Role of Trees in Church compound for Carbon Emission Reduction

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ደን የአየር ለውጥን ለመከላከልና የካርበን ክምችትን ለመቀነስ ከየትኛውም ሥነ ምሕዳር ክፍል በላይ ከፍተኛ አስተዋጽዖ ያደርጋል፡፡ በቤተ ክርስቲያን ቅጥር ውስጥ የሚገኙ ደኖች በሌሎቹ የአገሪቱ ክፍል ከሚገኙ የደን ዓይነት በተሻለ ተጠብቀው እና ተንከባክበው ይገኛሉ፡፡ የዚህ ጥናት አጠቃላይ ሁኔታ የሚያተኩረው በቤተ ክርስቲያን ቅጥር ውስጥ የሚገኙ ደኖች ወደ ከባቢ አየር የሚለቀቀውን ካርበን ለመቀነስ እና የዓለም ሙቀት መጨመርን በመከላከል ዙሪያ ያላቸውን አስተዋጽዎ ለመመልከት ሲሆን፤ በዚሁ መሠረት አዲስ አበባ በሚገኙ ሰባት አድባራትና ገዳማት ላይ ይህ ጥናት ተደርጓል፡፡ በሰባቱ የጥናት ቦታዎች የሚገኙ የዛፍ ዝርያዎች ክብ መጠናቸው (Diameter at Brest height) ከ10 ሴ.ሜ በላይ የሆኑት የተካተቱ ሲሆን የእያንዳንዱ ዛፍ ክብ መጠን፣ ቁመት (height)፣ መነሻ ርዝመት (Basal height) እና የቅርንጫፎቹ ርዝመት (crown height) ተለክቷል፡፡ በዚህ ልኬት ላይ በመመርኮዝ በቆመው ዛፍ ከመሬት በላይ ባለው አካሉ (Above Ground Biomass) እና ከመሬት በታች ባለው አካሉ (below ground biomass) ውስጥ የሚገኘው ካርበን ልኬታ ተሰልቷል፡፡ በቆመው ዛፍ ከመሬት በላይ ባለው ደረቅ ክብደቱ ውስጥ ያለውን ካርበን ለማወቅ አሎሜትሪክ ሞዴል (allometric model) የተጠቀመ ሲሆን ከመሬት በታች ባለው ደረቅ ክብደት ውስጥ የሚገኘውን ካርበን ለማወቅ ከመሬት በታች እና ከመሬት በላይ ያለውን ክፍልፋይ (Below Ground to Above Biomass ratio) ተጠቅሟል፡፡ በዚሁ መሠረት የጥናቱ ውጤት የሚያሳየው ክብ መጠናቸው ከ10 ሴ.ሜ በላይ የሚሆኑ 1519 ዛፎች የተገኙ ሲሆን በነዚህ ዛፎች ከመሬት በላይና ከመሬት በታች ደረቅ ክብደታቸው ውስጥ የካርበን ልክ በአማካይ ከ129.85±154.11 እና 25.97±30.82ቶን በሄክታር ይሆናል፡፡ በተጨማሪም በአማካይ እያንዳንዱ ዛፍ 0.6±0.69 ቶን ካርበን እንደተከማቸ ለማወቅ ተችለዋል፡፡ ከዚህ ጥናት ለመረዳት እንደተቻለው የአየር ለውጥን ለመቀነስ በሚደረገው የደን ማልማትና መንከባከብ አቅጣጫ የቤተ ክርስቲያን ደኖች ወደ ከባቢ አየር የሚለቀቀውን ካርበን በመቀነስ (carbon emission reduction) እና በሚገኝበት ቦታ ብዝኃ ሕይወትን በመጠበቅ (*insitu* biodiversity conservation) ዙሪያ የጎላ አስተዋጽዎ እንደሚያደርጉ ያመለክታል፡፡

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1. Introduction and Rationale

Greenhouse gases play an important role in the earth's climate system. Greenhouse gases include water-vapor, carbon dioxide, methane, nitrous oxide, and ozone. When the concentration of green house gases in the atmosphere increases, the temperature of the earth surface is also expected to increase. The rising global surface temperature is mostly related to increased[1] carbon dioxide concentration in the atmosphere.[2]

Concern about global warming has resulted in the investigation of innovative methods that can be used for diminishing the effect of greenhouse gases.[3] Developing methods for capturing carbon dioxide is one of the primary global areas of focus in the field of study of climate change mitigation. Carbon sequestration is defined as the process or mechanism of capturing and securely storing carbon dioxide from the atmosphere. Forests play an important role in the global carbon cycle. They sequester and store more carbon than any other terrestrial ecosystems and are important natural brake on climate change.[4]

Ethiopia comprises a variety of agro-climatic zones, which have made the country a botanical treasure house, containing close to 7000 different flowering higher plants out of which about 12% are endemic.[5] The diversity of flora is mainly found in the natural forests, which once covered about 35% of the country's total land mass. However, today most of them have shrunk to an area of only 2.5% of the total land size. Under such unfavorable conditions, conserving and maintaining diversity has become a very challenging task, and so far most approaches have not brought any significant results. However, northern and central Ethiopia in the typical area a considerable cover of forests, particularly indigenous trees, is seen around churches. These patches of natural forest have survived as a result of the traditional conservation system and the protective patronage of the Ethiopian Orthodox Tewahido Church.[6]

[1] Samalca, K.I., Gier, D.L. and Ali Hussin. 2009. *Estimation of tropical forest biomass for assessment of carbon sequestration using regretion models and remote sensing.*Berua, east calimantan, indonesia. 25-34

[2] Intergovernmental Panel on Climate Change. 2001. Climate Change 2001: Working Group I: The Scientific Basis. Cambridge University Press, New York. P. 10-15

[3] Intergovernmental Panel on Climate Change . 2007. *The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change:* Edited by Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K.B, Tignor M, Miller H.L. Cambridge University Press, Cambridg Jackson, J.E.Institute of Terrestrial Ecology, Edinburgh. 545-552.

