Role of Urban Forests for Carbon Emission Reduction in Addis Ababa:A review

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Abstract
Urban forests improve the microclimate and air quality. The objective of this review was to appraise research findings and to summarize the most important literatures on the role of urban forests for carbon emission reduction in Addis Ababa. Total number of identified papers were 11 that studied carbon sequestration potential of urban forests in Addis Ababa and of this church forests (three), public parks (four), botanical garden (one), Mountain forest (Three) and KMU compound included in the review of this paper. The selected research papers used similar allometric equations to calculate carbon stock of the different carbon pools. The mean carbon in the above ground and below ground biomass were 110.84 ± 46.33 t ha^{-1} and 21.68 ± 9.31 t ha^{-1} respectively. The mean carbon in dead litter and soil carbon were 6.33±5.72 t ha^{-1} and 121.02 ± 48 t ha^{-1} respectively. The variations observed in carbon stocks in the different urban forest types relate to area, density and size of trees available in each site. Urban trees reduce atmospheric carbon dioxide (CO_2) through sequestration which is important for climate change mitigation, they are also important for recreational, medicinal value and aesthetic and biodiversity conservation.

Keywords: Carbon sequestration, Climate change, Urban forests, Addis Ababa
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Introduction

Urban forests can play an important role in mitigating the impacts of climate change by reducing atmospheric carbon dioxide (Liu & Li, 2012). More than half of the world's population lives in urban Areas. More than half of Africa and Asia's population will live in towns and cities by 2050 (Nowak et al., 2013). Urbanization is estimated to result in 6 billion urban dwellers by 2050. Cities will be exposed to climate change from greenhouse gas induced radiative forcing, and localized effects from urbanization such as the urban heat island (McCarthy, Best, & Betts, 2010). One of the pressing issues in today's world is carbon dioxide emissions and climate change. Carbon dioxide is one of the more abundant greenhouse gases and primary cause for global warming. It constitutes 72% of total anthropogenic greenhouse gases, causing between 9-26% of the greenhouse effect (Surya, Senthivelu, kumar, & Nagendran, 2020).

Addis Ababa, the capital and the most populated city of Ethiopia a rapid and unplanned expansion and commercial development, along with population pressure is deteriorating the city environment with time. The ever growing populations, utilization of fuel wood and charcoal as bio fuel have been contributing to green spaces depletion in Addis Ababa (Gezahegne, 2014).

Urban forests in Addis Ababa are affected by various factors such as encroachment, illegal cuttings, weak law of enforcement and planting of improper species (Eyob, 2010). In addition the urban forests of Addis Ababa which are considered as the lungs of the city have been affected by anthropogenic activities, mostly by tree cutting for construction and fuel wood and settlement, resulting in a reduced species composition and diversity (Fetene & Worku, 2013). The city faced challenges from flooding, threats to human comfort and environmental injustice (Dubbale, Tsutsumi, & Michael, 2010).

A little over 5000 ha of land is covered by urban forest in Addis Ababa. The forests are mostly dominated by species of *Eucalyptus* and found on the mountains in the northern part of the city (Woldegerima, Yeshitela, & Lindley, 2017a). Urban forests improve the microclimate and air quality. Urban forests are increasingly important due to their role in sequestrating and storing carbon and thus helping to meet climate mitigation goals (Strohbach, Arnold, & Haase, 2012). Social benefits of forests include health, employment, education and recreation, community building and property value improvement (Kuchelmeister, 2000).

Though they are small in number and fragmented, several studies have been investigated on carbon sequestration of urban forest (Public parks, church forests and botanical gardens) in Addis Ababa. For instance, different studies showed that urban forests in Addis Ababa have a significant contribution in carbon emission reduction (Abiyu, Soromessa, & Belliethathan, 2013; Habtamu & Argaw, 2019; Marshet & Teshome, 2015) and have different ecosystem services (Woldegerima, Yeshitela, & Lindley, 2017b) mitigating urban heat island effect (Gudina, Dons, & Meilby, 2014; Teferi & Abraha, 2017) and sequestering and storing of Carbon (Habtamu & Argaw, 2019).

