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Research Article

Investigation of Woody Species Composition, Diversity, and Carbon Stock under Agroforestry Practices in Oromia National Region State, Central Ethiopia

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Agroforestry is a common practice in the tropics that is characterized by various activities such as parkland on cultivated lands or home garden agroforestry around homesteads. In Ethiopia, agroforestry is an ancient land use type that is practiced by smallholder farmers. Scattered trees in cropland or parkland trees and home garden trees are old agroforestry practices, and the most dominant practices exist in different parts of Ethiopia. They cover large areas of highland, midland, and lowland agroecologies of Liban Jawi District in West Showa of Oromia National Regional State, Central Ethiopia. However, woody species particularly in parklands are declining in many agricultural landscapes due to the overuses for fuel wood, charcoal production, and expansion of agricultural lands due to the degradation of nearby forests. In the study sites, comprehensive studies in terms of their composition, diversity, structure, and carbon stocks are still not well explored. In this context, we assessed woody species composition and diversity, structure, and carbon stocks because parkland and home garden agroforestry practices in three agroecologies of highland, midland, and lowlands in the district were not quantified. About 45 parkland woody species were collected from 150 plots of 5000 m^2, and 35 home garden woody species were collected from 70 plots of 400 m^2. As a result, a total of 80 species belonging to 52 families and 62 genera were collected from parkland and home garden agroforestry practices. Woody species diversity was analyzed using species richness, Shannon diversity index, and Shannon evenness index. In this study, the Shannon diversity (2.8) and Shannon evenness indexes (0.54) of woody species were computed in parkland agroforestry, in the meantime the Shannon diversity index (3.30) and Shannon evenness index (0.52) for woody species of the home garden were computed. The distribution of diameter classes of 10–30 cm had the highest number of trees and shrubs followed by 31–60 cm diameter classes. However, the highest number of trees and shrubs were in 61–90 cm diameter class in the home garden. In this study, woody species, such as *Citrus sinensis*, *Mangifera indica*, *Persea americana*, *Sesbania sesban*, *Vernonia amygdalina*, and *Azadirachta indica* were the dominant species under the two agroforestry practices. The values of carbon stack for highland, midland, and lowland in parkland agroforestry were 19.8 $MgCha^{-1}$, 17.6 $MgCha^{-1}$, and 17.5 $MgCha^{-1}$, respectively. Meanwhile, the total biomass of woody species in highland, midland, and lowland for homestead agroforestry was 32.6 $MgCha^{-1}$, 34.7 $MgCha^{-1}$, and 31.2 $MgCha^{-1}$, respectively. These resulted in carbon dioxide sequestered of 72.59 CO_2 equivalents (tha^{-1}), 64.52 CO_2 equivalents (tha^{-1}), and 64.16 CO_2 equivalents (tha^{-1}) in highland, midland, and lowland woody species, respectively. This study holds significant inputs for policymakers, regional administrators, environmentalists, and natural resource experts by informing the farmers' management and conservation of woody species on cultivated lands and home garden agroforestry plants around their homesteads which is serving as ecosystem services and climate mitigation response within Liban Jawi district. Under parkland and homestead agroforestry practices, communities should have know-how to predict the environmental consequences of the destruction of woody species on their farmlands.

1. Introduction

Agroforestry has been practiced for a long period of time in many parts of the world, and it is a new name for a set of old practices [1]. In Africa, many smallholder farmers practice different agroforestry practices [2]. Agroforestry practices are regarded as an ancient land use practice in Ethiopia [3]. Among those practices, home gardens, scattered trees in cropland, boundary planting, and live fences are old agroforestry practices, and the most dominant practices exist in different parts of Ethiopia [4–6]. The types of agroforestry practices are parkland and home garden which are found in northwestern parts of Ethiopia [7]. Parkland and home garden agroforestry practices are common practices by smallholder farmers in many parts of Ethiopia. Parkland also known as scattered trees in croplands is a common type of agroforestry practice in the tropics and characterized by well-known scattered trees on cultivated and recently fallow lands, which is developed as a result of crop cultivation on a piece of land that became a permanent activity [8]. Parkland agroforestry practice is also common and covers a large area of agricultural lands in northern Ethiopia [9]. The scattered *Faidherbia albida* in cropland is the oldest form of indigenous agroforestry practice which is present in central and eastern Ethiopia [10, 11]. In other ways, parkland agroforestry is the type of tree-based agroforestry land use practice whereby a tree is grown associated with cereal crops such as maize, teff, sorghum, barley, and wheat [12]. Different forms of homegarden agroforestry are reported in different parts of Ethiopia [13–15]. In southern and southwestern parts of Ethiopia, home garden agroforestry was common and the dominant agroforestry practice [16].

In Ethiopia, tree species integrated into the cropland of smallholder farmers characterized by various forms of traditional agroforestry systems from different countries and universal occurrence [17]. Many smallholder farmers retained and intercropping trees on their cropland in the central highland of Ethiopia. For example, *Cordia africana* (Lam) is being intercropped with maize in the subhumid agroecological zone of the country [18]. Trees retained or planted on cropland do not have any specific patterns; for instance, *Faidherbia albida*, *Croton macrostachyus,* and *Ficus vasta* (Forssk) are the most common tree species in parkland agroforestry [19].

Farmers grow or retain trees in their cropland to provide more products or services [8]. Multipurpose trees grown in and scattered trees on cropland are parts of agroforestry practice [20, 21]. The integration of tree species with annual crops is accounted as the modern way of increasing the production capacity of single land through diversifying the production with higher yields [12]. Farmers are maintaining multipurpose trees in their cropland for different purposes like firewood, food, fodder, windbreak, or soil fertility [20]. Other woody species, like *Millettia ferruginea* Hochst, *Cordia africana,* and *C. macrostachyus,* are useful for improving soil fertility and conserving soil moisture [15, 22]. According to Desalegn and Zebene [22], farmers maintained scattered trees in their farmland, mainly for their wood products. *Cordia africana* is one of the best-quality timbers in Ethiopia [23, 24].