[4] Intergovernmental Panel on Climate Change. 2001. *Climate Change 2001: Working Group I: The Scientific Basis.* Cambridge University Press, New York. P.20-22

[5] Food and Agricultural Organization, 2001. *Deforestation continues at a high rate in tropical areas*: FAOcalls upon countries to fight forestcrime andcorruption (Press Release 01/61), *FAO, Rome*, http://www/fao/org/WAICEN/OIS/PRESS_NE/PRESSENG/2001/pren0161.htm. Accessed on July 26, 2010

[6] Alemayehu Wassie. 2002. Opportunities, Constraints and Prospects of the Ethiopian Orthodox Tewahido Churches in Conserving Forest Resources: The Case of Churches in South Gonder, Northern Ethiopia. P.5-10

Church and monastery forests did not come into existence by mere chance: it was by the commitment and effort of the holy fathers and mothers based on a strong theological basis and biblical principles. The Holy Bible says about Eden: "And the Lord God planted a garden east-ward in Eden; and there he put the man whom he had formed. And out of the ground made the Lord God to grow every tree that is pleasant to the sight, and good for food…And a river went out of Eden to water the Garden; and from thence it was parted, and became into four heads." (Genesis 2:8-10). Therefore, the church, signifying Eden, is beautified with many plants, animals and other organisms as well as streams, which have sprung from these forests.

As religion is one of the strongest constituting elements of indigenous institutions, and contributes to the formation of indigenous civil society. Consequently, the role of religion, needs to be taken into account and its motivational power utilized in order to effectively plan and implement sustainability initiatives. The Ethiopian Orthodox Tewahido Church can be used as an entry point into Ethiopian society to popularize and gain support for ecological programmes. The Church has the cumulative knowledge of thousands of years experiences and the wise leadership of religious leaders, in managing and conserving resources, with strong sanctions known as 'gizet' for offenders. Above all it has a strong support base and can mobilize adherents.

Improving our knowledge of sours and sinks of carbon dioxide and other green house gases, and their sspatial and temporal variability is key to understanding and predicting global climate change and to enhance human capacity to undertake mitigation and adaptation actions. In addition, examination of the contribution of the sacred forests to biodiversity conservation offers perspectives on models for environmental protection. Thus, the role of sacred sites, particularly sacred groves, is attracting increasing interests of international organizations and conservation groups such as UNESCO, WWF and the like. They have significant relevance for the implementation of section 15.4.j of Agenda 21 of the Conservation of Biological Diversity, which stresses the use of traditional wisdom and practices for conservation and sustainable use of biological diversity.[7] [8]

In terms of atmospheric carbon reduction, trees in urban areas offer double benefits by direct carbon storage and avoidance of carbon production from fossil-fuel, and reducing the effect of energy conservation on the amount of carbon released into the atmosphere.[9] However, the role of sacred forests and urban forests for climate change mitigation and adaptation is not well studied in Ethiopia. In additon, the United Nation's Reducing Emissions from Deforestation and Forest Degradation (UN-REDD) works with nine member countries across Africa, Asia and Latin America, but Ethiopia has not been included in the programme due to lack of adequate scientific work in this area. Even if the EOTC is a strong institution protecting many forests, and has a tradition of natural resource conservation, no research has been done to estimate the carbon sequestration capacity and the benefit from the carbon trade market.

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[7] Chandrashekara, U.M. and Sankar S, 1998. *Ecology and management of sacred groves in Kerala, India*: Forest Ecology and Management. Vol 112, Issues 1-2: p. 165-177.

[8] Agenda 21. 1992. *Programme of Action for Sustainable Developmen:* Rio Declaration on Environment and Development Statement of Forest Principles; UNCED, Rio de Janeiro, Brazil. P.118-124

[9] Nowak, D.J.1993. Journal of Environmental Management 37, 207-217 Atmospheric Carbon Reduction by Urban Trees Usda Forest Service, Northeastern Forest Experiment Station, 5801 N. Pulaski Ra, Bldg C., Chicago, Illinois 60646, U.S. P.207-2016

Thus, it is of paramount importance to take into account church forests in the National Climate Change Adaptation and Mitigation Program and carbon trade fund. In view of this, this study will looked into how trees are being tradtionally conserved by the EOTC, which has been successful in resisting deforestation for many decades in certain parts of the country, and to address their role in sequestering carbon dioxide. Despite what the EOTC has done to conserve a significant proportion of the forests in the country, the Church has not received the appropriate recognition and support it deserves. Therefore, the aim of this study is to quantify the amount of carbon sequestered in the selected church forests and to explore possibilities of using them in the future for attracting funds.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in the city of Addis Ababa, Ethiopia. The city receives an annual average rainfall of about 1150 mm. The mean monthly temperature is 16.25^0c. The study sites are mostly found in the north of Addis Ababa due to the existence of some very old churches in that area.

