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ANALYSIS OF CARBON STOCK POTENTIAL FOR GOJJAMDUR COMMUNITY FOREST, NORTHWEST ETHIOPIA

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ABSTRACT

Understand the interrelate importance of the community forest ecosystem enables to pay attention for the wellbeing of the forest by the local community. On the surface of the earth, there are a numbers of community forests which keep the balance of the surrounding environment for the continuity of life. Among those, Gojjamdur community forest is one of the dense community managed forest in Northwest Ethiopia which gives valuable importance for the surrounding community. Thus, among the different importance, it serves as a store house of carbon. Thus, analyse the carbon stock potential of the forest is the key consideration of the study. In order to achieve the purpose, soil, litter, and tree DBHs sampleswere used. These samples were collected from 59 sample plots with 20m inter plot distance and the sample plots were taken randomly from the forest. The soil and litter samples were analysed in laboratory while the biomass value of the individual treewas analysed by allometric equation. The study finds that the community forests stored carbon ranging from 109.84 to 987.81 t/ha. From the result, it can be concluded that the forest has been acting as a storehouse of carbon.

So, it is possible to infer that community management forest has a positive impact on increasing the carbon stock potential of the terrestrial and thus it contributes on the mitigation of global climate change.

Keywords*:* carbon; community forest; Gojjamdur; potential; stock

1.Introduction

Forests have many interrelated benefits for the continuity of life on earth surface (Attarchi and Gloaguen, 2014; Neigh, 2014).They serve as home of wild animals(Menevand,2014), sources of raw materials for industries, medicines, fire wood (Menevand,2014; Schure,2014; Peltier et al.,2014a;Schure,2011), for construction(Schure,2014), food for wild animals, sources of oxygen and stock carbon dioxide in carbon form and protect soil from erosion (Zdruli et al., 2017;Leifeld,2013;Luo et al.,2010;Xia et al.,2010; Detwiler,1986). Having these all benefits; deforestation and forest clearance widely spread on the earth surface by human beings and wild fire (Valery et al., 2016). Thus, the world forest coverage decreased from time to time on wards by anthropogenic activities (IPCC, 2000). Forest ecosystem covers thirty percent of the world terrestrial land area and play an important role the global carbon stock which is equivalent to conserve eighty percent of the earth's terrestrial carbon biomass (Dixon, 1994). In addition, the world forests store two hundred eighty nine giga tone of carbon in their biomass from which store eighty percent of the total above-ground organic carbon and forty percent of the total below-ground organic carbon in worldwide(FAO,2010; Banskota et al., 2007;Richard,2006;FAO,2005).

The amount of carbon sequestered by a forest can be estimated from the biomass accumulation since half of forest dry biomass weight constitutes carbon (FAO, 2008;Banskota et al., 2007, FAO, 2005; Cairns et al., 2003; MacDicken, 1997). The carbon assessments are performed for both above and below-ground(Robinson et al., 2013) because this carbon generally represents the total living carbon in a forest and does not pose significant logistical problems during field measurements (Phutchard et al., 2014; IPCC, 2007). Thus, estimating both the above and below-ground forest carbon is the most important step in measuring the carbon stock of the forests and helps to determine the contribution of forests to the global carbon cycle(IPCC,2007). Moreover, the emitted carbon dioxide from different sources is the most dreaded problem across the world (Houghton, 2005) and it is the most common greenhouse gas resulting in global warming (Kibebew and Tesema, 2014). When the carbon dioxide concentration increases in the atmosphere it can cause climate change impact (Houghton, 2005) and resulted in global temperatures continue to warm(IPCC,2010).Thus, surface of the earth will be inconvenient for the survival of all life in it if the contribution of the forest clearly understand to the global carbon cycle(IPCC,2007). The existing forest coverages of the world play the lion share role in stocking of the emitted carbon from different sources (Bonan, 2008).Even though, the forest coverage of the world has such lion share role to stock the emitted carbon from the different sources, the forest carbon stock assessment information is uncertain for many developing countries including Ethiopia (Wang et al., 2011). Ethiopia’s forest cover was about thirty five percent during twentieth century but declined to less than three percent in 1992(FDRE, 1998). Hence, it is important to know the role of the remaining amount forest coverage of carbon stock potential at global, national and regional levels (Tan et al., 2007; Wang, 2006); forests form an integral part for scientific research as the “forest carbon reservoir” which has a dynamic relationship with the climate system(Wang,2006). Accordingly, this study tried to analyse the Carbon Stock Potential and mapping of the Gojjamdur community forest in Machakel District, East Gojjam Zone, Amhara Regional state, Northwest Ethiopia.