Farmers in Ethiopia practiced various agroforestry practices in their parklands and homesteads. Smallholder farmers in Ethiopia deliberately retain trees from natural regeneration or planted them in their cropland for different purposes of income generation, cultural, material uses, and economical, ecological, social, and biophysical conditions which have livelihood implications [25–27]. Moreover, dispersed trees grown on parkland agroforestry characterize a large part of the Ethiopian agricultural landscapes [28]. However, woody species on parkland agroforestry are getting declined in many agricultural landscapes due to the overuses for fuel wood, charcoal production, expansion of agricultural land, and degradation of nearby forests [29].

In Liban Jawi District, no scientific information was assessed about woody species composition, diversity, structures, and carbon stock of woody species for parkland and homestead agroforestry practices. These issues encourage us to go for study and come out with scientific information for the continuity of management of these agroforestry practices. This study aimed to assess woody species composition and diversity, assess woody species structure, and assess the carbon stock of woody species in the Liban Jawi District of Oromia Regional State**,** Central Ethiopia. This study answers the following research questions: (1) What is the composition and diversity of tree species in parkland and home garden? (2) What is the structure of tree species in parkland and home garden agroforestry practices? (3) What is the carbon stock of tree species in parkland and home garden agroforestry practices in Liban Jawi District?

2. Materials and Methods

2.1. Description of the Study Area. This study was conducted in Liban Jawi District, West Showa Zone of Oromia National Regional State in Central Ethiopia. Liban Jawi District is located between 8° 50′ 0″ and 9° 10′ 0″ N and 37° 10′ 0″ and 37° 40′ 0″ E (Figure 1). It is located 47 km from Ambo, the capital city of West Showa Zone, and 175 km far away from Addis Ababa, the capital city of Ethiopia, in the west direction. Liban Jawi District is bounded by Toke Kutaye in the east, Celiya in the west, Jibat in the south, and Mida Kegn district in the north direction [30].

2.2. Selection of the Study Sites. In this study, sites were classified into highland, midland, and lowland agroecological zones based on their altitudinal ranges for data collection. A total of 15 rural kebeles (the lowest administrative area in Ethiopia) existed in three agroecology of Liban Jawi District. Among these, six administrative kebeles were purposively selected based on the existence of woody species diversity in parkland and home garden agroforestry practices. Among selected kebeles in that agroecology, two

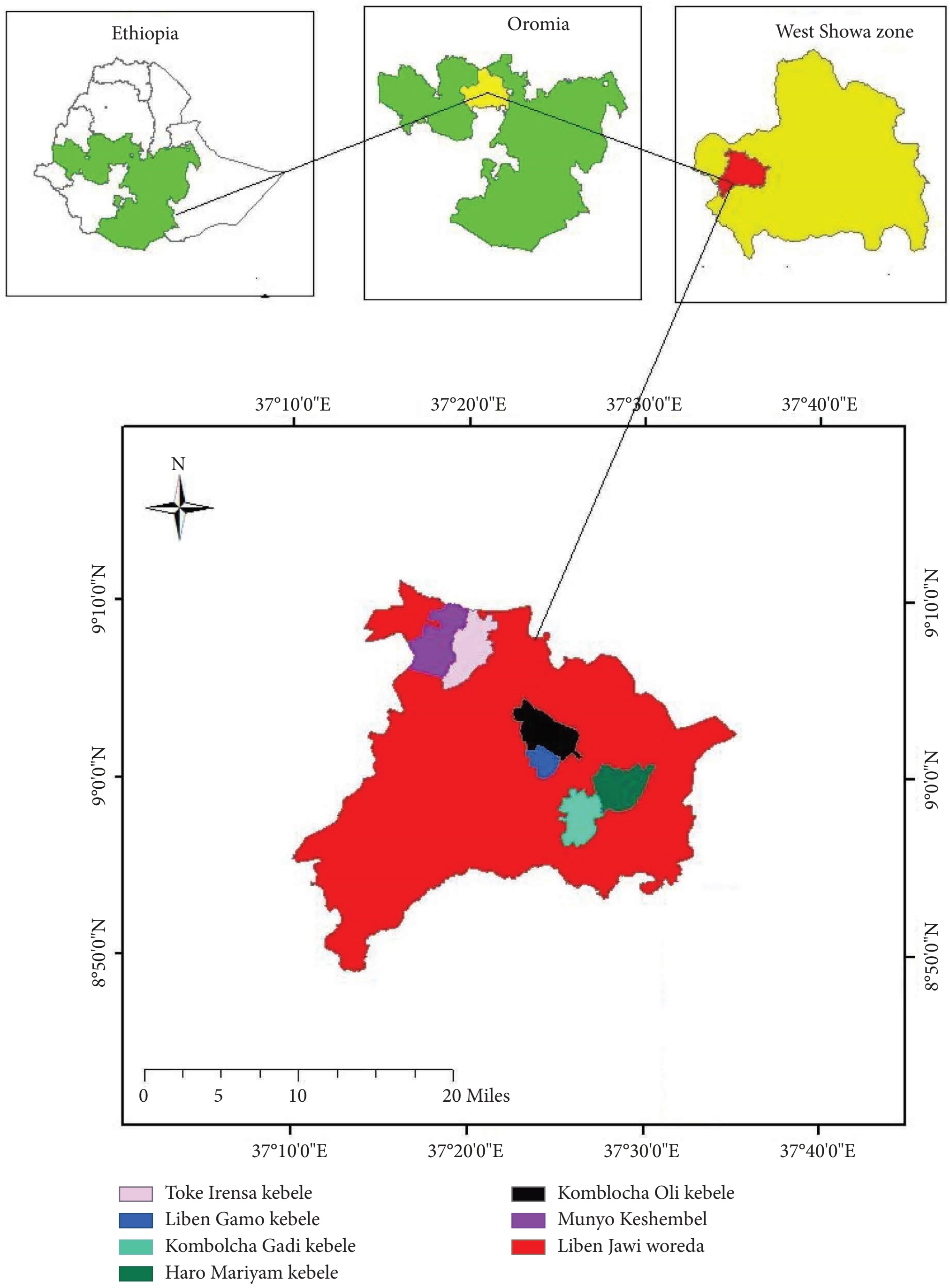

Figure 1: Map of the study sites.

kebeles of Kombolach Gadi and Haro Mariam were selected from lowland agroecology, two kebeles Liben Gamo and Kombolach Oli were selected from the midland agroecology, and two kebeles Toke Irensa and Munyo Keshembel were also selected from highland agroecology.

