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Research Article

Woody Species Diversity and Biomass Carbon Sequestration in Private Residential Green Infrastructure of Dilla Town, Southern Ethiopia

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Urban forests have an important role in biodiversity conservation, environmental improvement, and ecosystem services including climate change mitigation enhancement. The objectives of the current study were to: assess plant types and management strategies of the owners; woody species' composition, structure, and diversity; and estimate aboveground biomass of trees and associated carbon stock in private residential green infrastructure (PRGI) at Dilla town. This study was conducted at three kebeles, the lowest administrative unit in Ethiopia. Ninety-four households were randomly selected from a proportional sample size for each kebele. A complete inventory of woody species was done after measuring the area occupied by plants at each household. At plot level, the aboveground biomass of sampled trees was calculated by using an allometric biomass equation developed for agroforestry species. Diversity was described by using different indices The free software EstimateS 9.1.0 was used to generate data for the construction of sample-based rarefaction curves and SPSS version 20 for descriptive statistics. Based on plant types and arrangement, the households manage their PRGI in 15 categories on area size, ranging from 10 m^2 to 1229 m^2, with an average holding size of 207.5 m^2. A total of 66 plant species belonging to 45 families were identified. Overall, a total of 1220 stem ha^{-1} contributed to an aboveground carbon stock of 64.35 ton ha^{-1} of which 50.4% is from fruit trees and the rest from timber trees. The results suggest that PRGIs can serve as reservoirs of non-native and native plant species, including five native tree species currently facing conservation concerns.

1. Introduction

Urban forests are significantly important in enhancing food security, energy availability, better health, and ameliorating air pollution, high humidity, and high temperature in the urban atmosphere [1, 2]. Urban forests can be managed in the form of green belts, woodlots, parks, home gardens, street trees, and private or public residential areas. Private residential green infrastructures (PRGI) are managed for multidimensional benefits [1] while traditionally urban home gardens are managed mainly for security and subsistence [3, 4]. Empirical evidence from different parts of the globe indicate that the owners of PRGI manage diverse plants with different combinations and arrangements for food, fodder, medicinal value, income supplementation, ornamentals [4–6], and for soil fertility improvement and better cooling effect of trees with high canopy [7–11]. In some cases, fruit trees, when managed by female households as reported, can dominate PRGIs: for Northern Thailand [12]; for Accra [13]; in Ethiopia. For Arba Minchi town; [4] and for Jimma town [14]. Evidence on area size allocation for both home gardens and PRGIs are variable. In Ethiopia, urban home gardens' area size ranges from 220 to 1235 m^2 at Arba Minch town [4] and from 300 to 1200 m^2 at Sebeta town [5]. For tropical home gardens in rural areas [15] reported sizes ranged from 0.01–4.00 ha. The greater the proportion of green space within the urban matrix, the lower the surface and air temperatures [16].

Urban forests and trees are the vital components of urban biodiversity and play a great role in carbon sequestration. Urban green spaces provide diverse urban ecosystem services such as climate change adaptation and mitigation, nutrient cycling, soil and water conservation, pollination, food and nutrient availability, habitat improvement, and resilience which are often associated with species diversity [2, 13, 17]. Different authors have reported the contribution of urban home gardens/PRGI to plant biodiversity conservation. For example, there are 1166 plant species in Sheffield, UK [6]; 186 plant species in São Luís city, Maranhão State, Brazil [7]; 94 woody species in Accra, Ghana [12]; and 62 plant species in Ekiti State, Nigeria [3]. Evidence from urban centers in Ethiopia conserves: 258 plant species in Hawassa [11], 138 plant species in Sabata [5], 72 plant species in Mekelle [10], 70 woody species in Abra Minch [4], 86 woody species for Adama [18]. For tropical home gardens, [15] reported the existence of 135 plant species. Contrary to these reports, a slightly lower number of woody species (40) was reported for Jimma town [14]; 37 tree species in Port Harcourt city and 46 tree species in Ilorin city urban forest in Nigeria [19].

The potential ecosystem services of PRGIs include reduction of atmospheric carbon dioxide through carbon sequestration [20]. The extent of such a benefit depends on management and environmental conditions that influence tree growth. Growing environment in urban areas and management employed can create differences in tree architecture as a result allometric equations used for secondary forests underestimated biomass carbon of street tree while tropical forest allometric equations overestimate their biomass carbon stocks [21]. Due to such limitations, allometric equations developed for agroforestry by [22] may better predict the above-ground biomass of tropical trees in urban centers. Due to the narrow area coverage of the study, allometric equations developed [23] for urban tree biomass estimation in Pachaiyappa's College, Chennai, India, may not be good estimators of urban tree biomass in Ethiopia. The differences in tree abundance in diameter classes are attributable to differences in aboveground biomass values. For example, [19] reported an average carbon density of 7.82 tons/ha for Ilorin urban forest, Nigeria; [24] reported a total carbon storage of 26.15 kg m^{-2} for residential green spaces; [19] also reported an average carbon density of 136.15 tons/ha for urban forest in Port Harcourt; [25] reported higher biomass carbon (150 tons ha^{-1}) values for urban park and garden studied in Nagpur, India; [26] reported a higher value of 383.67 tons/ha carbon stocks in green spaces of botanical garden green space in Myanmar.

Private residential urban green infrastructure provides a multifunctional benefit for urban people. Among the significant contributions, environmental, economic, and social benefits to urban dwellers have been reported by different authors. In Ethiopia, studies on the environment's role in enhancing values to city health in Addis Ababa by [27]; cooling effect at Hawassa, Sodo, and Bodity by [26]; and at Hawassa and Bahir Dar by [29]. Similarly, the biodiversity conservation role of PRGIs has been reported for Arbamich [4], Sebeta [5], Hawassa [11], Mekelle [10] and Jimma [14]. The economic role including food and income diversity is reported by [10, 11, 29]; increases in tax revenue in Hawassa and Bahir Dar by [29]. Sociocultural benefits include better recreation in Bodity town as reported by [28]; in Hawassa and Bahir Dar by [29]; in Mekelle by [10]; and in spiritual by [10].

From the review made by Lyn-Kristin Hosek [1], it is clear that there are limited studies in the urban center of Africa. The above-mentioned evidence from different part of the world and local studies indicate the existence of wide variation with respect to management strategies, extent of plant biodiversity, and carbon sequestration contributions. The potential of PRGI for biodiversity conservation and carbon sequestration depends on the type of ecological settings and management strategies of the owners such as area sizes, preferences, and purposes. In addition, the general trend in the loss of and threat to plant biodiversity in urban centers of Ethiopia is different and the extent was not documented for Dilla town. The present study aimed to (i) describe major plant types and management strategy of the PRGIs by the owners; (ii) assess potential of PRGI for conserving woody species diversity and structure; and (iii) estimate aboveground biomass of trees and associated carbon stock at Dilla town.

