CO_2e (ton/ha)
Wood /forest land	0.211 ±.01	42.79 ±2.4	205.28 ±13.53	753.41 ±49.66

There is higher bulk density in the riverine forest than wood forest land. The analysis indicated that the higher the bulk density, the lower soil organic matter. Statically analysis of the correlation show that R= -0.038. This is strongly negative correlation between bulk density and carbon stock of the soil in the riverine forest. In another words, the lower bulk density the higher carbon stock of the Soil in riverine forest. The Correlations soil organic carbon and bulk density in the wood land forest/ forest land was R=+0.030 then there were weak positive relation between bulk density and carbon stock at the land forest. This means that as bulk density increase the carbon stock also increase.

Total Carbon stock in riverine and forest land/ wood forest

The maximum carbon stock density in riverine forest and wood/ land forest was recorded 837.08 ton/ha and 527.33 ton/ha respectively. The minimum carbon stock was 175 ton/ha in the riverine and 118.27 ton/ha in the forest land/woodland forest/ respectively. The highest carbon stock was recorder in riverine forest of the pool in AGB biomass, its value was 642.86 ton/ha and the minimum was recorded in dead wood biomass of carbon stock its value was 0.58 ton/ha. Both highest and lowest carbon stock was occurred in the riverine forest. Total carbon stock in the forest stratum was significant ($p=0.000<0.005$). It means that there was change between in the forest stratum. Three carbon pools such as AGB, BGB and SOM were higher carbon stock in the riverine forest than wood land forest. The mean carbon stock for three of carbon pools in the riverine forest for AGB was 221.11 was ton/ha (Table 10) for BGB was 17.68, SOM was 205.28 ton/ha respectively. The mean carbon stock stratum of wood/land forest carbon pools such as AGB, BGB, and SOM their value was 163.24 ton/ha, 13.05 ton/ha and 60.99 ton/ha respectively. Two of the carbon pools (dead wood and litter biomass) are higher in the wood/ land forest than riverine forest. The mean carbon stock in the wood/land forest carbon pools such as DWC and LC was 15.6105±1.41 and 9.17±.24 ton/ha respectively. The mean carbon stock in the riverine forest carbon pools of DWC and LC was 7.71±1.96 ton/ha and 8.40±.21 ton/ha respectively. As moving toward to the riverine forest there was less dead wood carbon stock and litter biomass, as moving toward wood land/ forest land/ there was more dead wood carbon stock and litter biomass. The total mean value of the riverine forest was 454.51±26.01 whereas the wood/land forest was 324.89± 17.25ton/ha. Statically output show that 0.000 < 0.005 then there was significant difference in the forest stratum and correlation $R= 0.015<1$ indicate one is increased the other is decreased. That means riverine forest has higher carbon stock than forest/woodland forest in the study area.

Table 10: The maximum and minimum carbon stock (ton/ha) in the forest stratum of each carbon pools

	Carbon pool	No. plots	Minimum	Maximum	Mean
Reverine forest	ABC	38	54.78	642.86	221.11
	BGC	38	4.38	51.43	17.68
	DWC	10	0.58	17.05	7.718
	LC	38	6.38	11.06	8.3966
	SOM	38	30.18	423.34	205.28
Wood land forest/forest land	ABC	38	29.79	335.76	163.24
	BGC	38	2.38	26.86	13.0592
	DWC	38	0.24	35.91	15.6105
	LC	38	6.51	12.09	9.1658
	SOC	38	29.55	229.13	123.8145

Land Use and Land Cover of Gambella National Park

Based on Figure 2, the land use and land cover classes for the study area in 1986 indicated that forest land 43.56%, grassland 31.43%, wood land 9.00%, shrub land 8.29%, bare land 7.64 % and water body 0.08%. The forest land cover and grass land were the largest coverage whereas wood land, shrub land, bare land and water body were the least coverage of the national park in 1986. It indicated that much of the National Park coverage was the natural vegetation consists of forest land and grass land that occupied about 74.99% of the total area while the remaining 25.01% was wood land, shrub land, and bareland and water body in year 1986.