2.3. Inventory of Woody Species. To identify parkland agroforestry that had diverse woody species, a reconnaissance survey was carried out for two consecutive weeks on each selected kebele. After identifying parkland agroforestry woody species in each kebele, data on woody species were collected by walking on transect lines designed to lay plots. For the woody species data collection, the first plot was taken by using random sampling techniques in the parkland agroforestry practice. In parkland agroforestry practice, a total of 150 plots were taken in $50\,m \times 100\,m$ ($5000\,m^2$) plot areas. The distance between each transect line was 500 m, and the distance between each plot was 400 m. In home garden agroforestry practices, 70 plots were taken in $20\,m \times 20\,m$ ($400\,m^2$) plot areas.

The circumference at breast height (CBH) and height of each woody species in both parkland and home garden agroforestry were measured in all plots. The DBH of each woody species per plot was measured by using a caliper. The height of each woody species was measured by using clinometers. All woody species ≥10 cm CBH (circumference at breast height at 1. 37 m from the ground) and tree species were measured for both parkland agroforestry and home garden agroforestry practices, see [31–33]. From the plots taken in both parkland and home garden agroforestry, all woody species and shrubs found in plots were identified in local names, counted, and collected for further identification. The scientific name for each woody species found in both parkland and home garden was recorded in their local field, and their scientific names were identified using the Ethiopia and Eritrea Flora books of volumes 2 to 7 floras of Ethiopia and Eritrea [34–40].

2.4. Woody Species Diversity Analysis. Diversity indices provide important information about the rarity and commonness of species in a community. In the study areas, woody species diversity was analyzed using species richness (n), Shannon diversity index (H'), and Shannon evenness index (E).

Shannon diversity index is calculated as

$$H' = -\sum \text{pi} \ln \text{pi}, \quad (1)$$

where H' is the Shannon diversity index, Pi is the proportion of total abundance represented by i^{th} species, and ln is the natural logarithm of pi

Species evenness is used to measure the homogeneous distribution of tree species in sample plots. It has attempted to quantify unequal representation against a hypothetical community in which all species are equally common [39]. The evenness of a population was calculated by

$$E = \frac{H'}{\left(H' \max\right)} = \ln S, \quad (2)$$

where E is evenness.

The higher the values of evenness, the more even the species in their distribution within the given area [40]:

$$H' \max = \ln S. \quad (3)$$

It is species diversity under maximum equitability conditions, where S is the total number of species in the sample and ln is the natural logarithm of the total number of species in each community.

The value of the evenness index falls between 0 and 1.

2.5. Structural Analysis. The basal area is the cross-sectional area of woody stems at breast height. It measures the relative dominance (the degree of coverage of a species as an expression of the space it occupies) of species in an area. It is the area outline of a plant near the ground surface and is expressed in $m^2 \cdot ha^{-1}$ [41, 42]. The basal area was calculated for each woody species in parkland and home garden agroforestry practices with CBH ≥ 10 cm, respectively:

$$\text{BA} = \pi \frac{(\text{DBH})2}{4}. \quad (4)$$

Where Π = 3.14 BA is the basal area (m^2) and DBH is the diameter at breast height (cm).

$$\text{Dominance} = \frac{\text{total basal area of species}}{\text{sampled area}} \times 100. \quad (5)$$

2.5.1. Importance Value Index. The importance value index (IVI) indicates the importance of species in farmland and home garden. It was calculated with three components according to [41] as follows:

$$\begin{aligned}
\text{Relative density (RD)} &= \frac{\text{density of individual species}}{\text{total density of individual}} \times 100, \\
\text{Relative dominance (RDom)} &= \frac{\text{dominance of species}}{\text{total dominance of individual}} \times 100, \\
\text{Relative frequency (RF)} &= \frac{\text{frequency of species}}{\text{sum frequency of all species}} \times 100, \\
\text{IVI} &= \text{RD} + \text{RF} + \text{RDom}.
\end{aligned} \quad (6)$$

2.6. Estimation of Tree or Shrub Biomass in Parkland and Home Garden Agroforestry. Carbon was estimated from different woody species available in parkland and home garden agroforestry using a nondestructive method. Particularly, biomass carbon estimation was carried out using the adopted method of Pandya [43].

2.6.1. Volume of Woody Species in Parkland and Home Garden Agroforestry. The height and diameter of the tree at the breast height of each species were converted into bio-volume as follows:

$$\text{Bio-volume (TBV)} = 0.4 \times \left(D^2 \times h\right), \quad (7)$$

where D is the diameter (cm) and h is the height of the tree (m).

2.6.2. Aboveground Biomass (AGB) of Woody Species. AGB is calculated by multiplying three biovolumes with wood density:

$$\text{AGB} = \text{TBV x } \rho, \quad (8)$$

where ρ is the wood density for woody species and "TBV" is the tree biovolume.

For his study, wood species density from the global wood density database was used [44].