2. Materials and Methods

2.1. Description of the Study Area. Geographically the Dilla town is located in 6°24′30″N Latitude and 38°18′30″E Longitude at an altitude of 1,613 m and at a distance of 359 km from Addis Ababa (Figure 1). The town covers 1123.47 hectares of land which lies in the eastern escarpment of the Ethiopian rift valley. Dilla is the administrative and major trade center of the Gedeo zone, having a total population of 84,952 with a density of 8004 persons/km^2 [30]. The area receives an annual maximum, medium, and minimum rainfall of 1400, 1150, and 900 mm, respectively. The mean maximum and minimum daily temperature is 25.40 and 13.40 degree centigrade, respectively [31].

2.2. Sampling Technique and Data Collection

2.2.1. Sampling Technique. Dilla town has nine kebeles, the lowest administrative unit in Ethiopia, administered under three subtowns (Table 1). For the present study, three kebeles, namely a Haroresa, Bereda, and Woldena were purposively selected for having a relatively higher proportion of residential compounds and population number. Residential compounds in Dilla are variable and some of them qualify as of home gardens. In this study, PRGIs included home gardens with trees.

In the present study, the sample size of households (HHs) was calculated by using approach of [32].

$$n = \frac{N}{\left(1 + N(e)^2\right)}, \tag{1}$$

where n = is household number or number of PRGI used for data collection; N = is total number of population (1715) practicing PRGIs in the three selected kebeles; and e = is level of precision (by using 90% confidence interval the value of

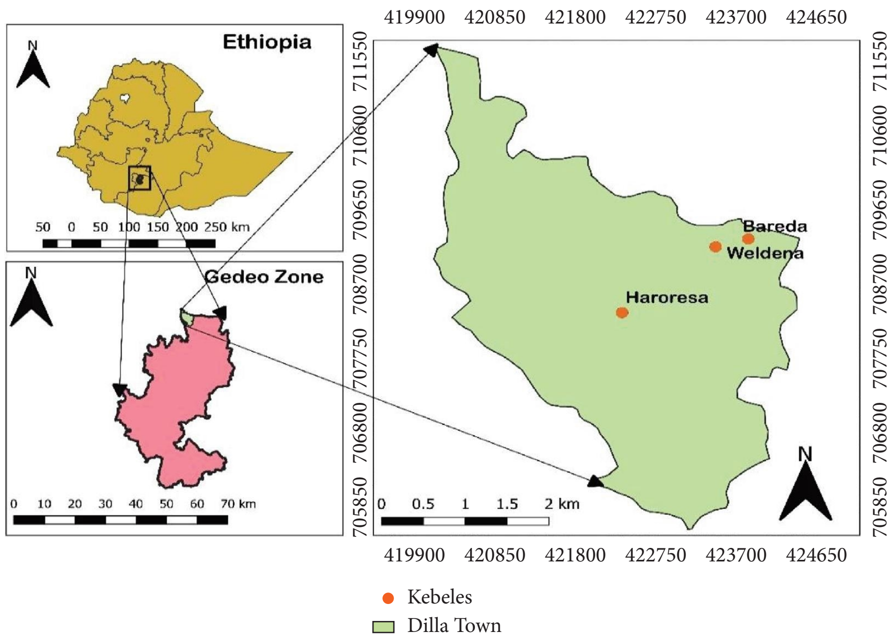

Figure 1: Map of dilla town showing the three sampled kebeles (Bereda, Weldena, and Haroresa), Ethiopia.

Table 1: Name of subtowns and nine kebeles, number of residential compounds in Dilla town.

Name of subtown	Name of kebele	No of residential compound		Total population in the kebele
		Total compounds	With PRGI	
Harowallabu	Haroresa	1271	954	15000
	Buno	914	503	Missing
	Hasedela	701	421	16179
Sessa	Bereda	1031	516	7065
	Odayaa	966	464	Missing
	Haroke	661	411	6554
Badacha	Woldena	408	245	5012
	Boeti	548	274	5204
	Harsu	366	275	6229
	Total	6836	4063	

Source. Dilla town kebele administration and urban agriculture offices.

"e" become 0.1). This formula gives 94 households (HH) in the three kebeles which was used as a sample size for data collection. Because of different number of population sizes in the three selected kebeles, equal proportional sample size was determined to distribute 94 households proportionally in the three kebeles by using the following formula:

$$N_h = n * \frac{N_h}{N}, \tag{2}$$

where n is total decided sample size from the three kebeles (94); N_{h} is number of HHs practicing PRGIs in one particular Kebele, which was 954, 516 and 245 for three of them; N is total number of HHs in the three kebeles practicing PRGIs (1715); and n_{h} is proportional sample number of HHs in a single Kebele. Based on this calculation, the proportional number of HHs from the three kebeles was determined as 15 (6.12%) households for Woldena, 28 (5.42%) for Bereda and 51 (5.35%) for Haroresa. Then, the sample households were randomly selected at each kebele.

2.2.2. Data Collection. Information on socioeconomic benefits and management employed for PRGI was collected from the households. In addition, during woody inventory, an area occupied by individual PRGI at a sampled household was measured with the guidance of the owner using a meter taper. The area size of individual PRGI holdings was found to be variable. The diameter at breast height of forked shrubs or trees was measured above the point of intersection and they were considered as a single tree. A woody plant with multiple stems or forks below 1.3 m height was treated as a single individual. All tree species with DBH ≥5 cm at 1.3 m height above the ground were measured on each plot of a sampled household and a complete count took place in the presence of the respective owner. Nonwoody species such as Enset, vegetables, tuber crops, and herbs (which are commonly used for food, medication, and spices) were recorded but not counted and used for biomass estimation. With respect to plant species identification, we identified all trees and shrubs based on our experience in local woody species taxonomy. For some herbaceous which were difficult to identify by researchers, we asked the owners to give local names. Then we identified by crosschecking the name and the description in flora of Ethiopia and Eritrea, volume two to volume seven, Eritrea [33, 34].

2.3. Data Analysis

2.3.1. Area Size and Their Classification. The household manages their PRGI by classifying them into eight categories, for which the number of species and stem number were estimated. The mean area size in m^2 of the PRGIs at three kebeles was also estimated. In addition, the strategies of 94 households in managing plant types and numbers and their uses were described.

2.3.2. Species Diversity

(1) Shannon Index Of Diversity. The Shannon index of diversity quantifies the uncertainty in the species identity of a randomly chosen individual in the assemblage [35]. It is estimated to provide a much more balanced estimate of diversity considering species abundance and is estimated as follows:

$$H' = -\sum_{i=1}^{s} pi \ln (pi). \tag{3}$$

(2) Simpson's Index Of Evenness. The reciprocal of Simpson's index ($1/D$) is always equal to the number of species observed in the sample [36]. This leads to a simple definition of Simpson's index of evenness and calculated as follows:

$$E_{1/D} = \frac{1/D}{S}, \tag{4}$$

where $E_{1/D}$ = Simpson's measure of evenness, $1/D$ = Simpson's index, S = number of species in the sample.