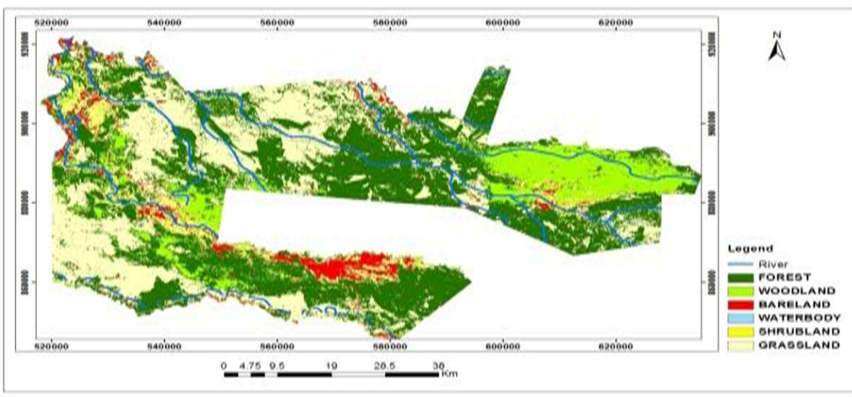

Fig. 2: Land Use land cover of Gambella National Park in 1986

In the case of the year 2000, based on Figure 2, the land use and land cover classes of grass land was 192,169ha (43.95%) and forest land was 137,858ha (31.53%) and indicated the largest share in 2000 for the study area. Whereas, the aerial coverage of wood land 35,450.2 ha (8.11%), shrub land 36,180.90ha (8.27%), bare land 35, 476.23ha (8.11%), and water body 147.67ha (0.03%) were the least coverage area respectively (see Table 11).

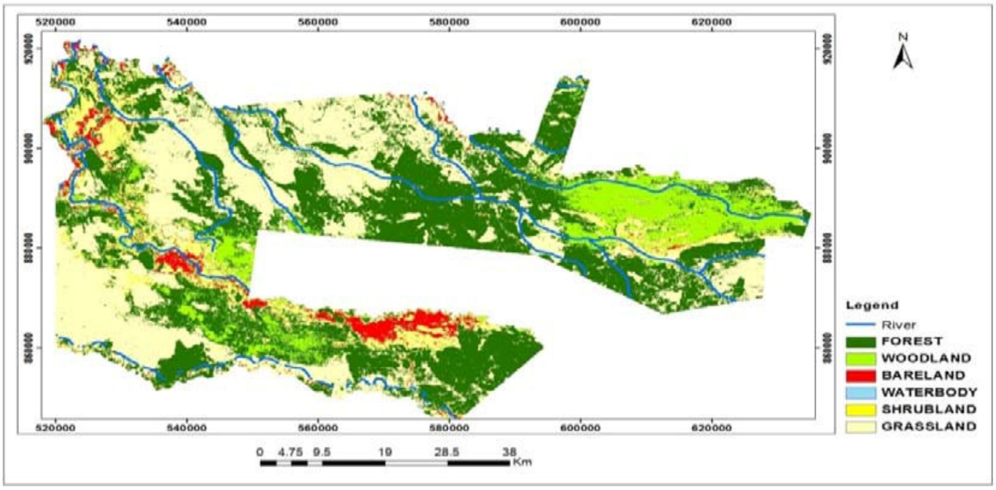

Fig. 3: Land use land cover of Gambella National Park in 2000

In 2011, the dominant land use and land cover classes were grass land covered 244,057ha (55.88%) & Forest land 84,552ha (19.34%) followed by shrub land covering 46,034.9ha (10.53%) while the least area coverage occupied by bar land 37,470.52ha (8.57%), wood land 25,026ha (5.72%) and water body was 141.66ha (0.0.03%) (Table 11).