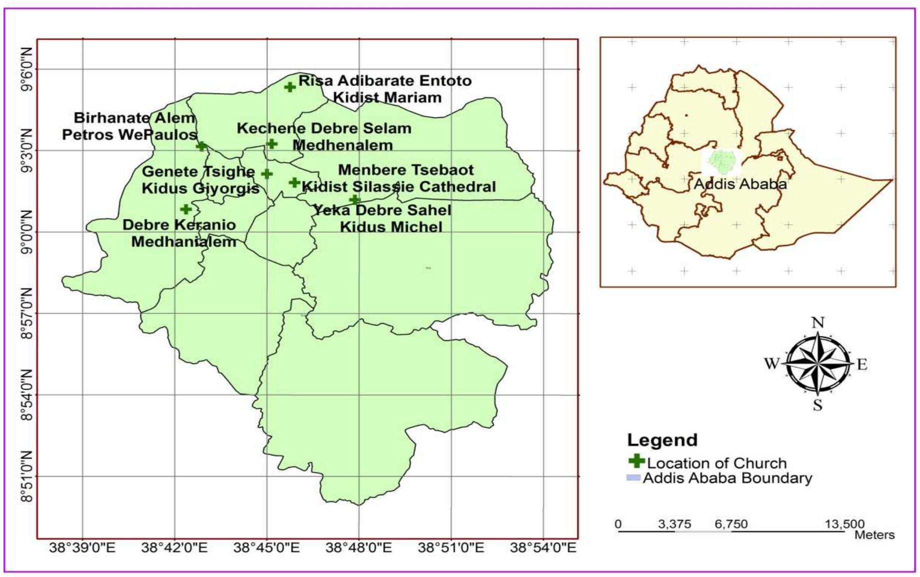

Fig 1. Map of the study area

Table 1. Year of establishment of the church, altitude, area of forest, and location of the study sites

Churches selected for study	Year of establish-ment	Alt (m)	Area (ha)	Location
Birhanate Alem Petros Wo Pawulos	1901	2538	0.126	$9^0$02'N and $38^0$42'E
Genete Tsige Kidus Giyorgis	1903	2473	0.765	$9^0$02'N and $38^0$45'E
Debre Keraniyo Medihanalem	1826	2381	0.209	$9^0$00' N and $38^0$42'E
Re'ese Adbarat Entoto Kidist Mariam	1370	2984	0.082	$9^0$05'N and $38^0$45'E
Kechene Debre Selam Medhanalem	1903	2451	0.631	$9^0$02'N and $38^0$44'E
Menbere Tsebaot Kidist Silasse Katederal	1924	2468	1.815	$9^0$01'N and $38^0$46'E
Yeka Debre Sahil Kidus Michael	1919	2408	0.086	$9^0$15'N and $38^0$47'E

From the aerial view, the churchyards are usually circular in shape. Churches are immediately surrounded by open spaces for worship and festivals, which in turn are enveloped by forests. In all churches, the graveyard is located at the southwestern side of the church. Hence, the southwestern part of the church typically has fewer trees than the rest of the church compound.

2.2. Sampling Design and Data Collection Methods

The sampling procedure for the forest survey was categorised in two stages. In the first stage 15 churches were selected from the 150 churches in Addis Ababa. This was done systematically from different sub-cities mainly based on altitude difference and their year of establishment. In the second stage 7 churches were selected from 15 churches depending on the types and number of trees they contained.

2.3. Estimation of Carbon in Above-Ground Biomass

The estimations of above and below-ground carbon depend on the above-ground biomass of living tree species. To estimate the above ground biomass, all tree species within the selected churches having Diameter at Breast Height (DBH) $\geq$ 10 cm were identified and recorded. Plant identification was done in the field by using the Flora of Ethiopia and Eritrea: volume 2,[10] [11] part 1 and part 2, and *Flora of Ethiopia*, volume 3,[12] as well as *Useful trees and shrubs for Ethiopia.*[13] For those species which were difficult to identify in the field, fresh specimens were collected and then pressed properly for identification at the National Herbarium of Addis Ababa University.

[10] Edwards, S., Mesfin Tadesse. and Hedberg, I. 1995. *Flora of Ethiopia and Eritrea:* volume 2, part 2. Addis Ababa, Ethiopia and Uppsala, Sweden.

[11] Edwards, S., Mesfin Tadesse., Sebsebe Demissew. and Hedberg, I. 2000. *Flora of Ethiop and Eritrea, 1st edn, Volume 2, Part 1*: Addis Ababa, Ethiopia and Uppsala, Sweden.

[12] Hedberg, I. and Edwards, S. 1989. *Flora of ethiopia*: volume 3. Addis Ababa and Asmara, Ethiopia and Uppsala, Sweden.

[13] Azene Bekele. 1993.*Useful Trees and Shrubs for Ethiopia*: Identification, Propagation and Management for Agricultural and Pastoral Communities. RSCU/SIDA.

The Diameter (at 1.3 m above the ground unless there is an abnormality) of all living trees (woody plants) was measured using diameter tape. A tree with multiple stems at 1.3 m height was treated as a single individual, and the DBH of the largest stem was taken. A canker, gall or branch tree at 1.3 m was measured at the smallest point below it where the stem assumes near cylindrical shape. A tree with multiple stems or fork below 1.3 m height was treated as a single individual. Trees on a slope area were measured on the uphill side, while the heights, crown height and basal height of all tree species were measured using a Haga hypsometer in a position where it was possible to observe the tip of the trees. Shapes of the crowns were determined by physical observation of the standing trees.