2. Materials and methods

2.1.Study area description

The study area lies between 5^0 27 to 5^0 32’ N and 38^0 15’ to 38^0 20’ E. In administrative term it is located in Machakel district, East Gojjam Zone, Amhara Regional State. The study area has spatial coverage of 89.86km^2 and the Gojjamdur forest is located around 329km North West of Addis Ababa and forms the parts of the northwest highlands of Ethiopia (Figure 1). The study area is consisting of different topographic conditions, which is characterized by moderate steep and steep in the north-western parts while gentle to level slopes at the north-eastern parts of the study area. The elevation ranges from 2129m to 3778 meter above sea level. According to FAO, 1999 classification the topography of the study area consists of level slope 31.45km^2 (34.99%), very gently slope 46.39km^2 (51.62%), gentle sloping 3.59km^2 (3.99%), sloping 4.49km^2 (4.99%), strongly slope 1.79km^2(1.99%), moderate steep 1.79km^2 (1.99%) and very steep 0.36km^2 (0.43%).

According to the National Meteorological Agency as measured at Amanuel town (10^{0}20’N and 37^{0}40’E with elevation 2411m), the climate condition of Gojjamdur community forest is generally characterized by sub-tropical agro ecology with mean rainfall of 1411.7 mm and the average temperature of the study area is between 10-20^{0}c. The study area has four seasons; summer, winter, autumn and spring. Autumn and spring are known as the main rain seasons while winter is dry season in the study area.

The livelihoods of the majority of the settlers in the study area are mainly depending on sedentary farming. In addition, mixed types agriculture on subsistence scale is the major livelihood of the people in the study area. Land and livestock are the most important assets of the people, with which they lead a sedentary life. A Variety of crops are produced by a house hold like Maize, teff, Wheat and etc.