The review on role of urban forest for carbon emission reduction in Addis Ababa is required for to summarize the researchs conducted on carbon sequestration potential appraising research findings and to support polices on restoration of urban green space.

Objectives

The general objective of this review paper is to estimate the carbon stock potential of urban forests by summarizing the most important literatures on the role of urban forests for carbon emission reduction in Addis Ababa.

Materials and Methods

Description of the study area

This review paper focused on urban forests of Addis Ababa which include Public parks, Church forests, and mountain forests from all sub-cities of the city.

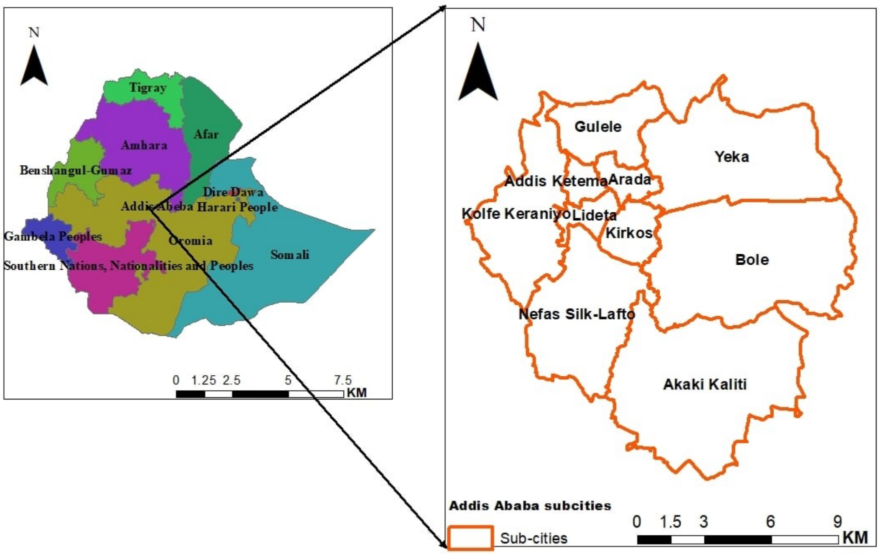

Fig1: Map of study areas

Review question and protocol

The review attempts to answer the following question.

- What is the contribution of urban forest in sequestering carbon in Addis Ababa?

In order to achieve the aim of the review paper on the role of urban forests for carbon emission reduction in Addis Ababa, 11 research papers conducted in Addis Ababa were used.

Search strategy

Researches of potential interest were identified by creating a comprehensive search algorithm. The first step was defining key terms by reviewing the final verified title and this was in turn, used to choose appropriate databases. Terms were then combined in relevant categories using Boolean logic operators ("OR" and "AND"). The search procedure was tested by the chosen database: ScienceDirect and literatures were identified using internet-wide search engines (Google and Google Scholar). The search was done from November 10 to 30, 2020. For each of the key words, substituting synonyms were also tested to check for any missed relevant reports. For inclusion and exclusion of articles in this review, the following four criteria were set and implemented.

- The report/article must be original research article,
- Each study must have evaluated carbon stock estimation of urban forest
- Each study area must be in Addis Ababa.
- The study time period should be from 2010-2020.

Urban forest carbon storage estimation
The Allometric equation used in all selected research papers is similar. This equation (Table 1) is applied for dry tropical forests where mean annual rainfall is below 1500mm (MacDicken, 1997). Addis Ababa is classified under dry zone which is receiving annual rain fall between 900 to 1500 mm (Table 1).

Results and Discussion
The selected research papers are original research paper conducted in Addis Ababa forests on the role of urban forests for carbon sequestration. Total number of identified papers are 11 and of this church forests (three), public parks (three), botanical garden (one), Mountain forest (Three) and KMU compound included in the review of this paper. List of the selected research papers with their total area and number of sites is shown on table 2 below.

Above and below ground carbon
A total of 34 sites were studied in church forests with total area of 71.22 ha, 14 public parks with total of area of 64.74 ha, three mountain forests with area of 11,873.42 ha and a botanical garden of 936 ha and a study from Kotebe metropolitan university area of 5.42 ha that represents urban forests of Addis Ababa. These areas are different in terms of their total area, year of establishment and forest conditions.