2.4. Determination of Basal Area (BA)

The basal area was calculated of all trees with a diameter at breast height greater than10 cm by using the formula:

$$BA = 0.785\ DBH^2$$ [14]

Where, DBH is the diameter of the trees at breast height.
Average tree diameter and height were calculated.

2.5. Estimation of Carbon in Above and Below-Ground Biomass

Biomass is defined as the total amount of live and inert organic matter above and below-ground, expressed in tons of dry matter per unit area. The above-ground and below- ground biomass of all tree species in the selected churches was estimated. For above -ground biomass estimation, different mathematical equations have been developed and used by many researchers.[15 16] These equations are species-specific, particularly in the tropics. The general equation has been developed in a modified form. It is more general in nature and applicable at field level. [17 18 19]Some of these equations are life-zone dependent, while others are not specified down.

It is not possible to cut down the trees to estimate their biomass. Concerning the mathematical terms, the models were developed by the FAO[20], Luckman, Negi and Brown. [21]

The model developed by Brown and his coworkers to estimate above-ground biomass was used in the present investigation due to its accuracy, compatibility with the life zone of the study and the life zone recommended for the equation.

[14] Yetebitu Mogus., Zewdu Eshetu. and Sisay Nune. 2010. *Manual for assessment and monitoring of carbon in forest and other land uses in Ethiopia (Draft).*

[15] Brown, S.A.J., Gillespie, J.R. & Lugo, A.E. 1989. *Biomass estimation methods for tropical forests with application to forest inventory data. For. Sci., vol.*35.p.881–902

[16] Negi, J .D.S., Manh, R.K. and Chauhan, P .S. 1988. *Carbon al location in different components of some tree species of India*: A new approach for Carbon estimation, *Current Science*, vol.85.p.193-205

[17] Alves, D.S., Soares, J.V.S., Amaral, E.M.K., Mello, S.A.S, Almeida, O., Fernandes, S. and Silveira A.M.1997. *Biomass of primary and secondary vegetation in Rondonia,western Brazilian Amazon*.Global change Biology,vol. 3. P.451-462.

[18] Brown, S. 1997. *Estimating biomass and biomass change of tropical forests, a primer*. FAO Forestry paper 134, FAO, Rome

[19] Schroeder, P., B r o w n, S., B i r d s e y, J.M.R. and Cieszewski, C. 1997. *Biomass estimation fo temperate broadleaf forests of the US using inventory data*. *Forest Science*, vol.43. P. 424−434.

[20] Food and Agricultural Organization. 1997. *Estimating biomass and biomass change of tropical forests*: a primer, Rome, Italy: FAO Forestry

[21] Luckman, A.; Baker, J.; Mora, T.; Corina da Costa F. and Frery, C.A.1997. *A study of the relationship between radar backscatter and regeneration tropical forest biomass for spaceborne SAR instruments. Rem Sen Env, vol.*60. P.1-13.

This method is nondestructive and therefore, the most suitable method. The equation used in this investigation is as follows:

$$Y= 34.4703 - 8.0671(DBH) + 0.6589(DBH^2)$$

Where Y = the above-ground biomass,
DBH= basal area

Then, below ground biomass (BGB) = Above-Ground Biomass (AGB) × 0.2
Finally, the carbon in the biomass was estimated by multiplying it with 0.47, while carbon was converted to carbon dioxide by multiplying it with 3.67.

3. Results and Discussion

3.1. Existing Forest Conditions

In the seven studied churches a total of 22 different tree species were recorded which had a DBH greater than 10 cm., *Menbere Tsebaot Kidist Silasse Katederal*and *Re'ese Adbarat Entoto Kidist Mariam* have the largest and smallest area, respectively, namely 1.815 ha and 0.082 ha. On average, the area of the study site covered by forest is 0.531 ha (Table 1).The total number of species in each site ranged from 3 at *Re'ese Adbarat Entoto Kidist Mariam* to 18 of *Menbere Tsebaot Kidist Silasse Katederal* (Table 2). In terms of tree density and diameter at breast height (DBH) greater than 10 cm, *Menbere Tsebaot Kidist Silasse Katederal* ranked first (442 individuals/ha) and *Re'ese Adbarat Entoto Kidist Mariam* ranked last (75 individuals /ha) (Table 2). *Juniperus procera* has the highest density (884 individuals in all study sites) while *Pinus radiata, Spathophi nilotica,* and *Araucaria jussieu* have the lowest density (2 individuals). Density of trees per hectare for *Genete Tsige Kidus Giyorgis* is virtually similar to that of the Munessa-Shashemene state forest (306 individual / ha). The rest differs from the results of various studies reported from different parts of the country.

Table 2. Number of species per church, total density (individuals /ha), in the seven churches.