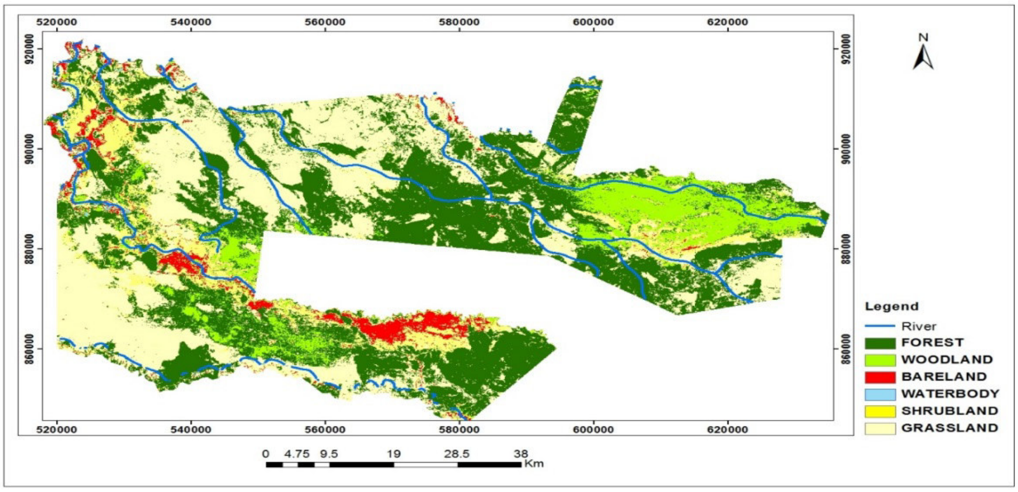

Fig. 4: Land use land cover of Gambella National Park in 2011

Table 11: Land Use Land Cover pattern of Gambella National Park in 1896, 200 and 2011

LULC classes	**1986**		**2000**		**2011**	
	Area		Area		Area	
	Ha	%	Ha	%	Ha	%
Forest	190,476.00	43.56	137,858.00	31.53	84,552.00	19.34
Grassland	137,449.00	31.43	192,169.00	43.95	244,057.00	55.81
Woodland	39,372.30	9.09	32,450.18	7.42	25,026.00	5.72
Shrub land	36,248.00	8.29 39,180.90			46,034.90 8.96	10.53
Bare land	33,394.80	7.64	35,476.23	8.11	37,470.50	8.57
Water body	341.88	0.08 147.67			141.66 0.03	0.03

Land use land cover change (LULCC)

As shown in Table 12 below, the result indicates that almost 105,924ha area of the forest has gone away in 25 years (between 1986-2011) gap which is about 24.22% loss. The other land use which has decreased was woodland and the estimated to be lost about 14,346.30 (3.28 %) in 25 years period and the water body also decreased by 200.22 ha (0.05%). In principle, the LU/LC decreased in a certain time has to go to other LU/LC and results increment of other LU/LC. Therefore, on the contrary shrub land, grass land and bare land have increased about 27.55% at the expense of decrease of the forestland, wood land water body between 1986 to 2011.

Table 12. The rate of LULCC for 25 years of Gambella National Park.

Land use land cover	LULCC 1986-2011 (ha)	Change in %
Forest	-105,924.00	-24.22
Grassland	106,608.00	24.38
Woodland	-14,346.30	-3.28
Shrub land	9,786.90	2.24
Bare land	4,075.70	0.93
Water body	-200.22	-0.05
Total	437282	

The rate of changes in land use and land cover classes of forest land between the years 1986 and 2011 had been reduced by an annual rate of about 8,827 ha/year which was 2 % lost each years. The wood land annual loss between1986-2011 continued to decline r a p i d l y at a rate of 1,195 ha/year (0.27%). The water bodies were reduced by 0.05%. The total increment of grass land was 24.38% and its annual increment was 2.03% and also the total increment of shrub land, bare land was 2.24 % and 0.93% respectively in the National Park.