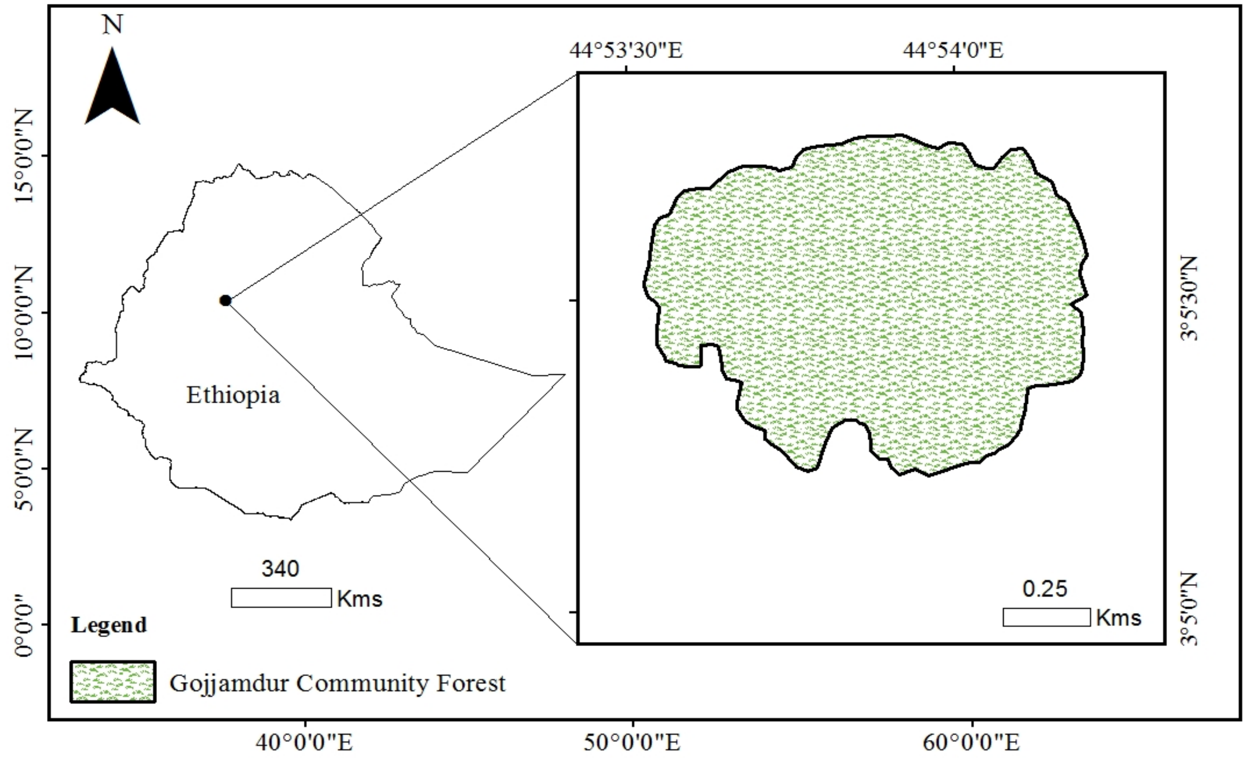

Figure 1. Location map of Gojjamdur community forest

2.2.Data sources and methods of collection

To quantify the carbon stock potential of the study area tree diameter at breast height (DBH), tree height, dead woods, litter, tree root and soil data were the fundamental parameters. Thus, the way of the research design, sampling technique, sources and methods of data collection are justified in detail as follows:

2.2.1. Research design

The research applied developmental research design. There are different types of developmental research designs but the appropriate and applicable research designs for this research were both survey and experimental research design. The survey research design was applied to collect the field data of the tree diameter at breast height (DBH), tree height, dead wood, litter and soil data while to distinguish the soil carbon, experiments in the laboratory were applied.

2.2.2. Sampling techniques

Gojjamdur community forest has similar vegetation cover; as a result, based on this vegetation cover random sampling technique was applied (Brown, 2003). To make the study manageable, sample plotswere used. A number of 59 sample plots were taken with the area of 10m*10m and determined by the following formula (Rembold et al., 2009).

$$N = \frac{\text{Ta x Si}}{\text{Ps x 100}} \quad (1)$$

Where N = number of sample plots, T_a= Total area of forest, Si= Sampling intensity, the forest (adopted sample intensity 0.1 %(Japhet et al., 2013 and Ps= plot size**.** While the distance between plots was 20m and determined by the following formula (Rembold et al., 2009).

$$D = \frac{\sqrt{Af\ x\ 10000}}{N} \quad (2)$$

Where; D = inter plots distance (m), Af = Area of the forest (ha) and N = number of plots. Sampling plots were later located in the field using a GPS device. The use of GPS receiver's enabled to locate the efficient and accurate placement of the plots (MacDicken, 1997). During inventory, a GPS facilitate orienting direction to the next plots.

Tree DBH and height data:the areas of each sample plots were determined measuring with linear meter. The Diameter of the individual tree was measured in which tree had DBH greater than 5cm using calliper and the local and botanical names of each trees were recorded helping by district forestry experts and a book of useful trees and shrubs for Ethiopia(Azene et al.,1993) was used as a reference. According to Bhishma et al.(2010), trees with multiple stems at 1.3 m heightwere treated as a single individual and DBH of the largest stem was taken. A tree with multiple stems below 1.3 m height was treated as a single individual tree. In addition, the tree height in the plot was measured with the Sunto hypsometer. In order to identify measured tree species; a complete measured trees were checked off by white spray.

Dead woods: the standing and fallen dead trees were counted in the plot and identified as dead wood. The dead woods biomass potential were estimated by measuring the large diameter at bottom and small diameters at head (top) of dead trees and the average of the two was taken to estimate the biomass(Parresol,2001b).

Litter: the fallen leafs; grasses and fine branches are considered as litter. Thus, 1m*1m of plot size was used to estimate the biomass and carbon contents from the four corners and centre of main plots. Moreover, the collected litters in the study area were weighted on the site to estimate fresh weight and all samples were mixed and sub-sample taken. The sub-sample litters were then oven dried and the dry weight was extrapolated to sub-plots, ha and study area. In addition, the carbon stock potential of the forest was also found under the roots of the vegetation. Thus, for the calculation of carbon stock in the root system, non-destructive method was employed.