2.6.3. Belowground Biomass (BGB) of Woody Species in Agroforestry. According to Macdicken [45], the standard method for estimation of BGB could be obtained as 20% of AGB. The belowground biomass was calculated by multiplying the AGB by 0.2 factors of the root-to-shoot ratio. The synthesis of global data and the conservative ratio of root-to-shoot biomass value were 5 : 1 [46]:

$$\text{BGB} = \text{AGB x } 0.2. \quad (9)$$

2.6.4. The Amount of CO_2 Sequestered for AGB and BGB of Woody Species. Biomass carbon stock was converted into CO_2 equivalent. To estimate the amount of CO_2 sequestered in any woody species, we multiply carbon contents by 3.67 [47]:

$$\text{CO2 sequestered} = \text{biomass of woody species x } 3.6663. \quad (10)$$

2.6.5. Total Biomass of Woody Species. The total biomass of woody species was calculated by summing up the aboveground and belowground biomasses [48]:

$$\text{Total biomass (TB)} = \text{aboveground biomass (excluding litter)} + \text{belowground biomass (excluding soil organic matter)}. \quad (11)$$

2.6.6. Carbon Storage Estimation in Woody Species. For any plant species, 50% of its biomass is considered carbon [49]:

$$\text{Carbon storage} = \text{biomass x } 50\%. \quad (12)$$

3. Results

3.1. Woody Species Composition and Diversity. A total of 80 species belonging to 53 families and 62 genera were recorded from the study area under agroforestry (Table1). From the identified species, 45 were found in parkland agroforestry (Table2) and 35 species were found in home garden agroforestry (Table 3). Among the identified species in the home garden agroforestry, 16 species were shrubs and 19 species were trees (Table 4). About 17 species were common for both parkland and home garden agroforestry. Among the total families identified from both agroforestry practices, 29 families were identified in parkland agroforestry (Table 2) and 24 families from home garden agroforestry (Table 5). Fabaceae and Moraceae were the most dominant families in parkland agroforestry practice (Table 2). Rosaceae and Rutaceae were the most dominant followed by Fabaceae and Lamiaceae families in home garden agroforestry practice (Table 5). About 16 families were common for both parkland and home garden agroforestry practices in the study of agroecologies.

The species richness, Shannon diversity index, and Shannon evenness of woody species in both parkland and home garden agroforestry are indicated in Table (2). Results showed that species richness in parkland agroforestry practice was 25, and the species richness in home garden agroforestry was 13. Species richness of midland, highland and lowland agroecology in parkland agroforestry was 38, 20, and 18, respectively, and in the home garden agroforestry was 20, 10, and 9, respectively. The highest Shannon diversity index was computed in midland (3.4), but the lowest Shannon diversity index was in lowland (2.3) parkland agroecology practice (Table 6). In parkland agroforestry practice, the overall mean Shannon diversity index was 2.8 and Shannon evenness was 0.54. Meanwhile, in home garden agroforestry, the overall mean Shannon diversity index was 2.53 and Shannon evenness was 0.47. The Shannon diversity index of midland, highland, and lowland in parkland agroforestry was 3.4, 2.7, and 2.3, respectively. In the meantime, the Shannon evenness of midland, highland, and lowland in parkland agroforestry was 0.62, 0.54, and 0.45, respectively. The Shannon diversity index of home gardens in midland, highland, and lowland was 3.2, 2.3, and 2.1, respectively, whereas Shannon evenness of midland, highland, and lowland in the home garden agroforestry was 0.51, 0.48, and 0.47, respectively (Table 6).

3.2. Structure of Woody Species

3.2.1. Effect of Agroecology on Structure of Woody Species. Results show that agroecology affected the IVI mean value of woody species under both parkland and home garden agroforestry practices ($P < 0.05$). But agroecology did not affect the mean value of woody species under both parkland

Table 1: List of woody species in the study areas.

Scientific name	Family	Growth form
Albizia grandibracteta Taub.	Fabaceae	T
Albizia gummifera (G.F. Gmel.)	Fabaceae	T
Allophylus abysinicus (Hochst).	Sapindaceae	T
Apodytes dimidiata E. Mey. Ex	Icacinaceae	T
Azadirachta indica A. Juss	Meliaceae	T
Bersama abyssinica Fres.	Sapindaceae	T
Calpurina aurea (Ait.)	Rutaceae	Sh
Casuarina equisetifolia L.	Casuarinaceae	T
Catha edulis (Vahl) Forssk	Celastraceae	T
Celtis africana Burm.f.	Ulmaceae	T
Citrus aurantifolia (Christm.)	Rutaceae	Sh
Citrus medica L. (Citron)	Rutaceae	Sh
Citrus sinensis (L.)	Rutaceae	Sh
Clausena anisata (Willd). Benth	Rutaceae	T
Coffee arabica L.	Rubiaceae	Sh
Cordia africana Lam.	Boraginaceae	Sh
Croton macrostachyus Del.	Euphorbiaceae	T
Cupressus lusitanica Mill.	Cupressaceae	T
Dodonaea angustifolia L	Sapindaceae	T
Ekebergia capensis Sparrman.	Meliaceae	T
Erythrina abyssinica Lam. Ex.	Fabaceae	T
Erythrina brucei Schweinf	Fabaceae	T
Euclea schemperi (A.DC).Dandy	Fabaceae	T
Faidherbia albida (Del.)	Fabaceae	T
Ficus sur Forssk.	Moraceae	T
Ficus sycomorus L.	Moraceae	T
Ficus vasta Forssk.	Moraceae	T
Gnidia glauca (Fresen.) Gilg.	Proteaceae	T
Grevillea robusta (A. Cunn.) Ex.	Proteaceae	T
Grewia bicolor (A.Juss)	Tiliaceae	T
Hagenia abyssinica (Bruce)	Rosaceae	T
Juniperus procera Hochst .Ex.	Cupressaceae	Sh
Justicia schimperiana L.	Acanthaceae	Sh
Lippia adoensis Hochst.	Verbenaceae	T
Maesa lanceolata Forssk.	Myrsinaceae	T
Mangifera indica L.	Anacardiaceae	T
Maytenus arbutifolia (A. Rich.)	Celastraceae	T
Millettia ferruginea (Hochst.)	Fabaceae	T
Nuxia congesta R.Br. ex Fresen	Buddleiaceae	T
Ocimum lamiifolium Hochst	Lamiaceae	Sh
Olea europaea L. subsp. cuspidata	Oleaceae	T
Osyris quadripartita Decne	Santalaceae	T
Otostegia integrifolia Benth.	Lamiaceae	Sh
Persea americana Mill.	Lauraceae	T
Pinus patula (Schiede ex Schltdl).	Pinaceae	T
Podocarpus falcatus (Thunb.)	Podocarpaceae	T
Premna schimperi Engl.	Lamiaceae	T
Prunus africana (Hook.f.)	Rosaceae	T
Prunus persica (L.). Batsch.	Rosaceae	T
Psidium guajava L.	Myrtaceae	T
Rhamnus prinoides L'Herit.	Rhamnaceae	Sh
Rhoicissus tridentata (L. f.) Wild & Drummond	Vitaceae	Sh
Rhus vulgaris Meikle	Anacardiaceae	T
Ricinus communis L.	Euphorbiaceae	Sh
Schefflera abyssinica (Hochst.Ex)	Araliaceae	T
Sesbania sesban (L.) Merr.	Fabaceae	Sh
Spathodea campanulata P. Beauv.	Bignoniaceae	T
Syzygium guineense (Willd.).CD.	Myrtaceae	T
Vachellia abyssinica Benth.	Fabaceae	T
Vachellia etbaica Schweinf.	Fabaceae	T
Vachellia sieberiana (DC.) Kyal	Fabaceae	T
Vernonia amygdalina Del.	Asteraceae	T
Vernonia myriantha Hook.f.	Asteraceae	T