From the selected urban forests highest AGC was recorded in church forests with 132.92 t ha^{-1}, followed by Botanical garden 102.63 t ha^{-1}. The lowest AGC and BGC were recorded in KMU 75.57 t ha^{-1} and 15.04 t ha^{-1} as shown on figure 1. The mean AGC 110.84 t ha^{-1} is higher than the values recorded in Chilimo forests (90.25 t ha^{-1}) and Sekele- Mariam forest (37.54 t ha^{-1}). The mean above ground carbon stock of urban forests is lower as compared with other natural forests (Bazezew, Soromessa, & Bayable, 2015; Girma, Soromessa, & Bekele, 2014; Teshager, Argaw, & Eshete, 2018; Yohannes, Soromessa, & Argaw, 2015).

Below ground Carbon followed the same trend as the above ground Carbon. The minimum BGC was in one of the public park (Marshet & Teshome, 2015) and maximum BGB was in Entoto forest (Getnet & Teshome, 2015) and their values were 5.1 and 34.4 t ha^{-1} respectively. The variations observed in carbon stocks in the different urban forest types relate to area, density and size of trees available in each site (Yilma & Derero, 2020). The factors affecting carbon stock distribution might be management in the particular site, available place or area for planting new tree, infrastructures, purpose of the areas and human interference [16] and year of establishment's as age of tree increase biomass also increase (Mamo, 2007) . The AGC and BGC of each selected urban forests is shown on table 3.

According to (Brown, 1997) above ground carbon stock are 47 t ha^{-1} for tropical dry forest and 36 t ha^{-1} for sub-Sahara Africa country while IPCC (IPCC, 2006) assessment, 126 t ha^{-1} was reported for tropical dry forest and 72 t ha^{-1} for open sub-Sahara Africa country and also (Murphy & Lugo, 1986) estimates for tropical dry forests that range between 30 and 273 t ha^{-1}. Generally, all literatures recorded carbon stock in the above ground biomass for tropical dry forest which receiving annual rain fall between 900–1500 mm were ranged between 30–126 t ha^{-1} carbon stock. The mean above-ground biomass of these urban forests 110.84 t ha^{-1} is in the range of recommended for tropical dry forest. Addis Ababa city receives annual mean rainfall of about 1128 mm. This makes the city classified under dry zone which are receiving annual rain fall between 900 to 1500 mm (Habtamu & Argaw, 2019).

The average carbon density of 110.84 t ha^{-1} of the urban forest of Addis Ababa is three times higher than the 33.22 t ha^{-1} average carbon density recorded from the urban forest of Shenyang, China (Liu & Li, 2012). This indicates that the urban forests of Addis Ababa have the potential to sequester substantial amount of carbon and contribute to climate change mitigation.

Soil organic carbon
Soils hold the largest carbon stock in terrestrial ecosystems (Assefa et al., 2017). From the selected research papers only eight of them measured SOC. In the study sites in 0.30 cm depth mineral soils 223.56 t ha^{-1} maximum and 92.23 t ha^{-1} minimum value carbon stocks were recorded in Gulele botanical garden and public park forests respectively (Figure 2 and Table 4). In some of the selected studies soil organic carbon was not studied (Entoto forest, KMU and Church forest) which might hinder to know the estimated figures of urban SOC. The carbon content of the soil in the parks was very complicated. It was difficult to find untouched soil because most soils come from another place to increase the park soil fertility which means it was a disturbed soil (Tsegaye, 2015). Generally studies indicate that mean carbon captured in the soil pool was relatively greater than the other pools.

Soil stores 2 or 3 times more carbon than that which exists in the atmosphere as CO_2 and 2.5 to 3.0 times as much as that stored in plants in the terrestrial ecosystem Houghton et al., (1996) cited in (Getnet & Teshome, 2015). The average value of soil organic carbon in urban forests 121.02 t ha^{-1} is similar with the natural forest of 121.28 t ha^{-1} in Menagasha Forest (Sahile, 2011), higher than Zequalla Monastery forests of 57.62 t ha^{-1} (Girma et al., 2014) and relatively comparable with 158 t ha^{-1} in the high elevation forested areas of the Taita Hills in south-eastern Kenya (Omoro, Starr, & Pellikka, 2013).