Soil data*:* the carbon stock potential of the forest also exists under the soil. So, to estimate the carbon stock potential of the forest; soil samples must be taken from the forest. Thus, soil samples were taken from the different parts of the forest. Before taking the soil samples from the sample areas in the forest, litter, grass and any other materials on the soil surface were removed. Thus, composite soil samples per plot were collected from the surface 0-30 cmof soil horizon with Augerfrom five places of a plot. The collection of the sample soils had two categories; disturbed and undisturbed soil samples. Within a plot, the disturbed soil samples were dugout and amalgamated together at respective depth of 0-30 cm in soil horizon. The collectedand mixedsamples were properly labelled and transported to Injibara University, Geographic Information System and Remote Sensing laboratory room. Then, the samples were spread on sheet of papers and dried by air in GIS and RS laboratory room. The reason that the soil samples were dried by the air in order to halt the sun volatile minerals if they were inside in the sample soils. After the samples had properly dried, they were crushed well with mortar and sieved by a 2 mm sieve diameter for the soil carbon determination. In contrast, undisturbed soil samples were also collected from the respective depths using cores sampler that were inserted into a metallic cylindrical core which is prepared for this purpose. For all plots, for bulk density determination, the undisturbed samples were collected only from centres of the plots.

Ground control points: the ground control points were collected from the field with Garmin 72 GPS to display the amount of stored carbon potential in the specific plot on the map in the study area.

2.3. Methods of data analysis and interpretation

2.3.1. Quantifying the carbon stock potential

Tree DBH and height data: the individual trees DBH and height in the sample plots were recorded properly, the above ground biomass of the individual tree in the sample plot was calculated using the following equation (Chave et al., 2014).

$$AGB = 0.0559\ x\ (Px\ D^2 xH) \quad (3)$$

Where, AGB =above ground biomass in kg, P= wood Density, D=Diameter (cm) at breast height of all woody species measured in all sample plots with DBH>=5_215cm at 1.3 cm height, H= Height (m) of each plant species in all sample plots

Roots: as Santantonio et al. [39] and MacDicken [21] suggest, the below ground biomass (root) of a plant is close to 20 percent of the total aboveground biomass of the vegetation. Accordingly, the root biomass of trees were estimated using the following formula:

$$\mathrm{BGB} = \mathrm{O.20\ x\ AGB} \quad (4)$$

Dead woods: dead wood biomass in kg in the study area was estimated by applying the techniques using Smalian formula (Parresol, 2001b), and converted to carbon. Allometric equations for the dead tree/shrub were considered accordingly as stated in FAO (2005).

$$Deadwoodvolume(V) = f(DS^2 + Dl^2)x\, {}^{L}/_{2} \qquad (5)$$

Where V, is volume of the wood (m^3), Ds is small diameter (cm), Dl is large diameter (cm), L is length (m), f is adjustment factor = 0.00007854. In addition, to calculate the biomass, apply the allometric equation of live tree of similar species (or related species). Deduct 2-3% for leaves correction.

Litter: after the litter samples were collected, they were dried in the oven and the dried weight was extrapolated in to sub-plots in the study area. Finally, carbon in dead litter for each site was determined by multiplying the dried biomass in the oven by conversion factor of 0.47(Pearson et al., 2005).

In addition, the carbon content in the biomass was estimated by multiplying the conversion factor of 0.47(Pearson et al., 2005) and the carbon stock potential of the given area per hectare was calculated using the following equation (Bhishma et al., 2010).

$$Cp = \frac{Ca}{1000} x \frac{10000}{Ap} \qquad (6)$$

Where: CP: - is the carbon content per hectare in each carbon pool in each plot, expressed in ton per hectare, Ca: - is the carbon content in each carbon pool in each plot, expressed in kilograms (kg) and Ap: - is the area of plot in each pool, expressed in square meter (m).

Moreover, the mean above ground carbon stock of the plot in carbon dioxide equivalent sink (tons/ha) in a given site was calculated using CO_2 equivalent formula (Pearson et al., 2007; Craig et al., 2010).

$$CO_2 \text{ equivalent} = \text{carbon stock (t/ha)}\ x\ \frac{44}{12} \qquad (7)$$

Soil data: the samples were made ready for the analysis of soil organic carbon and bulk density determination. To analysis the organic carbon content of the soil, 0.25-1g soil sample was taken for lab analysis measuring with sensitive balance. Then, two independent flasks were prepared because the two independent flasks had different uses in the organic carbon content analysis. Flask one in the analysis used for making blank or control factors (making balance in the analysis if there were any silly errors in the sample preparation on acids, detergents, soils etc.) and in this flask no needed sample soil added except the rest of other chemicals. In other sides, flask two was used for making analysis by holding both the sample soil and the chemicals. The main purpose of inserting the different chemicals in flask one except the sample soil was to know the organic carbon weight only excluding the other factors via subtracting the blank factors reading results.