The total losses of forest land and wood land were high in the National Park due to expansion of agriculture, fuel wood finding, and pole for construction. For example, the forest in the 2011 was decreasing but grass land/agricultural land in the same year increasing. Generally, the exploitation of forest and wood land is high thus resulted in converting forest land and wood land in to grass land, bare land and shrub land. In the study area the land use land cover change indicate that unless good management plan is implemented the carbon stock of the National Park will decrease in the years to come.

DISCUSSION

Gambella National Park has forest which is dry peripheral semi deciduous Guineo-Congolian tree species and important ecosystem services such as carbon sequestration for mitigation of climate change and conservation of biodiversity. According to [21], the dry peripheral semi- deciduous Guineo-Congolian forests are restricted to Baro River lowlands, in Gambella state. When the tree DBH is smaller it is envisaged that it could sequester less carbon but gradually increases in DBH and would accumulate more carbon [Terakunpisut *et al*., 2007]. Analysis of tree diameters with respect to the above ground biomass in the study area showed that tree species with lower range of diameter possess more density accumulated and less above ground biomass. On the other hand, trees having bigger diameters were few in number but accumulated more above ground biomass. There is inverse relationship between tree density and DBH of the tree whereas a direct relationship was observed between the above ground biomass and DBH of the tree in the study area. Therefore, higher DBH classes have higher carbon stock than lower DBH of the tree in the national park of Gambella. The lower height class of the tree indicated that high density of the tree. The species in the national park had different DBH and Height class. This showed that the forest has different patterns of vegetation, species composition and structure. The distribution of the forest species in the present study showed high number of individuals in the first three DBH classes whereas small values in the rest of the classes.

There are multipurpose trees species identified in the National Park such as *Vittelaria paradoxa* (Wado-Anguwak) and *Cordia africana* common in the Gilo sub basin. They have high potential for production of oil and as the result these species have to be conserved and developed to be researched for further utilization and conservation purposes in sustainable manner. They have been cleared for various investment and only few scattered woodland and savannah grasslands are dominant (PACT Ethiopia, 2012). It is conclude that in the study area the tree species have higher diameter and number than they have potential of store more carbon. The present carbon stock study in Gambella National Park covered an estimate of the biomass and carbon density in forest ecosystem components (vegetation, litter, dead wood and soil) and the variation of carbon stock between forest stratums in each carbon pool were done. This is helpful for providing relevant information and understanding the patterns of carbon stock between forest stratums of a representative tropical deciduous Guineo-Congolian species. According to Houghton [2001], the forest of the National Park has a large potential for temporary and long term carbon storage. In the forest ecosystems, greater carbon is stored in a large, long-lived species and in species with dense wood. The species such as *Grewia mollis*, *Diospyros abyssinmca*, *Celtis toka*, *Crateva adansonii, Vittelaria paradoxa, Combretum adenogonium*, *Terminalia macroptera* were contributed for the large amounts of biomass and carbon stocks while the least tree species were *Sarcocephalus latifolius*, *Ficus sycomoros*, *Cordia gharaf*, *Diospyros mespiliformis*, *Olyra latifolia* had less contribution. This unequal contribution of species to carbon stock of the forest site is could probably be due to the density, age and size difference among species.

Carbon stock in different carbon pools

The factor to determine carbon stock in the study area is based on drainage and species types. Therefore, riverine and terrestrials forest of National Park were important to estimate carbon stock for each carbon pools in this study. The mean carbon stock in above ground biomass of forest of Gambella National Park (192±12.83ton/ha) was lower than the one that reported from Bale Mountains Eco-Region forest of mean above ground forest carbon stock is 208 ton/ha ± 81 [23]. However, the study result is comparable to those reported for the above-ground mean carbon density estimate from global forest ranges which was 20 to 400 ton C/ha (Hairiah *et al*., 2001). In the study area, the maximum and the minimum range of above ground biomass is 29.79 to 642.84 ton/ha.