This index ranges from 0 to 1 and is relatively unaffected by the rare species in the sample.

2.3.3. Structure

(1) Abundance. It is defined as the measure of the number of individuals of the same species. The abundance values for each species encountered were calculated at all sample areas and their mean values at the three kebeles were estimated.

(2) Stem Density. It was defined as the ratio of the total number of individuals of each species recorded in all the sampled areas to the total number of plots. It is also defined as an expression of the numerical strength of the species. In addition, the distribution of stem numbers in six diameter classes was estimated.

(3) Frequency. Defined as the number of sampled areas in which the species occurs to the total number of sampled areas.

(4) Basal Area. To calculate the important value index, the basal area (BA) of all trees of a given species or of all trees in the sampled areas was estimated using the DBH values as:

$$\mathrm{BA} = \sum \pi \left(\frac{\mathrm{DBH}}{2}\right)^2. \tag{5}$$

(5) Important Value Index. It was calculated using the percentage of relative abundance (RA) + relative dominance (RD) + relative frequency (RF) as:

$$\begin{aligned} \mathrm{RA} &= \frac{\text{The number of in dividuals of species}}{\text{The total number of individu als of all species}} \times 100, \\ \mathrm{RD} &= \frac{\text{Basal area of individual species}}{\text{The total basal area of all species}} \times 100, \\ \mathrm{RF} &= \frac{\text{The frequency of species}}{\text{The total frequency of all species}} \times 100. \end{aligned} \tag{6}$$

2.3.4. Aboveground Biomass Carbon Stocks. Above ground biomass carbon stocks for each plot (Mg C ha^{-1}) were calculated as the product of dry matter biomass and carbon content. Tree aboveground biomass was calculated using the plot inventory data and allometric biomass equation developed by [22].

$$\mathrm{AGB} = 0.225 \times d^{2:341} \times p^{0.73}; R^2 = 098; n = 72, \tag{7}$$

where AGB is the aboveground biomass (kg dry matter/plant) and d is breast height diameter (cm) and ρ is species wood density (g cm^{-3}).

This equation was developed for trees and shrubs with a DBH greater than 2.5 cm grown in agroforestry land uses in tropical countries. For the reason that we measured trees with greater than 5 cm DBH, it is expected that there is an underestimation of biomass values. This equation can be used in areas having similar environmental conditions, mean annual rainfall ranging from 1028 to 1950 mm, and mean annual temperature ranging from 16.67 to 21.9°C. Having an average annual rainfall of 1331 mm and temperature of 21°C, the Dilla town feature is within the range of the required conditions to use this equation. The Global Wood Density database was used for sourcing the wood density of species [37].

$$\begin{aligned} &\text{Abovegroun d carbon stock per tree (kg)} \\ &\quad = \text{Biomass of trees (kg)} * 0.48. \end{aligned} \tag{8}$$

Carbon stock in each PRGI = summation of carbon stock of tree species in each PRGI.

$$\text{Total carbon stocks of the sample PRGI}\left(\text{kg}\cdot\text{ha}^{-1}\right)=\frac{\text{Summation of carbon stocks of each PRGIs}}{\text{area of each compoun d}\left(\text{m}^{2}\right)}*10,000\text{m}^{2},$$

$$\text{Carbon stock of the sample area}\left(\text{ton ha}^{-1}\right)=\frac{\text{total carbon stock of the sample area (kg/ha)}}{1000},\tag{9}$$

$$\text{Above groun d carbon stock in CO}_2\text{ equivalent}=\text{carbon stock}\left(\text{ton}\cdot\text{ha}^{-1}\right)\times\frac{44}{12}.$$

2.4. Statistical Analysis. The Statistical Package for the Social Sciences, SPSS-20 version, was used to analyze socioeconomic characteristic of households, area size, plant arrangements, plant functions, woody species, and structural diversity. The species–area relationship has been used to predict the numbers of species. Species richness increases with sample size, although the correlation shows a weak effect between area sizes and species diversity. To solve this problem, a rarefaction technique was used to rarefy species richness to the same number of individuals. It also needs to be emphasized that sampling robustness is essential for accurate representation of species richness patterns, and hence it is important to determine whether or not sampling effort was enough [38]. The sampling bias arises as a consequence of less and/or uneven sampling effort across the study kebeles which is helped to overcome through the use of sample and individual-based rarefaction [39].

In this study, the sample-based species accumulation curves and individual based rarefaction curves were calculated for plant species that make direct comparisons amongst communities on the basis of number of individuals in the smallest sample clearly show adequacy of sampling. Hence, conclusions drawn about private residential green infrastructure species diversity during the present study could be considered as robust. The free software EstimateS 9.1.0 [40] was used to generate data for the construction of sample-based rarefaction curves and individual-based rarefaction for species richness after rescaling the *x*-axis to individuals (39). Again, a sample-based species accumulation curve was constructed using the Vegan package in *R*. The vegan package provides tools for community ecology and basic functions for diversity analysis" in the *R* software program language. After the rarefaction, unbalanced one-way ANOVA analysis was used to separate mean differences using Tukey's HSD comparison test.

3. Results

3.1. Socioeconomic Characteristics of the Respondents. The households' settings in different socio-economic situations affect the management of tree/shrub species and their diversity in a given PRGI landholdings. The respondents are characterized as 37% males and 63% females (Table 2). Over 90 percent of the respondents were within the range of 14–54 years old. With regard to education level, most of the respondents (60%) were educated and completed at levels from grade nine to MSc. About 70% of the respondents' family size was in the range of 3–6 members. Employment was the principal occupation for about 51% of the respondents while trading activities were for 35% of the respondents.

3.2. Plant Arrangement, Management, and Landholding. The respondent households have different strategies to attain their objectives. Based on plant species types and arrangement in all PRGIs at the three Kebeles, 15 management categories can be identified (Table 3). Overall, about 25 percent ($N = 94$) of the PRGIs consist of more than six plant types, and all PRGIs contained fruit tree, coffee, and trees/shrubs indicating that the management strategy of the respondents is focused on woody species. At Woldena Kebele, the strategy seems to produce a higher proportion of shrubs (e.g., coffee).

With respect to land landholding allocation to PRGI at kebele level, detailed information is presented in Tables 4 and 5. An area occupied by plants in surveyed PRGI ranged from 10 m^2 to 1229 m^2 with average holding size of 207.5 m^2. Comparatively Woldena kebele has greater average PRGI area size, followed by Bareda (Table 4). The larger value at Woldena kebele is associated with its age being the oldest neighborhood part of the town where private owners got opportunity to hold larger land size, at the time of establishment of the Dilla town.