Next to this, 5ml potassium dichromate was added on both flasks at the same time. The purpose of the potassium dichromate in the soil sample container flask (f2) was to make solute with the sample soil. After these steps, other 7.5ml sulfuric acid was added on both flasks. At this time, the solution became hot due to chemical reactions and it needed to wait for 30 minutes until the reactions reacted completely. Moreover, 100ml distilled water was added in the two flasks. In addition, in both flasks**,** diphenylamine indicatorswere added. Instantly when the indicators were added in both flasks, the colour of the solution was changed in to black colour. The next phase from this was adding for titrating 0.5N (Normal; default given) in both flask solutions. Lastly, both flasks were titrated independently until the solutions were changed from black in to green colours. At the same time, the blank flask solution had given its on chemical reaction reading (B) on the titrator. Similarly, the soil sample flask solution had given its own chemical reaction reading(S) on the titrator. Then, using the following scientific formula, the organic carbon of the soil had found.

$$\%\mathrm{Oc} = \frac{(\mathrm{B} - \mathrm{S})\mathrm{N \ x \ 0.39}}{\mathrm{SW}} \tag{8}$$

When, OC=organic Carbon,B=Blank titrate reading, S= Soil sample titrate reading,N=Normal (0.5) andSW= Sample weight

Soil bulk density determination:before the different undisturbed cores' soil samples were inserted in an oven, the fresh weigh of the core soil samples had measured by the sensitive balance laid it on an aluminium sheet and the reading was taken**.** The cores' soil samples were dried in an oven with at a temperature of 105 °C for 24 hours. After 24 hours, the soil samples were taken out from dry oven and the dry weight of the cores' soil sample were again recorded. Finally, the dry bulk density of the soil was determined using the core method as describes in Blake and Hartage (1986).

$$BD(g/cm^3) = \frac{M_{ODS(g)}}{V_t(cm^3)} \quad (9)$$

Where: M_{ODS} = mass of the oven-dry soil (g), V_t = total volume of the soil core calculated from $V_t = \pi r^2 h$; r is the internal radius of the cores measured using a caliber (cm), and h is height of the cores measured using ruler. After core samples dried in oven, any coarse fragments that did not pass through the 2 mm sieve diameter were separated and the fine earth (< 2 mm) weighed and used as mass of the oven dry soil. Πis a constant which is equal to 22/7. Finally, soil organic carbon stock ton per hectare at the respective depth was calculated by:

$$MassSOC(t/ha) = \frac{OC(\%) x \frac{BD\left(\frac{t}{m^3}\right)}{Density\left(\frac{t}{m^3}\right)} x \frac{10000(m^2) x Depth(m)}{Volume(m^3)}}{Mass(t)} \quad (10)$$

Where: OC = Organic Carbon Concentration (%), BD = Bulk Density of soil (t/m^3) and D = Depth (m) of profile. Generally, the total forest carbon stock (t/ha) of a given site was obtained from: Mass= mass of the dry solid soil, Density= of water ($1cm^3$).

2.3.2. Mapping carbon stock potential

After the above ground carbon content, both root and soil carbon content of the individual plot in the forest were calculated. In addition, in order to produce the total carbon stock potential map of the forest, the GCPs of the individual sample plot was collected using GPS. Thus, the quantified total carbon stock potential and the GCPs of the individual sample plot were tabulated together and changed in to Arc map compatible data. After that, the corresponding GCPs and quantified carbon stock potential of the whole sample plots were overlaid on the Arc map environment as points. Finally, using these points, carbon stock potential map of the study area was produced using spatial analysis kriging ordinary semivariogram exponential model on Arc map 10.5 software.

2.4.Results

2.4.1. Carbon stock potential of Gojjamdur community forest in 2020

2.4.1.1. Above Ground Carbon Stock Potential

Tree carbon stock potential:the averagerecordstree carbon stock Potential of the study area is 471.37 t/ha. Moreover, as Pearson et al. (2007) andCraig et al. (2010) suggest, the carbon dioxide equivalent of the carbon stock of the given site is calculated by multiplying the carbon content ratio of molecular weight of Co_2 to carbon. Accordingly, Gojjamdur community forest tree carbon content potential in carbon dioxide equivalent stores1728.36 t/ha.