Churches	Species	Density individuals/ha
Birhanate Alem Petros Wo Pawulos	4	136
Genete Tsige Kidus Giyorgis	11	340
Debre Keraniyo Medihanalem	18	442
Re'ese Adbarat Entoto Kidist Mariam	8	136
Kechene Debre Selam Medhanalem	3	75
Menbere Tsebaot Kidist Silasse Katederal	10	153
Yeka Debre Sahil Kidus Michael	10	237

Juniperus procera and *Oleal africana* were commonly recorded in all study sites. However, species diversity decreased with the increasing age of churches. On the other hand, the number of indigenous tree_species increased with increasing age of churches. Churches built before the 19^{th} century, such as *Re'ese Adbarat Entoto Kidist Mariam* and *Debre Keraniyo Medihanalem*, have fewer species, and are specially dominated by *Juniperus procera a*nd *Olea africana* (Table 2).

The minimum mean height of 10m was recorded from *Phoenix reclinata* and *Euphorbia abyssinica*, while the maximum mean height of 33.67 m was recorded from *Eucalyptus saligna*. The mean minimum DBH of 15 cm was recorded from *Callistemon citrinus*, whereas the mean maximum DBH of 70.93 cm, was recorded from *Acacia abyssinica* (Table 3.).

Table 3. Density, Mean height and diameter of tree species

Species	Tree density (No / ha)	Height (m)	DBH (cm)
Juniperus procera	884	23.58	47.70
Olea africana	291	15.50	38.50
Millittia ferruginea	3	17.67	36.87
Cordia africana	8	18.75	46.38
Cupressus lusitanica	25	11.28	16.70
Dracaena Steudneri	42	11.57	29.13
Eucalyptus Saligna	88	33.67	58.59
Pinus radiata	2	16.00	23.50
Acacia melanoxylon	18	16.44	25.71
Casuarina cunninghamiana	26	18.35	38.05
Allophlus abyssinica	11	10.73	24.71
Phoenix reclinata	12	10.00	19.50
Dalbergia melanoxylon	8	18.13	60.29
Croton marostachyus	27	18.30	48.59
Spathodia nilotica	2	13.00	30.75
Euphorbia abyssinica	6	10.00	29.58
Araucaria jussieu	2	11.00	25.50
Callistemon citrinus	9	14.67	15.00
Ficus sur	22	16.59	44.48
Erythrina brucei	3	13.33	24.93
Acacia abyssinica	4	12.50	70.93
Grevillea robusta	26	21.23	51.62
Total	1519		

As shown in figure 1, most of the trees fall in the 40 - 50 diameter class intervals which comprise 22.71%.

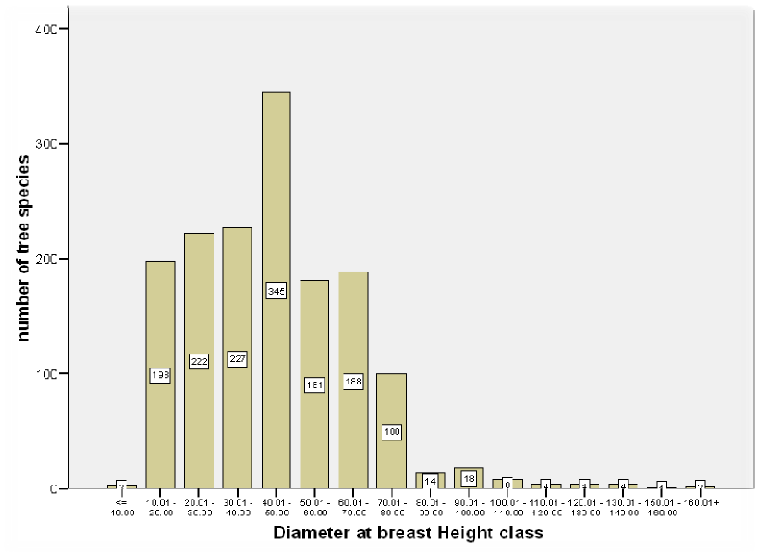

Fig 1. Diameter size distribution of species

3.2. Biomass

The minimum Above-Ground Biomass (AGB) was 42.61 t ha^{-1} at *Re'ese Adbarat Entoto Kidist Mariam* , while the maximum AGB is 944.99 t ha^{-1} at *Menbere Tsebaot Kidist Silasse Katederal* . The average biomass per hectare in the study sites was 276.289 t (Table 4).The minimum biomass per hectare is similar to the result recorded in different forest types in Nepal (38.70 t/ha), and the above ground-biomass per hectare recorded in *Menbere Tsebaot Kidist Silasse Katederal* and *Genete Tsige Kidus Giyorgis* are comparatively similar to the Munessa-Shashemene forest in site II (754.3 t/ha) and site I (403t/ha) respectively, while the average biomass is differed from the data which is cited by the IPCC for a tropical dry forest (130 t/ha).[22]

Results from different forests and different tree species in Ethiopia show that as the age of the tree increases, basal area and biomass also increase.[23] [24] The result in the study sites differed from other studies in the literature, and this may be due to very old trees on the site.

According to different literature, above-ground biomass in tropical dry and wet forests ranges between 30-273 t ha^{-1} and 213-1173 t ha^{-1}, respectively.[25] Above-ground biomass in Amazonian Brazil forests ranged between 290- 495 t ha^{-1}.[26]

[22] Saatchi, S. S., Houghton, R. A. Dos Santos Alvala, R. C., Soares, J. V. and Y.u. Y.. *Distribution of above ground live biomass in the Amazon Basin Glob. Change Biol.* 13 (2007). p. 5

[23] Nagash Mamo, Berhane Habte and Dawit Beyan.1995. *Growth and form factor of some indigenous and exotic tree species in Ethiopia. Forestry research center ministry of natural resources development and environmental protection, Ethiopia.*

[24] Nagash Mamo.2007.*Growth and yield estimation of the stand of Cupressus lustanica.Techinical manual 17.Ethiopian institute of Agricultural research.*

[25] Murphy, P.G. and Lugo, A.E. 1986b. Structure and biomass production of a dry tropical forest in Puerto Rico. *Biotropica*, vol. 18. p. 89-96.