Of the total sampled area (1.7505 ha) about 84% of the area was represented by less than 300 m^2 category (Table 5). From 2552 stems in three Kebele, over 71 percent were from 79 PRGIs. The woody species richness showed variations among area size categories (Figure 2) while there was an increasing trend in stem number with an increase in area sizes (Table 5).

The respondents manage their PRGIs for various purposes such as food and fodder. Medicinal value, ornamental, as spice, fuel wood, and income supplementation (Table 6). In Dilla town, there is an intense sun heat effect from November to March. During this period, all woody and nonwoody perennial species are known to ameliorate microclimate through respondents' preference for species that provide a cooling effect through their high canopy and evergreen features throughout the year.

Table 2: Socioeconomic characteristics of the owner of private green infrastructure in Dilla town.

Parameter	Description	Sex		Total
		Male	Female	
	Sex	35	59	94
Education	Illiterate	1	7	8
	Primary (1–8 grade)	9	21	30
	Secondary (9-10)	5	7	12
	Preparatory (11-12)	2	2	4
	Certificate/TVET/Diploma	12	17	29
	Bachelor (BSc or BA)	3	5	8
	Masters (MSc or MA)	3	0	3
Age in year	15–24	5	8	13
	25–54	26	46	72
	55–65	3	4	7
	>65	1	1	2
Family size no	<3 persons	4	6	10
	3–6	25	41	66
	6–9	6	11	17
	>9	1	0	1
Occupation	Trading	15	18	33
	Employee	16	32	48
	Daily labour in the town	4	—	4
	Farming outside the town	—	9	9

Table 3: Number of respondents and type of major components of private residential green infrastructure at three kebeles in Dilla town.

No of comp.	Major component of residential infrastructure	Kebele and number of respondents (%)			Over all (%)
		Bereda	Woldena	Haroresa	
7	Animals + trees + fruit trees + coffee + enset + medicinal herbs + pulse	11 (39.29)	3 (20)	6 (11.76)	20 (21.28)
6	Animals + trees + fruit trees + coffee + vegetables + medicinal herbs	nr	nr	3 (5.88)	3 (3.19)
5	Animals + trees + fruit trees + coffee + tuber crop	nr	3 (20)	1 (1.96)	4 (4.26)
3	Animals + trees + fruit trees	nr	nr	1 (1.96)	1 (1.06)
2	Fruit trees + coffee	nr	1 (6.67)	nr	1 (1.06)
5	Trees + fruit trees + coffee + enset + medicinal herbs	nr	1 (6.67)	9 (17.65)	10 (10.64)
6	Trees + fruit trees + coffee + enset + medicinal herbs + vegetables	nr	nr	5 (9.80)	5 (5.32)
6	Trees + fruit trees + coffee + enset + vegetables + tuber crops	9 (32.14)	2 (13.33)	nr	11 (11.7)
6	Trees + fruit trees + coffee + medicinal herbs + tuber crops + cereal	4 (14.29)	nr	2 (3.92)	6 (6.38)
4	Trees + fruit trees + enset + medicinal herbs	1 (3.57)	nr	nr	1 (1.06)
4	Trees + fruit trees + coffee + enset	1 (3.57)	3 (20)	2 (3.92)	6 (6.38)
3	Trees + fruit trees + medicinal herbs	1 (3.57)	nr	nr	1 (1.06)
3	Trees + fruit trees + coffee	1 (3.57)	2 (13.33)	16 (31.37)	19 (20.21)
3	Trees + fruit trees + enset	1 (3.57)	nr	nr	1 (1.06)
2	Trees + fruit trees	nr	nr	5 (9.80)	5 (5.32)
	Total	28	15	51	94

Note. nr = no record.

Table 4: Mean (m^2) and range of area sizes occupied by private residential green infrastructure at three kebeles in Dilla town. (N = 94).

Kebele	Area size (m^2)	
	Mean ± SD	Minimum – maximum
Bareda	225 ± 138.4	75–500
Woldena	263 ± 317.8	10–1229
Haroresa	181 ± 159.52	30–750

SD is standard deviation.

3.3. Species Composition and Diversity. A total of 66 plant species belonging to 45 families were identified on PRGI of 94 households at three kebeles of Dilla town (Figure 3; Table 7). Overall, Bignoniaceae and Lamiaceae were represented by four families each; Euphorbiaceae, Fabaceae, Moraceae, and Rutaceae represented by three families each; Anacardiaceae, Lauraceae, Cupressaceae, Solanaceae, Musaceae, and Meliaceae were represented by two families each. A single family represented the remainder. Of 66 species recorded, 51.5% were non-native

Table 5: Area size class, mean plot size, number of private residential green infrastructure (PRGIs), species woody richness and stem number per plot size class in Dilla town. ($N = 94$).

Area size Class m²	Area size m²	No of PRGI	Species number		Stem per plot
	Mean ± sd.t		Mean ± sd.t	Min-max	Mean ± sd.t
10–99	47.3 ± 15.5	27	5.4 ± 4.6	2–9	14.27.3
100–199	117.7 ± 26.3	24	6.0 ± 2.7	2–13	24.8 ± 11.6
200–299	207.2 ± 17.8	28	8.3 ± 2.9	3–14	30.1 ± 10.1
300–399	300.0 ± 0.0	4	9.0 ± 2.6	6–12	36.8 ± 12.1
400–499	420.0 ± 27.4	5	8.5 ± 3.2	5–13	39.8 ± 12.8
500–599	500.0 ± 0.0	2	7.8 ± 2.9	5–12	65.0 ± 4.2
600–700	616.6 ± 28.7	3	13.3 ± 2.5	11–16	55.3 ± 7.4
1229	1229	1	18		89

while 48.5% were native plants. Woody species account for 77% of the number (Tree = 28, Fruit tree = 12, and Shrub = 11).

In the present study, species richness increases with sample size (Figure 4), although the correlation shows a weak effect size (Moore et al. 2013), as shown in Figure 2. The mean of species abundance was higher ($P < 0.01$) in the PRGIs at Haroresa Kebele than at Woldena and Bereda Kebeles (Table 8). The mean values of Shannon–Wiener index were higher ($P < 0.05$) in PRGI at Bereda Kebele than at the other two kebeles (Table 8). A significant difference ($P < 0.05$) in the Simpson evenness index was found between Bereda Kebele and Haroresa kebeles. The mean value of species richness at Haroresa kebele was higher ($P < 0.05$) than at Woldena and Bereda kebeles (Table 8). The rarefaction curves (Figure 5) also indicate that PRGI at Haroresa kebele supports the presence of higher species richness than at Woldena Kebele and Bereda Kebele.

Sorenson's similarity of the species composition of PRGI between kebeles indicates that Woldena shares more species (85.1%; $N = 66$) with Bereda Kebele and (81.9%) with Haroresa kebele whereas Bereda kebele shares relatively low species (76.3%) with Haroresa. The overall similarity among kebeles ranges from 76.3–85.1%.