Litter carbon stock potential: the average litter organic carbon stock records in the study area is 22.12 t/ha. Moreover, as Pearson et al. (2007) and Craig et al. (2010) suggest, the carbon dioxide equivalent of the carbon stock of the given site is calculated by multiplying the carbon content by the ratio of molecular weight of Co_2 to carbon. Accordingly, the forest litter carbon content potential in carbon dioxide equivalentstores81.12t/ha.

Root carbon stock potential: the forest carbon is also found in roots and thus to estimate the carbon stock of the study area none destructive (conservation) method was employed. As Santantonio et al. (1977) andMacDicken (1997) suggests, the below ground biomass (root) of a plant is close to 0.2 percent of the total above ground biomass. Accordingly, the estimated average root carbon stock in the forest is 117.84t/ha**.** Moreover, as Pearson et al. (2007) and Craig et al. (2010) suggest, the carbon dioxide equivalent of the carbon stock of the given site is calculated by multiplying the carbon content by the ratio of molecular weight of Co_2 to carbon. Accordingly, the forest root carbon content potential in carbon dioxide equivalent stores432.08t/ha.

2.4.1.2. Below ground carbon stock potential

Soil carbon stock potential: the soil organic carbon stock for depth 0-30 cm in the forest is 104.87 t/ha. Moreover, as Pearson et al. (2007) andCraig et al. (2010) suggest, the carbon dioxide equivalent of the carbon stock of the given site is calculated by multiplying the carbon content by the ratio of molecular weight of Co_2 to carbon. Accordingly, theforest soil carbon content potential in carbon dioxide equivalent stores 384.523 t/ha. Generally, the forest stocks 716.2t/ha. Similarly, the forest stocks with carbon dioxide equivalent of 2,626.07 t/ha in 2020.

2.4.2. Carbon stock potential map of the Gojjamdur community forest in 2020

The spatial carbon stock potential of the study area isunevenly distributed from place to place. Based on the result, the carbon stock potential of the study areais recorded from minimum of 109.84 t/ha and maximum of 987.81 t/ha. In addition, based on the spatial distribution of carbon stock, the most central parts of the target area are stocked minimum amount of carbon while maximum amount of carbon is stocked at the north western and north eastern centeral parts of the study area. (Figure 2).