[26] Alves, D.S., Soares, J.V.S., Amaral, E.M.K., Mello, S.A.S, Almeida, O., Fernandes, S. and Silveira A.M. 1997. *Biomass of primary and secondary vegetation in Rondonia,western Brazilian Amazon*. Global change Biology, vol. 3.p. 451-462.

Similarly, the above-ground biomass reported in the present study (42.61–944.99 t ha^{-1}) is within the range reported for various tropical dry and moist forests, mixed and old growth forests, and evergreen moist tropical forests (Bandhu et al., 1973, Huttel and Bernhard-Reversat, 1975, Huttel 1975, Kira, 1978, all cited in Brown and Lugo 1982; Brown, 1997). Moreover, the average above-ground biomass in the present study forest site (276.289 t ha^{-1}) is two-fold higher than the previous estimates (about 101 t ha^{-1}) of plant biomass for forests of Ethiopia. On the other hand, above ground biomass in tropical and subtropical forests in Puerto Rico ranged between 80 - 190 t ha^{-1}. Although the central and eastern afromantane forest in Ethiopia is generally characterized by distinct climate seasonality, plant biomass production in the forest is closely similar to that of (moist/ wet) rainforests in tropical Asian and Latin American countries.[27]

Table 4. AGB, Below-Ground Biomass (BGB), carbon in AGB and carbon in BGB (t ha^{-1})

Name of church	AGB t ha^{-1}	Carbon in AGB	BGB t ha^{-1}	Carbon in BGB t ha^{-1}
Birhanate Alem Petros Wo Pawulos	65.82	30.94	13.16	6.19
Genete Tsige Kidus Giyorgis	397.96	51.25	79.59	37.41
Menbere Tsebaot Kidist Silasse Katederal	944.99	187.04	189.00	88.83
Debre Keraniyo Medihanalem	109.04	154.46	21.81	10.25
Re'ese Adbarat Entoto Kidist Mariam	42.61	444.15	8.52	4.01
Yeka Debre Sahil Kidus Michael	44.96	20.03	8.99	4.23
Kechene Debre Selam Medhanalem	328.65	21.13	65.73	30.88
Average	276.29	129.86	55.26	25.97

Below-Ground Biomass also showed the same trend as the above-ground biomass. The minimum BGB was found in *Re'ese Adbarat Entoto Kidist Mariam* , and the maximum BGB in *Menbere Tsebaot Kidist Silasse Katederal*, their values being 8.52 and 189.00 tons, respectively (Table 4).

3.3. Carbon in the Above-Ground Biomass

The minimum and maximum carbon per tree was 0.01 and 7.53 tons for *Juniprus procera* and *Grevillea robusta* respectively. The mean carbon per tree was 0.60 tons (SD= 0.69). The maximum carbon per hectar was 444.15 tons, found at *Menbere Tsebaot Kidist Silasse Katederal*, and the minimum carbon was 20.03 t ha^{-1} at *Re'ese Adbarat Entoto Kidist Mariam* (Table 4). The average carbon in the above-ground biomass was 129.86 t ha^{-1}. The overall summations of above ground carbon in the sites were 908.99 tons.

[27] Brown, S. 1997. *Estimating biomass and biomass change of tropical forests, a primer.* FAO Forestry paper 134, FAO, Rome

The trend of carbon dioxide in the Above-Ground Biomass is the same as for carbon. The minimum carbon dioxide per tree was 0.03 while the maximum was 27.61 tons. The average carbon dioxide per tree was 2.19 tons with a standard deviation of 2.51 which indicates large trees sequestered more carbon dioxide than small trees. The sequestering capacity difference between large and small tree makes large standard deviation from mean. The total carbon dioxide sequestered in the above ground biomass pool was 3332.98 tons.

3.4. Carbon in the Below-Ground Biomass

The minimum and maximum carbon per tree in the below-ground biomass ground is 0.003 and 1.51 tons, respectively. The mean carbon in the below-ground biomass per tree was 0.12 tons with a standard deviation of 0.14. The minimum and maximum carbon per hectare in the below-ground biomass was 4.02 and 88.83 tons, respectively. The mean carbon in the below-ground biomass ground is 25.97 t ha^{-1} with a standard deviation of 3.82.

In Ethiopia, there was inadequate data on the estimated carbon sequestration level of forests before this study. For instance, the Humbo project is the only one which attempted such an exercise, yet it estimated the sequestration potential of a thirteen year old forest[28]. According to Brown (1997), Above-Ground Biomass carbon stock is 47 tha^{-1} for tropical dry forest, and 36 tha^{-1} for Sub- Saharan African countries. According to an IPCC (2006) [29] assessment, 126 tha^{-1} was reported for tropical dry forest, and 72 tha^{-1} for open Sub-Saharan African countries.[30] Houghton (1999) recorded 55 tha^{-1} carbon for tropical dry forests and 30 tha^{-1} carbon for an open forest in Sub-Saharan African countries. The recorded carbon stock in the above-ground biomass in most literature ranges between 30–126 tha^{-1} carbon for tropical dry forest life zone, which receives on annual rain fall between 900–1500 mm. The result recorded in *Birhanate Alem Petros Wo Pawulos* is similar to the result recorded by Houghton (1999) for Sub-Sahara Africa open forests while the result recorded in *Debre Keraniyo Medihanalem* is similar to the result recorded by Houghton (1999) for tropical dry forest. The results recorded in four of the study sites fall within the range recorded for tropical dry forest while the results of the other three study sites fell within the range recommended for tropical moist and wet forest life zones receiving an annual rain fall greater than 1500 mm. Carbon in Below-Ground Biomass shows the same trends as the above ground biomass.