The frequency of occurrence of species across the PRGIs is variable. Overall, fruit tree species occurred in a large proportion in PRGIs (Figure 3, supported by Table 7). The combined IVI values of three kebeles for the top three woody species were in the order of: *Coffea arabica* > *Mangifera indica* > *Persea Americana* (Table 7). Similarly, the combined IVI values of timber trees were in the order of *Cordia Africana* > *Grevillea robusta* > *Vernonia amygdalina*. Among the kebeles, six top-ranked, woody species showed a difference in IVI values (Table 9). *Coffea arabica* ranked first at Woldena and Bareda, while *Mangifera indica* ranked first, second and third at Haroresa, Bereda, and Woldena Kebele, respectively.

3.4. Woody Species Structure and above Ground Biomass Carbon. Overall, 1220 stem ha^{-1} were recorded in the studied PRGIs. The highest (529) stems ha^{-1} was from Haroresa, followed by Bereda stems (447) stems and Woldena (223) stems ha^{-1}. The contribution of stem number to each diameter class at three kebeles was variable (Figure 6).

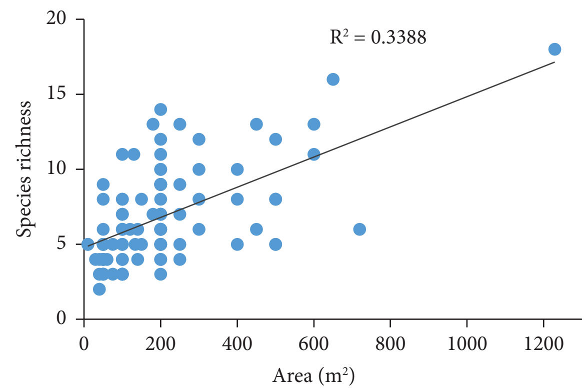

Figure 2: The relationship between area sizes and woody species richness in private residential green infrastructure at the study kebeles, Dilla town.

A large proportion of stem number, 66%, 62.4% and 61% were in the diameter classes ranging from 10–30 cm at Haroresa, Bereda, and Woldena kebele, respectively. In the larger diameter classes, a small number of trees occurred, particularly in older neighborhood (Woldena).

3.4.1. Aboveground Carbon Stock. Total aboveground carbon stock was 64.35-ton ha^{-1} in which fruits tree accounted 50.4 percent and timber trees accounted 48.8 percent. The highest aboveground carbon stock 69.58-, .64.29-, and 54.58-ton ha^{-1} at kebele level was from Haroresa, Bereda, and Woldena, respectively. Out of the overall 64.35-ton ha^{-1} aboveground carbon stock, the highest value (30%) was in the 21–30 cm diameter class, followed by 23.78% in the 11–20 cm diameter class and 19.51% in the 31–40 cm diameter class (Figure 7).

4. Discussion

4.1. Management and Resource Utilization. In the present study, the principal occupation of the majority of respondents was employment (51%; $N = 94$) and trading (35%), indicating that less time might be given for intensive management of plant such as ornamental and other horticultural. Due to a shortage of time, respondents preferred woody species that require less intensive management e.g., 94% of PRGIs contained fruit trees, coffee, and trees/shrubs.

Table 6: Species types and associated uses of private residential green infrastructure in Dilla town.

Use type	No of species	Species name
Food	16	*Mangifera indica* L *Persea americana* mill *Moringa.stenopetala*, *Psidium guajava* L annona senegalensis pers. Enset (ensete ventricosum (welw.) cheesman), *Musa paradisiacal*, *Carica papaya*, *Prunus persica* (L.), *Manihot esculenta*, *Colocasia esculenta*, *Allium cepa*, *Ananas comosus*, *Saccharum officinarum* and *Phaseoulus oulgaris*
Fodder	11	*P. americana*, *M. paradisiaca*, *M. azandarach*, *Ensete ventricosum S. nilotica*, *S. officinarum*, *P. granatum*, *Cordia africana*, *Croton macrostachyus Vernonia amygdalina Milletea ferruginea*
Microclimate melioration	8	*M. azandarach*, *M. indica*, *Delonix regia* (Hook.) Raf, *Millettea ferruginea* (Hochst.) Baker, *Olea africana* Mill. *Afrocarpus falcatus* (Thunb.) *E. ventricosum*, *Grevillea robusta* A. Cunn. Ex R. Br
Medicinal value	10	*Vernonia amygdalina* Del, *Melia azedarach* L, *M. stenopetala*, *Ruta chalepensis* L, *Ocinum basilicum*, *Lippia adoensis* hochst, *Ensete ventricosum* (welw.), *Punica granatum* L *Allium cepa* L. *Rhus vulgaris* meikle
Spice	5	*Mentha piperita* (Nana), *R. chalepensis*, *Lippia adoensis* hochst, *O. Basilicum* rosmarinus officinalis (NILL)
Income supplementation	11	C. *arabica*, *M. indica*, *M. paradisiaca*, *P. americana*, *P. Persica*, *A. senegalensis*, *E. ventricosum*, *Saccharum officinarum* L *M. stenopetala*, *Musa paradisiacal*, *Carica papaya*
ornamental purpose	7	*Dracaena steudneri* engl, *D. regia*, *Cupressus lusitanica* miller. *Borassus aethiopum* mart. And *Punica granatum*, *Spathodea nilotica Seem*, *Grevillea robusta*

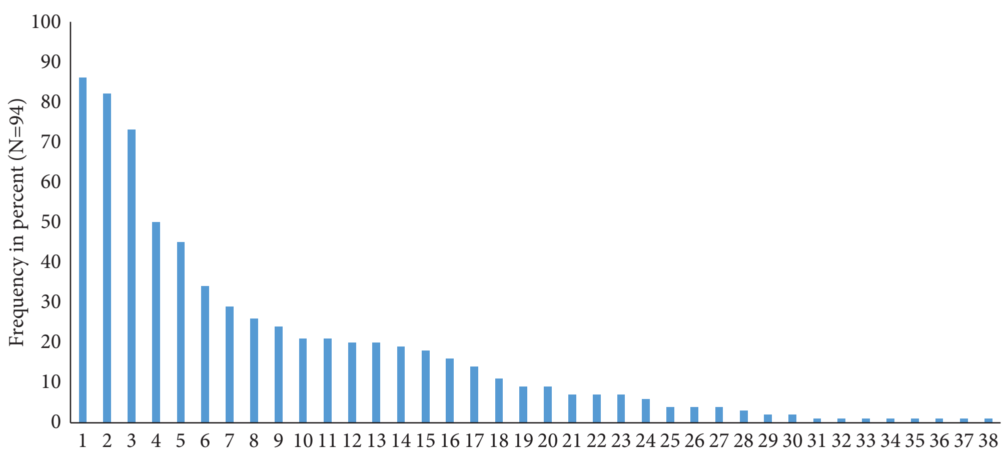

Figure 3: Occurrence (in percent) of woody species in the ranking order of residential green infrastructure ($N = 94$) in Dilla town. Note. See legend for species in Table 7.