This value is also much smaller than the values of other natural forest in Ethiopia. For example Danaba community forest 186.4 t ha^{-1} (Bazezew et al., 2015) Gedeo Forest 183.69 t ha^{-1} (Yohannes et al., 2015) and Sekele-Mariam forest 138.79 t ha^{-1} (Mekonnen & Tolera, 2019). As reported in (Luke, 2018) cited in (Mekonnen & Tolera, 2019), the average soil organic carbon in Ethiopia ranges from 94 to 133 ton/ha, urban forests SOC is in the range of this value. A difference in SOC among studies related to differences in tree species, soil nutrient availability, climate, topography and disturbance regime as distribution of carbon stocks in forests is known to vary with these factors (Aregu, 2015). Soil carbon stocks are influenced by factors such as climate, geology and weathering history, and biotic variables such as species composition and density (Fernandez et al., 2013) cited in (Assefa et al., 2017). SOC and LC of each study sites are shown on the following table below.

Litter Carbon

From the selected research papers only eight of them measured litter carbon (LC). The maximum 18.64 t ha^{-1} and 5.23 t ha^{-1} minimum litter carbons were recorded in Gulele botanical garden and in church forests respectively (Table 4 and Figure 2). The minimum litter carbon was 1.15 t ha -1 in study of selected urban parks (Tsegaye, 2015).

The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density), climate and relatively fast decomposition rate in the tropics (Binkley & Fisher, 2013). In most parks dead litter was not accessible since it is collected for fuel purpose and also considered as waste which decrease the beauty of the park (Habtamu & Argaw, 2019). The average carbon stock in litter biomass of urban forest was 6.33 t ha^{-1} which ranges from 1.15 to 18.64 t ha^{-1}.

The mean dead litter value of urban forest is higher than the values cited in (IPCC, 2006) while carbon in dead litter pool was 2.1t ha^{-1} for tropical dry forests and 49 t ha^{-1} for moist boreal broad leaf forests. It is also in the range of tropical and sub-tropical forests in Puerto Rico that ranged between 3.1-8.61 t ha^{-1} (Weaver & Murphy, 1990). In a related study, dead litter fall ranged between 4.88- 6.71 t ha^{-1} in a dry forest in India (Singh & Singh, 1991) and between 3-10 t ha^{-1} for a variety of dry tropical forests (Murphy & Lugo, 1986).

The LC content found in urban forest was also relatively greater than the values recorded in some other studies conducted in Ethiopia. For instance the average carbon stock in the litter biomass was 3.4 t ha^{-1} in Egdu Forest (Feyissa, Soromessa, & Argaw, 2013), 0.9 t ha^{-1} in Tara Gedam Forest (Gedefaw & Soromessa, 2014) and 0.019 t ha^{-1} in forests of Semien Mountain National Park (Simegn, Soromessa, & Bayable, 2014). As shown on graph 2 there is variation of LC in different urban forests. Highest LC was shown on botanical gardens and the lowest was recorded in church forests. The litter quantity and quality varies with tree species, forest types and age (Lorenz & Lal, 2009). The lowest carbon stock in litter pool could due to small amount of litter fall (Feyissa et al., 2013). According to this study the carbon in the dead litter plays a significant role in the contribution of carbon emission reduction in urban forests.

Statistical summary of the different Carbon pools

The minimum 25.4 t ha^{-1} and maximum 172 t ha^{-1} AGC was recorded in selected Public Park and Entoto forest respectively. Urban forests were providing environmental service by sinking mean 110.84 ± 46.33 t ha^{-1} carbon in the above ground biomass. In the study site 5.10 t ha $^{-1}$ minimum and 34.40 t ha^{-1} maximum carbon stocks in the BGC were recorded with 21.68 ± 9.31 t ha^{-1} mean carbon stock (Table 5). Trees in addition to the above ground biomass significant amount of carbon stock were captured in their roots.