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[28] The World Bank, 2011. Humbo Ethiopia Assisted Natural Regeneration Project. CCB - VALIDATION REPORT Report No. GR10W0016D (14 February, 2011). JACO CDM., LTD

[29] Intergovernmental Panel on Climate Change. 2006. *Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories.* Prepared by the National Greenhouse Gas Inventories Programme.Edited by Eggleston H. S, Buendia L, Miwa K, Ngara T, and Tanabe K (Japan: Institute For Global Environmental Strategies). P.205-218

[30] Houghton, R. A.1999. The annual net flux of carbon to the atmosphere from changes in land use 1850–1990 *Tellus* B **51** 298–13

4 **Conclusions**

The number of individual trees per hectare conserved by the seven studied churches are comparable with trees per hectare in the other forests in the country which shows the church's contribution for forest conservation. But the carbon sequestered in this forest is higher than most other forests in the country due to the age of the trees and relatively good management. This indicates that the contribution of the church forest around Addis Ababa for carbon sequestration and urban climate regulation is very significant. The carbon sequestration difference between indigenous and exotic tree species found in the same age category is also significant. The carbon sequestration difference in the DBH classes does not depend much on altitude and year of establishment. In theory, altitude and age of trees affect carbon sequestration. But in this study, altitude and age of trees did not significantly affect carbon sequestration. However, tree density and the area occupied by forests affects the carbon amount sequestered in each study site. The church forests studied are potentially suitable for carbon marketing. Considering these forests for climate change mitigation and fund attraction is a win-win situation in the climate change mitigation programs. Intensifying such indigenous practices and knowledge for biodiversity conservation, climate change mitigation and urban greening options is very important.

5 **Recommendations**

Based on the conclusions drown above the following recommendations are forwarded.

- This study could serve as spring board for further documentation of the role of the EOTC in climate change mitigation and adaptation.
- Ethiopia has more than 35,000 churches and monasteries, so conducting similar studies is recommended.
- Research about the carbon sequestration potential of certain forests and forest types in the country have not been conducted. Therefore, it would be appropriate to recommend similar studies in similar or other forest types through out the country.
- To sustain forests in the study site, requires awareness creation among church scholars and those in authority and more incentives including environmental awards for the Church and financial support for the environmental services the Church forests are providing.
- Considering churches and other sacred places for *in-situ* biodiversity conservation is very important.
- In urban areas like Addis Ababa, which lack sufficient green areas, treating Church forests as urban greening projects may be a good option.

Appendices

Appendix 1. Tree species, number of trees in each study site, minimum/ maximum/ mean height/ DBH and standard deviation

Study site

Study site	species		N	Min	Max	Mean	Std.
V	*Juniperus procera*	Height	183	10	36	26.98	5.85
		DBH	183	10.5	105	49.514	16.79
	Olea europaea	Height	17	6	34	15	6.38
		DBH	17	14	72	29.29	14.36
	Millettia ferruginea	Height	1	17	17	17	.
		DBH	1	28	28	28	.
	Dracaena steudneri	Height	2	7	11	9	2.83
		DBH	2	15.6	20	17.8	3.11
	Eucalyptus saligna	Height	21	32	44	38	3.95
		DBH	21	42	67	53.09	7.24
	Pinus radiata	Height	1	13	13	13	.
		DBH	1	13	13	13	.
	Acacia melanoxylon	Height	4	15	20	16.5	2.38
		DBH	4	11	34	18.75	10.63
	Euphorbia abyssinica	Height	4	7	9	8	0.82
		DBH	4	19	24	22	2.16
	Ficus sur	Height	1	18	18	18	.
		DBH	1	27	27	27	.
	Acacia abyssinica	Height	3	12	12	12	0
		DBH	3	29	55	39.67	13.61

Study site	species		N	Min	Max	Mean	Std.
VII	*Juniperus procera*	Height	69	10	35	23.12	4.69
		DBH	69	10.5	84.4	48.51	15.59
	Olea europaea	Height	21	10	21	16.95	2.85
		DBH	21	14.5	63	42.55	14.26
	Cordia africana	Height	6	17	19	17.67	0.82
		DBH	6	32	64	44	11.51
	Eucalyptus saligna	Height	34	32	35	33.23	0.85
		DBH	34	42	64	55.35	9.01
	Acacia melanoxylon	Height	2	11	12	11.5	0.70
		DBH	2	12	22.7	17.35	7.57
	Allophlus abyssinica	Height	8	6	13	10	2.62
		DBH	8	13	39.5	23.15	10.31
	Dalbergia melanoxylon	Height	1	24	24	24	.
		DBH	1	160	160	160	.
	Ficus sur	Height	7	11	20	17.14	2.91
		DBH	7	25	93	60.86	25.41
	Erythrina brucei	Height	3	13	14	13.33	0.58
		DBH	3	23	27.8	24.93	2.53
	Grevillea robusta	Height	2	10	13	11.5	2.12
		DBH	2	15	15.5	15.25	0.35