Similar trend of fruit tree dominance in urban home gardens management was reported by [12] for Northern Thailand; [4] for Arba Minchi; [13] for Accra; and [14] for Jimma. The newer neighborhood (at Haroresa) has higher proportion (48%) of fruit trees while the older neighborhoods (Woldena) focus on coffee.

The PRGI area size ranged from $10\,m^2$ to $1229\,m^2$ which is within the range of 220 to $1235\,m^2$ for urban home gardens at Arba Minch [4]; for Sebeta town ($300–1200\,m^2$) [5]. The present holding size is also with the range (0.01–4.00 ha) of rural home gardens values for tropical home gardens area size in a rural setting [15]. Among Kebeles, the larger area size was found at an older neighborhood (Woldena) supporting the report of [41] from Canada. Overall, the management strategies of respondents indicate that a large proportion (84%; $N = 94$) of PRGIs had plot size less $300\ m^2$ with a mean of $120\,m^2$ containing a mean number of 7 woody species and 30 stems.

Urban forests are significantly important in enhancing food security, energy availability, better health, and the amelioration of air pollution, high humidity, and high temperatures in the urban atmosphere [1, 2]. The multidimensional purposes of managing the PRGIs contributed to the conservation of 16 species for food; 11 for fodder; 10 for Medicinal value; 11 for income supplementation; and 7 species for ornamentals and almost all perennials provide shade. The greater the proportion of green space within the urban matrix, the lower surface and air temperatures due to shade [16].

4.2. Species Composition, Diversity, and Structure. Climate change adaptation and mitigation, nutrient cycling, soil and water conservation, pollination, food and nutrient availability, habitat improvement, and resilience are associated with the benefits of plant biodiversity. The total number of plant species (66) recorded in the studied

Table 7: Name of plant species and important value index (IVI) of woody species recorded in private residential green infrastructure in Dilla town.

No	Scientific name	Family name	Source	IVI %
1	*Mangifera indica* L.	Anacardiaceae	Non-native	59.496
2	*Persea americana* mill.	Lauraceae	Non-native	42.52
3	*Coffea arabica* L.	Rubiaceae	*N*	46.536
4	*Psidium guajava* L.	Myrtaceae	Non-native	14.205
5	*Cordia africana* Lam.	Boraginaceae	*N*	17.252
6	*Melia azedarach* L.	Meliaceae	Non-native	14.064
7	*Grevillea robusta* A. Cunn. Ex R. Br.	Proteaceae	Non-native	15.708
8	*Millettea ferruginea* (hochst.) baker.	Fabaceae	*N*	8.73
9	*Cupressus lusitanica* miller.	Cupressaceae	Non-native	9.004
10	*Bersama abyssinica* fresen.	Melianthaceae	*N*	5.467
11	*Vernonia amygdalina* Del.	Asteraceae	*N*	4.983
12	*Dracaena steudneri* engl.	Asparagaceae	*N*	6.421
13	*Moringa stenopetala* (baker f.)	Moringaceae	*N*	6.948
14	*Casuarina equisetifolia* L.	Casuarinaceae	Non-native	7.529
15	*Croton macrostachyus* hochst. Ex delile	Euphorbiaceae	*N*	7.096
16	*Annona senegalensis* pers.	Annonaceae	Non-native	4.868
17	*Spathodea nilotica* seem.	Bignoniaceae	*N*	3.802
18	*Ricinus communis* L.	Euphorbiaceae	*N*	2.219
19	*Citrus sinensis* (L.) osbeck	Rutaceae	Non-native	1.964
20	*Eucalyptus camaldulensis* dehnh.	Myrtaceae	Non-native	3.456
21	*Citrus aurantiifolia* (christm.)	Rutaceae	Non-native	1.608
22	*Jacaranda mimosifolia* D. Don	Bignoniaceae	Non-native	2.201
23	*Morus mesozygia* stapf.	Moraceae	*N*	1.553
24	*Borassus aethiopum* mart.	Arecaceae	*N*	2.618
25	*Callistemon citrinus* (curtis) skeels	Myrtaceae	Non-native	1.304
26	*Celtis africana Burm*. F.	Lauraceae	*N*	1.253
27	*Olea africana* Mill.	Oleaceae	*N*	0.903
28	*Pinus patula* schlecht. And chamiso	Pinaceae	Non-native	2.94
29	*Ficus elastica* roxb. Ex hornem	Moraceae	Non-native	0.529
30	*Afrocarpus falcatus* (thunb.)	Podocarpaceae	*N*	0.411
31	*Delonix regia* (hook.) raf.	Fabaceae	Non-native	0.291
32	Discopodium penninervum hochst.	Solanaceae	*N*	0.257
33	*Eucalyptus citriodora* hook.	Myrtaceae	Non-native	0.212
34	*Juniperus procera* L.	Cupressaceae	*N*	0.553
35	*Prunus persica* (L.) batsch	Rosaceae	Non-native	0.354
36	*Punica granatum* L.	Lythraceae	Non-native	0.2
37	*Rhus vulgaris* meikle	Anacardiaceae	*N*	0.203
38	*Alstonia macrophylla* wall. Ex G. Don	Apocynaceae	Non-native	0.291
39	*Faidherbia albida* (delile) A. Chev.	Fabaceae	*N*	
40	*Allium cepa* L.	Amaryllidaceae	Non-native	
41	*Ananas comosus* (L) merr	Bromeliaceae	*N*	
42	*Carica papaya* linn	Caricaceae	Non-native	
43	*Carissa spinarum* linn.	Apocynaceae	*N*	
44	*Colocasia esculenta* (L) schott	Araceae	Non-native	
45	*Cymbopogon citratus* stapf.	Poaceae	Non-native	
46	*Ehretia cymosa* thonn.	Boraginaceae	*N*	
47	*Ekebergia capensis* sparrm.	Meliaceae	Nt	
48	*Enset (Ensete ventricosum* (welw.) cheesman)	Musaceae	*N*	
49	*Euphorbia tirucalli* L.	Euphorbiaceae	*N*	
50	*Gossypium hirsutum* L.	Malvaceae	Non-native	
51	*Lippia adoensis* hochst	Verbenaceae	Non-native	
52	*Manihot esculenta* crantz.	Euphorbiaceae	Non-native	
53	*Mentha piperita* L.	Labiatae	*N*	
54	*Musa paradisiaca* L.	Musaceae	Non-native	
55	*Nicotiana tabacum* L	Solanaceae	Non-native	
56	*Ocimum gratissimum* L.	Lamiaceae	*N*	
57	*Ocinum basilicum* L.	Lamiaceae	*N*	
58	*Phaseolus vulgaris* L	Fabaceae	Non-native	
59	*Piper nigrum*	Piperaceae	Non-native	

Table 7: Continued.