The overall dead wood carbon stock fall within the range of the reported result 1.2-3.3 ton/ha for the drier life zones in tropical forests [24]. In the study area the dead wood was 13.97±1.27ton/ha is recorded. The findings indicated that the carbon stock for the deadwood is generally larger than tropical forests. In addition, deadwood dynamics are closely related to forest management [25] suggested that the warm and humid climate induces quick decomposition of dead-wood. Since the study area is located in tropical areas, the rate of decomposition is relatively fast. This study results high availability of deadwood carbon in the lowland area (Gambella National Park) of Ethiopia. The probability getting of dead wood in the riverine forest was low comparing to terrestrials forest (wood land without river) due to wetting by the river. In contrast to the above ground and below ground biomass, the dead wood carbon did not show higher in riverine forest. The mean carbon stock in litter pool of the present study is higher compared to values reported for tropical dry forests (2.1 ton/ha) [26]. The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density) and climate [27]. Due to erratic and high temperature of the study area, litter biomass is higher as compared to IPCC. Soil carbon mainly depends on the climate and other physical and geological factors and to a lesser extent influenced by the manipulation of forest cover and management practices and is thus more stable and its carbon stock vary between 30 to 141 t/ha (IPCC, 2006). Comparing with IPCC 2006, Gambella National Park soil carbon stock is 29.5 ton/ha to 423.24 ton/ha. It is the fact that the park is lowland and has high variability of climate then results decomposition of dead organic matter at higher rate. The mean bulk density of the forest site was low 0.19 g/cm^3, (ranging between 0.25 to 0.12 g/cm^3) which indicates that the study site has high organic matter content in the soil. Thus, the higher mean SOC stock is due to the presence of high SOM and fast decomposition of litter which results in maximum storage of carbon stock [28]. Overall, the present result revealed that the study forest soil of Gambella National Park has large carbon stock and thus sequestered large amount of CO_2 contributing to the mitigation of global climate change.

Total carbon stock density

In the study area the average carbon stock was 394±12.21 t/ha and its total carbon stock varies between 118.27 t/ha to 837.08 t/ha. In Uganda, 155,900ha of National Parks (Kibale, Semuliki and parts of Ruwenzori) exhibiting carbon densities between 191 to 457 ton/ha and its mean carbon stock is 324 ton/ha [29]. However, the result of the study indicates that the forest of Gambella National Park has higher carbon stock potential than National Parks of Uganda, (Kibale, Semuliki and parts of Ruwenzori). The present study was compared to various parks of the world (Table 13). Tai National Park in Cote d'Ivoire, had the carbon stock of 188 ton/ha. Similarly, in Congo, Kahuzi - Biega National Park had carbon stock of 167 ton/ha. Therefore, this study is approximately equal or greater than the carbon stock these parks.

Table 13: Top WHF sites of the tropical zone having highest C stock in total biomass per hectare (exclude soil).

No.	Name of World Heritage Forest site (WHF)	Country	Carbon stock ton/ha	WH Site Size (ha)	Forest Cover WHF
1	Tai National Park	Coted'Ivoire	188	330000	30
2	Gunung Mulu National Park	Malaysia	167	52864	100
3	Kinabalu Park	Malaysia	167	75370	70
4	Tikal National Park	Guatemala	150	57600	20
5	Subterranean River National park	Philippines	163	5753	50
6	Cocos Island National Park	Costa Rica	165	199790	11
7	Kahuzi - Biega National Park	Congo	167	600000	30

During the establishment of Gambella National Park the total area coverage was 500,161ha for conservation of specific wild animals but in recent years, the National Park area is demarcated by reducing its size/area. This reduction area is currently held by investments such as Karature, Saudi Star and some local farmers. Before investments activities are taken place, the land was occupied by forest and wood land and the investments have impacted highly on the forest parts of the Gambella National Park before new demarcation of the park. The current demarcation area of the national park is 43,782ha which is by 62,879ha. Therefore, investment activities have great impact on the carbon stock and biodiversity conservation in the last two decade.