Study site	species		N	Min	Max	Mean	Std.
IV	*Juniperus procera*	Height	65	6	33	22.45	6.29
		DBH	65	10	132	66.36	23.69
	Olea europaea	Height	2	8	8	8	0
		DBH	2	13	26	19.5	9.19
	Eucalyptus saligna	Height	8	27	42	35.12	5.72
		DBH	8	36	132	71.62	37.25
III	*Juniperus procera*	Height	64	9	32	19.84	5.70
		DBH	64	10	94	38.24	16.90
	Olea europaea	Height	50	6	26	17.36	3.66
		DBH	50	15	162	56.48	26.17
	Millettia ferruginea	Height	1	20	20	20	.
		DBH	1	49	49	49	.
	Dracaena steudneri	Height	1	12	12	12	.
		DBH	1	20	20	20	.
	Eucalyptus saligna	Height	1	27	27	27	.
		DBH	1	46	46	46	.
	Acacia melanoxylon	Height	4	16	17	16.5	0.58
		DBH	4	13	18	16	2.16
	Casuarina cunninghamiana	Height	1	17	17	17	.
		DBH	1	32.5	32.5	32.5	.
	Ficus sur	Height	14	8	29	16.21	6.15
		DBH	14	12	55	37.5	11.23
VI	*Juniperus procera*	Height	182	7	33	23.88	6.10
		DBH	182	11.5	97	45.64	16.21
	Olea europaea	Height	119	6	27	15.29	4.49
		DBH	119	12	117	33.98	19.47

Study site	species		N	Min	Max	Mean	Std.
	Cupressus lusitanica	Height	10	8	17	12.7	2.67
		DBH	10	10	25	15.95	3.87
	Dracaena steudneri	Height	11	4	40	13.54	11.42
		DBH	11	12	76	25.63	19.39
	Eucalyptus saligna	Height	16	20	35	30.69	4.67
		DBH	16	18.5	68	52.53	18.78
	Casuarina cunninghamiana	Height	22	8	30	18.68	6.64
		DBH	22	12	68	39.25	16.28
	Allophlus abyssinica	Height	2	13	13	13	0
		DBH	2	28	36	32	5.66
	Phoenix reclinata	Height	9	6	10	9.33	1.41
		DBH	9	13	30	18	5.45
	Dalbergia melanoxylon	Height	4	11	21	17.75	4.57
		DBH	4	16	60	37.25	18.02
	Croton macrostachyus	Height	27	7	37	18.29	5.96
		DBH	27	22.5	92	48.59	19.82
	Spathodea nilotica	Height	2	12	14	13	1.41
		DBH	2	16.5	45	30.75	20.15
	Euphorbia abyssinica	Height	2	11	17	14	4.24
		DBH	2	41.5	48	44.75	4.60
	Araucaria jussieu	Height	2	10	12	11	1.41
		DBH	2	23	28	25.5	3.53
	Callistemon citrinus	Height	9	10	19	14.67	3.08
		DBH	9	12	17	15	1.73
	Acacia abyssinica	Height	1	14	14	14	.
		DBH	1	162	162	162	.

Study site	species		N	Min	Max	Mean	Std.
	Grevillea robusta	Height	24	9	32	22.04	6.32
		DBH	24	15	91	54.65	20.57
II	*Juniperus procera*	Height	189	4	33	21.26	8.03
		DBH	189	10.5	134	47.70	22.86
	Olea europaea	Height	81	4	27	14.50	4.94
		DBH	81	12	76	35.50	12.73
	Cupressus lusitanica	Height	15	4	20	10.33	5.07
		DBH	15	11	28.5	17.2	5.74
	Dracaena steudneri	Height	28	4	18	10.96	3.62
		DBH	28	12	64	31.63	14.61
	Eucalyptus saligna	Height	8	19	44	30.5	7.35
		DBH	8	30	136	87.44	38.82
	Pinus radiata	Height	1	19	19	19	.
		DBH	1	34	34	34	.
	Acacia melanoxylon	Height	8	9	23	17.62	4.56
		DBH	8	12	52.5	36.12	13.57
	Casuarin cunninghamiana	Height	3	16	17	16.33	0.58
		DBH	3	28	33.5	31.1	2.82
	Allophlus abyssinica	Height	1	12	12	12	.
		DBH	1	22.6	22.6	22.6	.
	Phoenix reclinata	Height	3	10	15	12	2.64
		DBH	3	19.5	29	24	4.77
	Dalbergia melanoxylon	Height	3	11	23	16.67	6.03
		DBH	3	15.8	126	57.77	59.61

Study site	species		N	Min	Max	Mean	Std.
I	*Juniperus procera*	Height	132	9.33	34.67	24.40	6.70
		DBH	132	13	81	42.98	14.70
	Olea europaea	Height	1	20	20	20	.
		DBH	1	28.5	28.5	28.5	.
	Millettia ferruginea	Height	1	16	16	16	.
		DBH	1	33.6	33.6	33.6	.
	Cordia africana	Height	2	19	25	22	4.24
		DBH	2	52	55	53.5	2.12

Notes to Contributors

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