No	Scientific name	Family name	Source	IVI %
60	*Plectranthus edulis* L.	Lamiaceae	*N*	
61	*Rhamnus prinoides* L. Herit.	Rhamnaceae	*N*	
62	*Rosmarinus officinalis* (nill).	Lamiaceae	*N*	
63	*Ruta chalepensis* L.	Rutaceae	*N*	
64	*Saccharum officinarum* L.	poaceae	Non-native	
65	*Strychnos spinosa* lam.	Loganiaceae	*N*	
66	*Zea mays* L	Crambidae	Non-native	

N = native species; number from 1–38 shows percent of frequency of occurrence and IVI of woody species for which diameter were recorded.

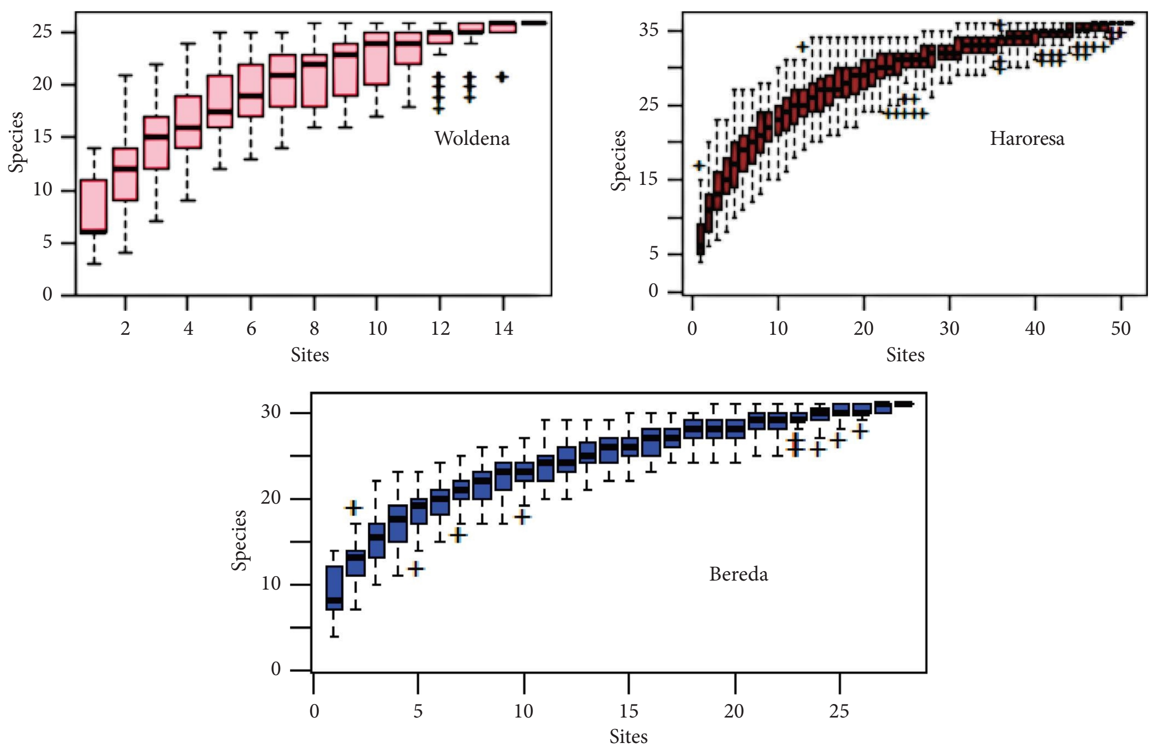

Figure 4: Sample plot-based tree species accumulation curve in private residential green infrastructure across three kebeles.

Table 8: Mean abundance (N), Shannon–Wiener index (H′), species richness (S), and Simpson evenness index (E) of woody species in private residential green infrastructure, Dilla town.

Diversity indices	Mean (±sd)			Overall mean	*F*-value	*P* value
	Bereda ($n = 28$)	Haroresa ($n = 51$)	Woldena ($n = 15$)			
N	395.1b ± 224.2	667.3a ± 381.6	222.4bc ± 124.3	428.3	14.75	2.825*e*−06
H′	2.259a ± 0.17	2.208ab ± 0.16	1.908c ± 0.21	2.125	21.31	2.564*e*−08
S	23.31b ± 5.9	26.93a ± 6.8	18.43bc ± 5.5	22.89	10.88	5.795*e*−05
E	0.974ab ± 0.56	0.661c ± 0.49	0.766bc ± 0.42	0.801	3.42	0.0369

Note. mean.

PRGIs is lower compared to some of the previous studies. For example, different authors reported higher species values: [6] 1166 plant species; [7] 186 plant species; [13] 94 woody plant species; [11] 258 plant species; [5] 138 plant species; [12] 72 plant species; [4] 70 woody species; [18] reported 86 woody species. Contrary to this, a slightly lower (40) number of woody species was reported by [14] for home gardens in Jimma town; [19] reported the occurrence of 37 tree species in Port Harcourt city, and 46 tree species in Ilorin city urban forest in Nigeria. For nearby home gardens/agro forests in rural areas [9], reported 120 woody species and [42] reported 58 woody species. The present study showed the occurrence slightly higher number (51.5%; $N = 94$) of non-native plant species

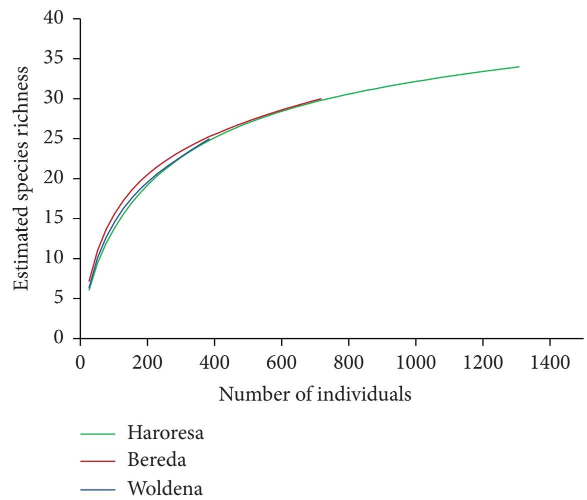

Figure 5: Comparisons of species richness between private residential green infrastructure in the study kebeles using individual-based rarefaction techniques.

Table 9: Frequency (RF), relative density (RDD), relative dominance (RD), and important value index (IVI) of six most abundant woody species at three kebeles in Dilla town.