The highest carbon stock was found in soil pool. The maximum SOC 223.56 t ha^{-1} and minimum 69.2 t ha^{-1} were recorded in Gulele Botanical garden and public parks respectively. This shown urban forests captured 121.02 ± 48.91t ha^{-1} mean carbon stock which is higher than the other carbon pools. Estimating litter biomass in urban areas is a challenge since it is collected for fuel (Tsegaye, 2015). From the selected studies 1.15 t ha^{-1} minimum and 18.64 t ha^{-1} maximum carbon stocks in dead litter were recorded in Public Park and Gulele botanical garden respectively while mean carbon stock in dead litter was 6.33 ± 5.72 t ha^{-1}. The average stock sequestered in the above ground biomass was 110.84 t ha^{-1}. This shown significance of urban forests for climate change mitigation role in addition to other ecosystem services.

Conclusion

This review paper confirms that urban forests in Addis Ababa have significant role for carbon emission reduction and climate change mitigation by storing total Carbon of 262.33 t ha^{-1}. The largest carbon stock was found in the soil organic carbon 121.02 t ha-1 followed by the aboveground biomass of 110.84 t ha^{-1}. Urban forests have a potential to decrease the rate of atmospheric concentration of carbon dioxide. In addition they are also important for medicinal value, recreational and aesthetic and biodiversity conservation.

Differences in policy and institutions in the different age categories could have contributions to the difference observed patterns in urban forests. Attention has to be given on the conservation of the urban forests to enhance the carbon sequestration capacity so as to mitigate climate change. Furthermore Urban forests are a potential candidate for in-situ conservation sites for indigenous tree species. The practice of managing and conserving urban forests should be scaled up as the integral components in urban greening.

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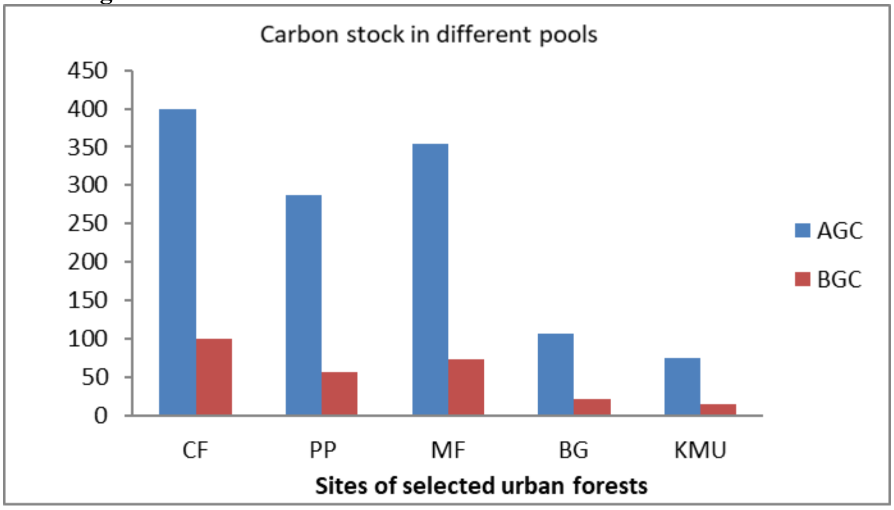

Figure 1 AGC and BGC of selected urban forest sites (CF= church forests, PP= Public parks, MF= Mountain forests, BG= botanical garden KMU= Kotebe Metropolitan university)

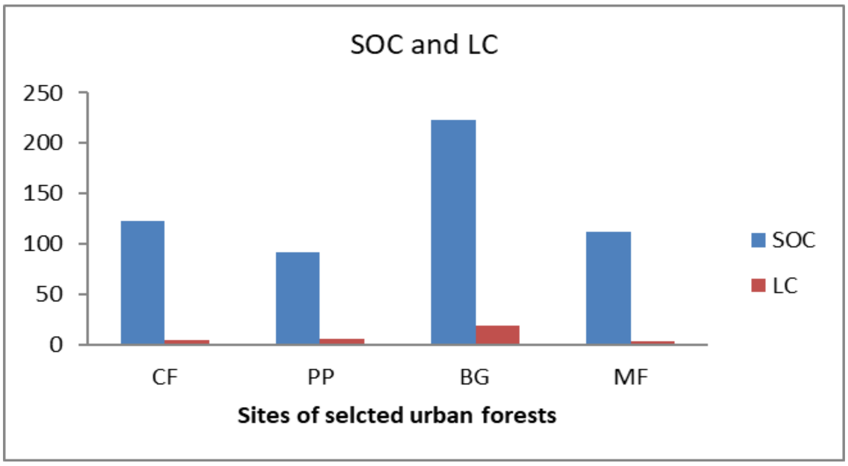

Figure 2 SOC and LC of selected urban forest sites

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Table 1: Commonly used allometric equations for measuring different carbon pools in the selected