Table 2: Family of woody species collected from parkland agroforestry.

Family woody species	Frequency of family	% of family
Anacardiaceae	1	2.1
Araliaceae	1	2.1
Asteraceae	2	4.2
Boraginaceae	1	2.1
Buddleiaceae	1	2.1
Capparidaceae	1	2.1
Celastraceae	1	2.1
Cupressacea	2	4.2
Ebinaceae	1	2.1
Euphorbiaceae	1	2.1
Fabaceae	11	23
Icacinaceae	1	2.1
Lamiaceae	1	2.1
Moraceae	4	8.3
Meliaceae	2	4.2
Myrtaceae	1	2.1
Myrsinaceae	1	2.1
Oleaceae	1	2.1
Pinaceae	1	2.1
Podocarpaceae	1	2.1
Proteaceae	1	2.1
Rosaceae	2	2.1
Rutaceae	1	2.1
Santalaceae	1	2.1
Sapindaceae	2	4.2
Tiliaceae	1	2.1
Thymedaeaceae	1	2.1
Ulmaceae	1	2.1
Vitaceae	1	2.1
Total	47	96.4

Table 3: List of woody species collected from parkland agroforestry in the study area.

Species name	Family	Local name	Growth form
Albizia grandibracteta	Fabaceae	Imalaa	T
Albizia gummifera (G.F. Gmel.)	Fabaceae	Ambabesaa	T
Allophylus abysinicus (Hochst).	Sapindaceae	Sarara	T
Apodytes dimidiata E. Mey. Ex	Icacinaceae	Qumbala	T
Azadirachta indica A. Juss	Meliaceae	Muka mini	T
Bersama abyssinica Fres.	Sapindaceae	Lolchiisaa	T
Clausena anisata (Willd). Benth	Rutaceae	Ulmaayyii	T
Celtis africana Burm.f.	Ulmaceae	Cayyii	T
Cordia africana L.	Boraginaceae	Wadeessaa	T
Croton macrostachyus Del.	Euphorbiaceae	Bakkannisaa	T
Cupressus lusitanica Mill.	Cupressaceae	Gaatiraa faranji	T
Dodonaea angustifolia L	Sapindaceae	Ittachaa	T
Ekebergia capensis Sparrman.	Meliaceae	Somboo	T
Erythrina abyssinica Lam. Ex.	Fabaceae	Ambaltaa	T
Erythrina brucei Schweinf	Fabaceae	Walensuu	T
Euclea schemperi (A.DC).Dandy	Fabaceae	Mi;eessaa	T
Faidherbia albida (Del.)	Fabaceae	Garbii	T
Ficus sur Forssk	Moraceae	Harbuu	T
Ficus sycomorus L.	Moraceae	Odaa	T
Ficus vasta Forssk.	Moraceae	Qilxuu	T
*Grevillea robusta (*A. Cunn.) Ex.	Proteaceae	Graviliyaa	T
Grewia bicolor (A.Juss)	Tiliaceae	Haroresa	T
Gnidia glauca (Fresen.) Gilg.	Proteaceae	Qaqaroo	T
Hagenia abyssinica (Bruce).	Rosaceae	Heexoo	T
Juniperus procera (Hochst).Ex.	Cupressaceae	Gatiraa faranjii	T

Table 3: Continued.

Species name	Family	Local name	Growth form
Maesa lanceolata Forssk.	Myrsinaceae	Kombolcha	T
Maytenus arbutifolia (A. Rich.)	Celastraceae	Kombolcha	T
Millettia ferruginea (Hochst.)	Fabaceae	Birbiraa	T
Nuxia congesta R.Br. ex Fresen	Buddleiaceae	Anfaraa	T
Olea europaea L. subsp. cuspidata	Oleaceae	Ejersaa	T
Osyris quadripartita Decne	Santalaceae	Waatoo	T
Podocarpus falcatus (Thunb.)	Podocarpaceae	Birbirsa	T
Premna schimperi Engl.	Lamiaceae	Urgeessaa	T
Prunus africana (Hook.f.)	Rosaceae	Hoomii	T
Pinus patula (Schiede ex Schltdl).	Pinaceae	Shawushawee	T
Rhoicissus tridentata	Vitaceae	Dhangagoo	T
Rhus vulgaris Meikle	Anacardiaceae	Xaaxessaa	T
Schefflera abyssinica (Hochst.Ex)	Araliaceae	Gatamaa	T
Sesbania sesban (L.) Merr.	Fabaceae	Sesabaniya	T
Syzygium guineense (Willd.).CD.	Myrtaceae	Baddeessaa	T
Vachellia abyssinica Benth.	Fabaceae	Laaftoo	T
Vachellia etbaica Schweinf.	Fabaceae	Doddotaa	T
Vachellia sieberiana (DC.) Kyal	Fabaceae	Laaftoo adii	T
Vernonia amygdalina Del.	Asteraceae	Eebicha	T
Vernonia myriantha Hook.f.	Asteraceae	Rejjii	T

Table 4: List of trees and shrubs collected from home garden agroforestry in the study area.