Kebele	Species name	RF (%)	RDD (%)	RD (%)	IVI (%)
Woldena	*Coffea arabica*	14.993	44.647	9.953	69.592
	Persea americana	11.994	14.806	29.943	56.743
	Mangifera indica	7.996	9.567	11.891	29.454
	Cordia africana	5.997	4.556	9.001	19.553
	Vernonia amygdalina	7.996	4.1	2.031	14.127
	Grevillea robusta	5.997	2.278	4.981	13.256
Bareda	*Coffea arabica*	10.325	29.847	5.922	46.094
	Mangifera indica	11.733	17.73	16.422	45.884
	Persea americana	11.733	14.286	18.732	44.751
	Cordia africana	8.448	5.867	13.425	27.74
	Psidium guajava	6.57	4.719	3.261	14.551
	Moringa oleifera	2.347	1.148	9.954	13.448
Haroresa	*Mangifera indica*	14.822	31.633	31.159	77.614
	Coffea arabica	9.881	24.49	5.01	39.381
	Persea americana	12.351	9.475	14.487	36.313
	Grevillea robusta	6.484	4.446	8.076	19.007
	Melia azedarach	4.632	3.571	7.342	15.545
	Psidium guajava	8.337	4.155	2.219	14.711

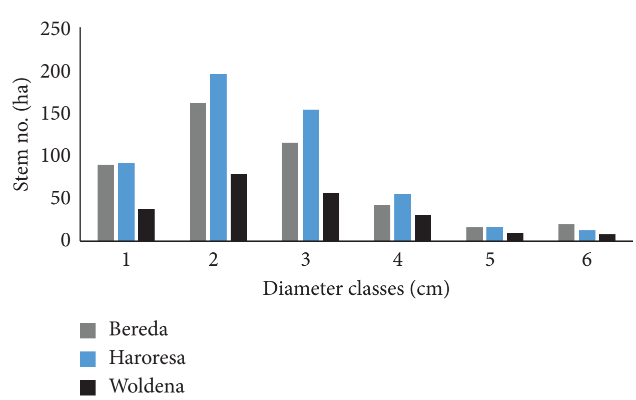

Figure 6: Number of stems per ha in each diameter at breast height class in private residential green infrastructure at three kebele of Dilla town.

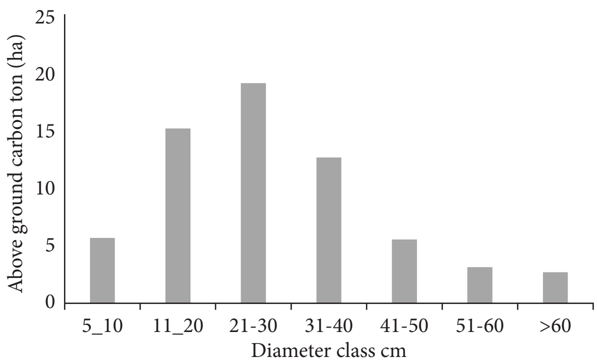

Figure 7: Overall aboveground carbon stock (per ha) within each diameter at breast height class in private residential green infrastructure, Dilla town.

than native species. A similar trend was reported by [16, 18]. Smith [6] reported 1166 plant species of which 70% were non-native. On the contrary, [42] reported the existence of 86% ($N = 58$) of native woody species in nearby agro forests.

The woody Shannon–Wiener diversity index (H′) and Simpson Evenness index (E) showed a medium and high score of 2.14 and 0.789, respectively. For urban forest, [19] reported higher values of (H′) (3.39) for Port Harcourt and (3.61) for Ilorin cities. The significantly higher ($P < 0.05$) species richness at Haroresa kebele indicates a greater variety of species in the newer neighborhood. On the other hand, the contribution of tree species to absolute species richness was 80% ($n = 35$ species) at Haroresa, 83% ($n = 30$) at Bereda, and 92% ($n = 25$) at Woldena. In general, the similarity of the species ranged from 76.3–85.1% among the study kebeles, indicating their role in habitat connectivity for biodiversity conservation and overall environmental services.

In the present study, the frequency of occurrence of species across the PRGIs is variable. For example, fruit trees species such as *Mangifera indica*, *Persea Americana*, and *Psidium guajava* occurred in large proportion. The structural distribution indicated a very small number of old trees in the study kebeles, with a high number of tree species between diameter classes of 10–30 cm.

5. Implications to Carbon Sequestration

Urban trees reduce atmospheric carbon dioxide through sequestration and contribute to climate change mitigation. Overall mean of aboveground biomass (AGB) carbon stock of woody species was 64,35 tonha^{-1} with CO_2 equivalent 236.5 value for which fruits tree accounted 50.4 percent and timber trees 48.8 percent. Out of the overall above-ground carbon stock, the highest value (30%) was from the stem diameter class ranging from 21–30 cm. The mean AGB carbon of PRGIs was within the range of 12–228 Mg C ha^{-1} reported for agroforestry systems globally [43]. This value is close to nearby agroforests [44] where the AGB carbon (trees, coffee, ensete, herbs and litter) ranges from 16 to 93 Mg ha^{-1} with a mean value of 58.3 Mg ha^{-1}. The highest contribution (50%) was from fruit trees followed by nonfruit trees (48%). Compared with the present study, [25] reported higher biomass carbon (150 tons ha^{-1}) for urban parks and gardens studied in Nagpur, India. A study conducted in an urban forest in Port Harcourt [19] reported a higher average carbon density of 136.15 tons ha^{-1}. The same authors reported a lower average carbon density of the urban forest of 7.82 tons ha^{-1} in the Ilorin urban forest. From a study in the northwest of Chicago [24] reported a total carbon storage of 26.15 kg m^{-2} for residential green spaces. A higher value (383.67 tons ha^{-1}) of carbon stocks was reported by [26] for the botanical garden green spaces of a secondary city in Myanmar.

6. Conclusion

The urban populations in and around Dilla town need sustainable ecosystem services from urban green infrastructure. A good portion of these needs can be provided through PRGIs that are managed in 15 management categories on an area size ranging from 10 to 1229 m^2. The PRGIs contributed to the conservation of 66 plant species of which 16 species are used for food, 11 for fodder, 10 for Medicinal value, 11 for income supplementation, 7 species for ornamentals, and almost all perennials provide shade. Woody species account for 77% of the 66 plant species (Tree = 28, Fruit tree = 12, and Shrub = 11). Urban trees reduce atmospheric carbon dioxide through sequestration and contribute to climate change mitigation. The studied PRGIs provide overall mean of above-ground biomass carbon stock 64.35 ton ha^{-1} with CO_2 equivalent 236.5 value for which fruits tree accounted for 50.4 percent and trees for 48.8 percent.

Data Availability

The data supporting the conclusions of the study can be accessed through email to corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts interest.

Authors' Contributions

Both Zebene and Yohanis designed the study. Yohanis conducted field data collection and analysis. Zebene and Yohanis have done result interpretation and manuscript preparation. Both authors read and approved the final manuscript.

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