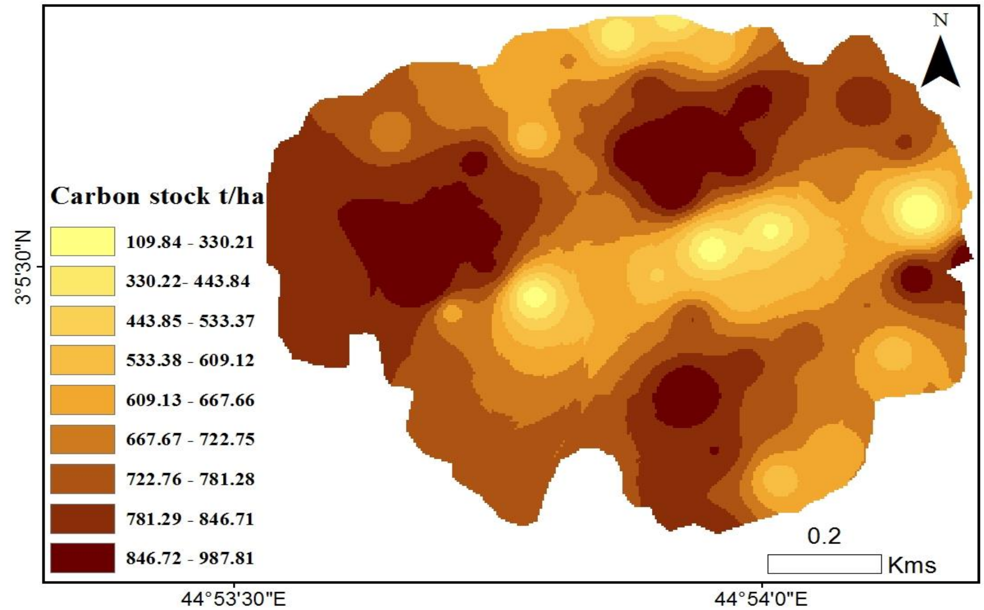

Figure 2. Carbon stock potential map of the study area for 2020

2.5. Discussions

2.5.1. Forest carbon stock assessment and mapping

The allometric models and sampling approach used may bring errors to assess carbon stock potential, and thus both may have substantial side effect on the outcomes of ground based carbon stock potential estimation (Chave et al., 2005). Locally developed and calibrated allometric equestion have the power to reduce this uncertainty in carbon stock potential estimation (Chave et al., 2005). In this study, the convenient allometric models used for analysing the carbon stock potential of the target area which are developed by Chave et al.(2014);Craig et al.(2010);Pearson et al.(2007), MacDicken(1997) andSantantonio et al.(1977). Thus, using these models, the average carbon stock potential of Gojjamdur community forest stocks 716.2 **t**/ha in 2020. This is directly agreed with the findings of Suresh and Anjana (2020), which is conducted in Sal community managed forest and the result shows that the mean vegetation carbon stock of the forest stores 175.5 Mg ha^1, which ranges from minimum of 148.5 and maximum of 202.3 Mg ha^1. In addition, the Gojjamdur community managed forest has high carbon stock potential due to it has been managing for long period of time as enclosed forest from the surrounding external influences than the community forests managed for a shorter duration (Suresh and Anjana,2020). In this regard, several previous studies have shown a similar type of carbon accumulation in community managed forests (e.g. Thapa and Shrestha, 2015; Pandey et al., 2014; Bhattarai et al., 2012; Baral et al., 2009).

In addition, according to Kibebew and Tesema (2014), a study on carbon stock assessment in pastoral PRIME target areas is conducted in Somali, Afar, and Oromia Regions reported that the mean terrestrial carbon stock in Harshin, Daketo, Mulu and Afdem grazing system are 73.924 ± 26.426, 90.203 ± 42.837,160.536 ± 31.477 and 58.622 ± 9 t ha-1 respectively. In addition, the mean value of the carbon stock for the Halydege, Dubluk, Dire, Dida Dheda, and Golba Genale grazing system are 45.628 ± 3.463, 29.519 ± 17.771, 81.697 ± 20.248, 67.687 ± 17.585, and 138.026 ± 11.350 t ha-1 respectively. Moreover, at Mollale in Gewane grazing system, the carbon source is only the soil and it is 33.43 tha-1. Similarly, the average carbon stock potential of Gojjamdur community forest stocks 716.2 **t**/ha in 2020 and it coincides with a study conducted by Kibebew and Tesema (2014). But, the carbon stock amount difference recorded between the two studies are laid on geographical, vegetation cover and climatic disparities.

Moreover, according to Abebayehu (2013), a study on evaluating organic carbon storage capacity of forest soil in Kafa Zone, Bita District, Southwestern Ethiopia, the quantity of organic carbon stores 639.64 ± 286.10 t ha^{-1}in the soil. Similarly, the average carbon stock capacity of Gojjamdur community forest stocks 716.2t/ha in 2020 and it matches with a study conducts by Abebayehu (2013). But, the carbon stock amount differences record between the two studies lays on geographical disparities.

2.6. Conclusions

Community managed forest plays an important role in climate change regulation by carbon stock potential. Also, it is one of the most effective ways of reducing forest degradation and soil erosion since it has planted in the most extreme degraded area. In addition, it is a systematic planting of trees with the aim of giving both long- and short-term benefits to local populations, and to enhance the carbon sink capacities for the environmental stability. In relation to this, the spatial carbon stock potential of the Gojjamdur community forest is unevenly distributed from place to place. Based on the result, the forest stocks an average of 716.2t/ha carbon potential with range of minimum of 109.84 t/ha and maximum of 987.81 t/ha.

2.7. Recommendations

The study shows Gojjamdurcommunity managed forest has a good sequester of carbon potential. Based on the result of the study, Gojjamdur community managed forest the following recommendations have been forwarded.

- It shall be possible and useful to do further studies about change detection analysis to detect deforestation, farmland expansion around the forest and other LULC changes within the study area.
- The carbon sequestration potential of Gojjamdur community managed forest shall be studied by locally developed specific allometric equation to increase the reliability and acceptance of the existing data on forest carbon stocks. This will contribute towards a clear understanding of the existing biomass content of the forest.
- Encouraging integration between communities and government to promote knowledge, understanding about community managed forest conservation and to find methods for rehabilitation of the degraded forests will help to increase the potentiality of forests as a carbon sink to meet the challenge of global warming.

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Conflicts of Interest

The author declares that I have no conflicts of interest

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