Species name	Family	Local name	Growth form
Azadirachta indica A. Juss	Meliaceae	Nimi	T
Calpurina aurea (Ait.)	Fabaceae	Ceekaa	Sh
Casuarina equisetifolia L.	Casuarinaceae	Shawishawe	T
Catha edulis (Vahl) Forssk	Celastraceae	Jiimaa	Sh
Celtis africana Burm.f.	Ulmaceae	Cayyii	T
Citrus aurantifolia (christm.)	Rutaceae	Loomii	Sh
Citrus medica L. (Citron)	Rutaceae	Turungoo	Sh
Citrus sinensis (L.)	Rutaceae	Burtukaanaa	Sh
Clausena anisata (Willd). Benth	Rutaceae	Ulmaayyii	T
Coffee arabica L.	Rubiaceae	Buna	Sh
Cordia africana Lam.	Boraginaceae	Waddeessa	T
Croton macrostachyus Del.	Euphorbiaceae	Bakkannisaa	T
Cupressus lusitanica Mill.	Cupressaceae	Gatiraa faranjii	T
Faidherbia albida Del.	Fabaceae	Laaftoo garbii	T
Grevillea robusta (A. Cunn.)	Proteaceae	Gravilliyaa	T
Hagenia abyssinica (Bruce)	Rosaceae	Heexoo	T
Juniperus procera Hochst .Ex.	Cupressaceae	G/habasha	T
Justicia schimperiana L.	Acanthaceae	Dhumugaa	Sh
Lippia adoensis Hochst.	Verbenaceae	Koshonnota	Sh
Mangifera indica L.	Anacardiaceae	Maangoo	T
Millettia ferruginea Hochst.	Fabaceae	Birbiraa	T
Ocimum lamiifolium Hochst	Lamiaceae	Ancabbii diimaa	Sh
Olea europaea (L.). subsp. cuspidata	Oleaceae	Ejersaa	T
Otostegia integrifolia Benth.	Lamiaceae	Xunjitii	Sh
Podocarpus falcatus (Thunb.)	Podocarpaceae	Birbirsa	T
Persea americana Mill.	Lauraceae	Avokadoo	T
Prunus africana (Hook. f.)	Rosaceae	Hoomii	T
Pinus patula Schiede ex Schltdl.	Pinaceae	Shawshawe	T
Prunus persica (L.). Batsch.	Rosaceae	Kokii	T
Psidium guajava L.	Myrtaceae	Zaayituna	T
Rhamnus prinoides L'Herit.	Rhamnaceae	Geeshoo	Sh
Ricinus communis L.	Euphorbiaceae	Qoobboo	Sh
Sesbania sesban (L.) Merr.	Fabaceae	Sasbaniya	Sh
Spathodea campanulata P. Beauv.	Bignoniaceae	Annonobo	T
Vernonia amygdalina (Del.)	Asteraceae	Ebbichaa	T

T = tree; Sh = shrub.

Table 5: Family of woody species collected from home garden agroforestry.

Family woody species	Frequency of family	% of family
Acanthaceae	1	2.4
Anacardiaceae	2	4.8
Asteraceae	1	2.4
Bignoniaceae	1	2.4
Boraginaceae	1	2.4
Casuarinaceae	1	2.4
Celastraceae	1	2.4
Cupressaceae	2	4.8
Euphorbiaceae	2	4.8
Fabaceae	4	9.5
Lamiaceae	4	9.5
Lauraceae	1	2.4
Meliaceae	1	2.4
Myrtaceae	1	2.4
Oleaceae	1	2.4
Pinaceae	1	2.4
Podocarpaceae	1	2.4
Proteaceae	1	2.4
Rhamnaceae	2	4.8
Rosaceae	5	11.9
Rubiaceae	1	2.4
Rutaceae	5	11.9
Ulmaceae	1	2.4
Verbenaceae	1	2.4
Total	42	100

Table 6: Species richness (n), Shannon diversity (H'), and evenness (E) among the three agroecologies of parkland and home garden in the study areas.

Agroecology	Parkland agroforestry			Home garden agroforestry		
	Species richness (n)	Shannon (H')	Evenness (E)	Species richness (n)	Shannon (H')	Evenness (E)
Highland	20	2.7	0.54	10	2.3	0.48
Midland	38	3.4	0.62	20	3.2	0.51
Lowland	18	2.3	0.45	9	2.1	0.41
Overall mean	25.33	2.8	0.54	13	2.53	0.47

and home garden agroforestry practices ($P > 0.05$). In this study, it was found that in lowland agroecology was the highest mean value of IVI (16.67 ± 3.46), but the lowest mean value of IVI was recorded at midland agroecology (7.9 ± 0.52) for parkland agroforestry practice (Table 7), whereas in lowland agroecology, the highest mean value of IVI was 33.33 ± 2.80, but the lowest mean value of IVI was recorded at midland agroecology (15 ± 0.97) for home garden agroforestry practice.

3.2.2. Basal Area for Selected Woody Species in Parkland Agroforestry. The total basal area of all parkland agroforestry woody species in highland, midland, and lowland agroecology was calculated for each woody species in the study area. Among the three agroecologies, parkland agroforestry in lowland had the highest basal area for woody species (Table 8). For the woody species *Prunus africana* ($0.54\,m^2{\cdot}ha^{-1}$), *Olea europaea* subsp. *cuspidata* ($0.42\,m^2{\cdot}ha^{-1}$), *Faidherbia albida* ($0.24\,m^2{\cdot}ha^{-1}$), and *Ficus sur* ($0.26\,m^2{\cdot}ha^{-1}$), the highest basal area were computed in parkland agroforestry, but *Allophylus abyssinica* ($0.08\,m^2{\cdot}ha^{-1}$), *Cupressus lusitanica* ($0.08\,m^2{\cdot}ha^{-1}$), *Clausena anisata* ($0.08\,m^2{\cdot}ha^{-1}$), and *Juniperus procera* ($0.04\,m^2{\cdot}ha^{-1}$) were the species with the lowest basal area in parkland agroforestry of highland sites (Tables 8 and 9). The total basal areas of woody species in highland, midland, and lowland agroecologies were $3.3\,m^2{\cdot}ha^{-1}$, $5.8\,m^2{\cdot}ha^{-1}$, and $3.85\,m^2{\cdot}ha^{-1}$, respectively, in parkland agroforestry practice (Tables 10–12).