The Causes of Land use land Cover Change

Land use land cover change is the direct reflection of the dynamics of socio-economic development. All the factors of deforestation such as the prevalence of various types of agricultural activities, fire wood and charcoal production, cutting trees to fulfill the demand of constructional materials, settlement expansion and income generation are directly or indirectly related to population growth [30]. In the study area the investment is increasing toward the National Park without demarcation and absence of clear buffer zone between the National Park and the investment activities/local community. These activities reduce ecosystem survives such as carbon sequestration of the national park. If protected areas are nearby investment, grazing and conversion of land for agricultural purposes in these areas will increase even further. This is already taking place in Awash National Park and Gambella National Park (Vreugdenhil *et al.,* 2012). The agro ecological condition of the area is convenient for agriculture due to the topography flatness and availability of water resource. Due to this, crop production and livestock rearing is the basic economic activity in the local community of the region. The indigenous community makes fire to rejuvenate new grass at the dry season of every year. These activities make losses of carbon stock and aggravate the climate change by emission of carbon dioxide to the atmosphere.

CONCLUSION & RECOMMENDATIONS

Conclusion

The present study suggests that there are different species occurring in Gambella National Park which makes it best for conservation of biodiversity. The most dominant species was *Grewia mollis*, *Diospyros abyssinica*, *Celtis toka*, *Crateva adansonii* and *Vittelaria paradoxa.* The study shows that the higher the DBH class, the lower the density of the tree and the forest was mostly dominated by small sized trees. Each tree has its own carbon storage capacity and the higher the DBH of the tree the higher the carbon stock. The largest carbon stock per species was observed in *Grewia mollis, Diospyros abyssinica, Crateva adansonii* and *Terminalia macroptera.* The least carbon stocking species was *Sarcocephalus latifolius, Cordia gharaf* and *Diospyros mespiliformis*. The analysis showed that there was different carbon storage capacity of species in the forest area of the National Park. The largest carbon stock was in the above ground biomass amounting 192.18±12.8 ton/ha followed by soil organic carbon 164.552±9.56 ton/ha. The least carbon stock was recorded in below ground biomass (15.37±1.03 ton/ha), in dead wood biomass (13.97±1.27ton/ha) followed by litter biomass 8.78±0.16ton/ha. Furthermore, the total carbon stock density in the study sites was high and ranges from 118 to 837ton/ha. The forest stratum of the study area's carbon stocks density for each carbon had varied. As a result moving toward to riverine forest more carbon stock was available than terrestrials forest even if more species were recorded in the terrestrial forest. The land use land cover change in the National Park concludes that forest land, wood land and water bodies showed considerable decrease by 27.64% in the last 25 years whereas grass land, bare land and bush/shrub land had increased by 27.55%.

Recommendations

The following recommendations were given from the findings of the present study as a solution to mitigate the impacts on the National Park and encourage the carbon sequestration.

- The research result of existing forests of the National Park was dominated by small sized trees though they have sequestered large carbon stock. Therefore, even if the park is conserved, protecting it from deforestation fully from human interference is necessary to continue its carbon storage and augment in the mitigation of climate change.
- Land use and land cover change analysis is a good indicator of the trend of their dynamics. Therefore, socio-economic data of the area is necessary to increase efficiency and accuracy to use the result of the analysis for decision making.
- Since, the vegetation type in Gambella National Park is diverse in structure, composition and species the choice of appropriate allometric equation for each vegetation species type is required for future determination of carbon stock.
- EWCA and the regional government should made fundamental thinking in the policy of National Park management in such a way of promoting carbon trading by the system of REED+ for additional financial incentive to the local community who are depending on the national resource for ensuring the sustainability of the park.
- It is the fact that there is scarcity of data on carbon stock and sequestration potential in the National Parks/Protected Areas. Therefore, there is a need for more research in the National Park and other protected areas of Ethiopia.

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