No	Carbon pools	Basic formula	Reference
1	AGB	Y= 34.4703 - 8.0671(DBH) + 0.6589(DBH^2)	(Brown et al.,1989)
2	BGB	BGB = AGB*0.2	(MacDicken, 1997)
3	SOC	SOC = BD * D* % C	(Pearson et al., 2005)
4	CL	CL = LB * % C	(Pearson et al., 2005)

Table 2. List of selected papers

No	Study site	No of study sites	Total Area (ha)	Reference
1	Church forests	7	37.14	(Tura, Argaw, & Eshetu, 2013)
2	Church forests	10	23.49	(Abiyu et al., 2013)
3	Church forests	17	10.59	(Yilma & Derero, 2020)
4	Public parks	2	24.82	(Marshet & Teshome, 2015)
5	Public parks	4	16.6	(Tsegaye, 2015)
6	Public parks	8	23.32	(Habtamu & Argaw, 2019)
7	Botanical garden	1	936	(Agonafir & Worku, 2017)
8	Yeka forest	1	5.42	(Getnet & Teshome, 2015)
9	Yerer forest	1	6000	(Aregu, 2015)
10	Entoto forest	1	5868	(Woldegerima et al., 2017b)
11	KMU	1	5.4	(Habtamu et al., 2020)

Table 3 : AGC and BGC of selected study sites

No	Site	AGC (t ha^{-1})	BGC (t ha^{-1})	Reference
1	Church forests	129.86	25.97	(Tura et al., 2013)
2	Church forests	112.9	17.82	(Abiyu et al., 2013)
3	Church forests	156	31.2	(Yilma & Derero, 2020)
4	Public parks	25.4	5.1	(Marshet & Teshome, 2015)
5	Public parks	118.74	23.75	(Tsegaye, 2015)
6	Public parks	143.3	28.1	(Habtamu & Argaw, 2019)
7	Botanical garden	102.63	20.53	(Agonafir & Worku, 2017)
8	Yeka forest	42.26	8.43	(Getnet & Teshome, 2015)
9	Yerer forest	140.6	28.12	(Aregu, 2015)
10	Entoto forest	102.7	34.4	(Woldegerima et al., 2017b)
11	KMU	75.57	15.11	(Meseret, 2020)
	Average	**110.84**	**21.68**	

Table 4. SOC and LC of selected sites

No	Site	SOC(t ha^{-1})	LC(t ha^{-1})	Reference
1	Church forest	135.94	4.95	(Tura et al., 2013)
2	Church forest	108.9	3.282	(Abiyu et al., 2013)
3	Church forests	-	-	(Yilma & Derero, 2020)
4	Public parks	113.55	5.17	(Marshet & Teshome, 2015)
5	Public parks	93.93	1.15	(Tsegaye, 2015)
6	Public parks	69.2	10.5	(Meseret & Mekuria, 2019)
7	Botanical garden	223.56	18.64	(Agonafir & Worku, 2017)
8	Yeka forest	144.75	2.01	(Getnet & Teshome, 2015)
9	Yerer forest	78.33	4.97	(Aregu, 2015)
10	Entoto	**-**	**-**	(Woldegerima et al., 2017b)
11	KMU	**-**	**-**	(Habtamu et al., 2020)
	Average	**121.02**	**6.33**	

Table 5. Statistical summary of the different carbon pools

	N	Minimum	Maximum	Mean	Std. deviation
AGC	11	25.40	172	110.84	46.327
BGC	11	5.10	34.40	21.68	9.314
SOC	8	69.20	223.56	121.02	48.908
LC	8	1.15	18.64	6.33	5.717

Statements and declarations

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Conflict of Interest

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