3.2.3. Basal Area of Selected Woody Species in Home Garden Agroforestry. *Azadirachta indica*, *F. albida*, *C. lusitanica*, and *C. anisata* were the species with the highest basal area, and *J. procera, P. africana, Sesbania sesban,* and *Millettia ferruginea* were woody species in home garden agroforestry in the highland of the study sites (Tables 13 and 14). *A. indica*, *Calpurnia aurea, C. africana,* and *C. Macrostachyus* woody species were with the highest basal area, and *O. europaea* subsp. *cuspidata, J. procera, Podocarpus falcatus,* and *Spathodea campanulata* were with the lowest basal area

Table 7: Mean basal area and IVI of woody species in the three agroecologies under parkland and home garden agroforestry practices.

Parameter	Highland ($N=20$)	Midland ($N=38$)	Lowland ($N=18$)
Parkland agroforestry			
Basal area (m^2/ha)	0.17 ± 0.03^a	0.15 ± 0.03^a	0.21 ± 0.06^a
IVI	15 ± 3.38^a	7.9 ± 0.52^b	16.67 ± 3.46^a
	Highland ($N=10$)	Midland ($N=20$)	Lowland ($N=9$)
Home garden agroforestry			
Basal area (m^2/ha)	0.85 ± 0.17^a	0.69 ± 0.17^a	0.50 ± 0.16^a
IVI	30 ± 2.34^a	15 ± 0.97^b	33.33 ± 2.80^a

Superscripts with similar letters are statistically not significant, but different letters are statistically significant.

Table 8: Selected species with the highest basal area under parkland agroforestry in different agroecologies.

Agroecology	Species name	BA ($m^2 \cdot ha^{-1}$)	RF	RDom	RD	IVI
Highland	*Prunus africana* (Hook.f.)	0.54	22.3	20.03	18.3	60.6
	Ficus sur Forssk.	0.26	12.2	20.2	13.5	45.9
	Faidherbia albida Del.	0.24	5.7	19.6	11.6	36.9
	Olea europaea L.	0.42	13.3	2.1	3.6	19
	Maytenus arbutifolia (A.Rich)	0.13	1.1	12.3	3.1	16.5
Midland	*Faidherbia albida* Del.	0.2	5.1	2.3	11	18.4
	Acacia abyssinica Hochst.	0.29	7.8	2.19	5.1	15.09
	Prunus africana (Hook.f.)	0.22	1.8	0.7	12	14.5
	Albizia gummifera (G.F.Gmel.)	0.4	5.7	3.15	2.5	11.35
	Croton macrostachyus Del.	0.8	2.3	2.35	3	10.9
Lowland	*Croton macrostachyus* Del.	1.22	30.1	21.09	17.2	68.39
	Maytenus arbutifolia A.Rich	0.2	2.8	9.9	14.7	27.4
	Acacia abyssinica Hochst.	0.42	6.8	8	10.9	25.7
	Ficus vasta Forssk.	0.24	9.2	9.25	5.6	24.05
	Cordia africana L.	0.28	6.7	7.93	7.85	22.48

Note. BA is the basal area, RF is the relative frequency, RDom is the relative dominance, RD is the relative density, and IVI is the importance value index.

Table 9: Basal area of parkland agroforestry.

Species name	Abundance	BA per plot (m^2)	BA (m^2/ha)
Albizia grandibracteta	1	0.08	0.1
Albizia gummifera (G.F. Gmel.)	10	1.7	0.4
Allophylus abysinicus (Hochst)	1	0.11	0.08
Apodytes dimidiata E. Mey.	13	1.74	0.35
Azadirachta indica A.Juss	2	0.08	0.08
Bersama abyssinica Fresen.	2	0.14	0.08
Clausena anisata (Willd). Benth	3	0.41	0.16
Celtis africana Burm.f.	5	0.45	0.13
Cordia africana L.	42	7.46	0.84
Croton macrostachyus Del.	88	11.23	2.02
Cupressus lusitanica Mill.	1	0.05	0.08
Dodonaea angustifolia L	9	0.83	0.18
Ekebergia capensis Sparrm.	15	2.99	0.3
Erythrinaabyssinica Lam. Ex.	5	1	0.13
Erythrina brucei Schweinf	9	1.9	0.22
Euclea schemperi (A.DC).Dandy	5	0.46	0.14
Faidherbia albida (Del)	22	4.3	0.44
Ficus sur Forssk	26	5.77	0.52
Ficus sycomorus L.	3	0.57	0.08
Ficus vasta Forssk.	17	3.9	0.34
Grevillea robusta	1	0.06	0.08
Grewia bicolor	1	0.09	0.1
Gnidia glauca (Fresen.) Gilg	1	0.26	0.1
Hagenia abyssinica (Bruce)	8	1.46	0.21
Juniperus procera Hochst.	2	0.25	0.08

Table 9: Continued.

Species name	Abundance	BA per plot (m^2)	BA (m^2/ha)
Maesa lanceolata Forssk	2	0.25	0.08
Maytenus arbutifolia (A.Rich.)	29	2.66	0.38
Millettia ferruginea (Hochst)	7	1.02	0.19
Nuxia congesta R.Br. ex Fresen	13	1.25	0.26
Olea europaea L. subsp.	42	5	0.84
Osyris quadripartita Decne	7	1	0.19
Podocarpus falcatus (Thunb.)	19	3.91	0.38
Premna schimperi Engl.	4	0.25	0.11
Prunus africana (Hook.f.)	38	5.9	0.76
Prunus patula(Schiede ex Schltdl.)	1	0.05	0.08
Rhoicissus tridentata	3	0.2	0.36
Rhus vulgaris Meikle	2	0.04	0.08
Schefflera abyssinica (Hochst)	1	0.11	0.08
Sesbania sesban (L.) Merr.	2	0.33	0.08
Syzygium guineense (Willd.)	4	0.39	0.08
Vachellia abyssinica Hochst.	43	5.55	0.57
Vachellia etbaica Schweinf.	12	1.74	0.5
Vachellia sieberiana (DC.) Kyal.	1	0.28	0.1
Vernonia amygdalina Del.	28	2.74	0.56
Vernonia myriantha Hook.f.	1	0.05	0.08
Total	551	80.01	13

Table 10: Parkland agroforestry woody species data collected from highland agroecology.

Species name	Abundance	BA per plot (m^2)	BA (m^2/ha)	RF	RDom	RD	IVI
Allophylus abysinicus Hochst.	1	0.11	0.08	3.1	0.4	5.1	8.6
Clausena anisata (Willd).	1	0.2	0.08	7.1	0.3	1.1	8.5
Cupressus lusitanica Mill.	1	0.05	0.08	1.2	0.3	5.3	6.8
Ekebergia capensis Sparrm.	9	1.71	0.18	2.3	1.7	7.5	11.5
Faidherbia albida Del.	12	2.45	0.24	5.7	19.6	11.6	36.9
Ficus sur Forssk.	13	2.99	0.26	12.2	20.2	13.5	45.9
Hagenia abyssinica (Bruce).	6	1.26	0.16	6.5	2.3	2.4	11.2
Junperus procera (Hochst).	1	0.12	0.04	1.2	0.9	4.1	6.2
Maesa lanceolata Forssk.	2	0.21	0.08	1.4	2.3	2	5.7
Maytenus arbutifolia(A.Rich)	10	0.77	0.13	1.1	12.3	3.1	16.5
Nuxia congesta R.Br.	10	0.96	0.2	1.5	7.02	3.6	12.12
Olea europaea subsp. *cuspidata* L.	21	3.04	0.42	13.3	2.1	3.6	19
Osyris quadripartita Decne.	3	0.33	0.08	0.2	0.3	3.3	3.8
Podocarpus falcatus (Thunb.)	9	2.12	0.18	1.2	3.6	2.1	6.9
Premna schimperi Engl.	3	0.2	0.08	3.2	0.51	0.2	3.91
Prunus africana (Hook.f.)	27	4.61	0.54	22.3	20.03	18.3	60.6
Rhoicissus tridentata	2	0.15	0.06	5.3	1.04	2.2	8.5
Schefera abyssinica (Hochst).	1	0.11	0.08	4.1	0.6	1.1	5.8
Vachellia abyssinica Hochst	8	1.08	0.11	5.2	3.1	6.2	14.5
Vernonia amygdalina Del.	12	0.74	0.24	1.9	1.4	3.7	7
Total	152	23.2	3.32	100	100	100	300

Table 11: Parkland agroforestry woody species data collected from midland agroecology.

Species name	Abundance	BA per plot (m^2)	BA (m^2/ha)	RF	RDom	RD	IVI
Albizia grandibracteta	1	0.08	0.1	1.2	2.38	1.1	4.68
Albizia gummifera (G.F.Gmel.)	10	1.7	0.4	5.7	3.15	2.5	11.35
Azadirachta indica A.Juss	2	0.08	0.08	0.7	4.7	2.2	7.6
Apodytes dimidiata E. Mey.	1	0.02	0.03	1.5	3.7	1.1	6.3
Bersama abyssinica Fresen.	2	0.14	0.08	2.17	3.7	2.1	7.97
Cordia africana Lam	28	4.68	0.56	4.8	4.1	1.1	10
Croton macrostachyus Del.	27	2.63	0.8	2.3	2.35	3	10.9
Celtis africana Burm.F.	3	0.31	0.08	3.07	3.6	2.1	8.77

Table 11: Continued.

Species name	Abundance	BA per plot (m^2)	BA (m^2/ha)	RF	RDom	RD	IVI
Dodonaea angustifolia L. f.	3	0.36	0.06	3.6	1.9	3.3	8.8
Ekebergia capensis Sparrm.	6	1.28	0.12	2.4	2.7	3.2	8.3
Erythrina brucei Schweinf	3	0.49	0.08	3.3	2.7	3.3	9.3
Erythrina abyssinica Lam.	2	0.42	0.05	2.4	1.8	2.2	6.4
Euclea schemperi (A.DC).D	2	0.15	0.06	2.4	2.8	2.2	7.4
Faidherbia albida Del.	10	1.85	0.2	5.1	2.3	11	18.4
Ficus sur Forssk	13	2.78	0.26	3.4	3.2	3.8	10.4
*Ficus sycomorus*Forssk.	3	0.57	0.08	2.5	4.7	3.1	7.65
Ficus vasta Forssk	5	0.92	0.1	4.5	1.3	1.4	7.2
Grevillea robusta R. Br.	1	0.06	0.08	1.2	2.3	1.1	4.6
Hagenia abyssinica (Bruce)	2	0.2	0.05	2.4	1.4	2.2	6
Juniperus procera Hochst.	1	0.13	0.04	1.5	2.8	1.1	5.4
Maytenus arbutifolia (A. Rich)	4	0.34	0.05	2.1	1.9	4.4	8.4
Millettia ferruginea (Hochst)	3	0.42	0.08	3.7	3.7	2.2	9.6
Nuxia congesta R.Br.	3	0.29	0.06	3.4	1.6	2.2	7.2
Osyris quadripartita Decne	1	0.26	0.03	1.2	0.6	1.1	2.3
Olea europaea L.	21	1.96	0.42	3.5	1.7	2.8	8
Podocarpus falcatus (Thunb)	10	1.79	0.2	2.8	2.5	1.9	7.2
Prunus africana (Hook.f.)	11	1.29	0.22	1.8	0.7	12	14.5
Pinus patula (Schiede ex).	1	0.05	0.08	1.2	2.3	1.1	4.6
Premna schimperi Engl.	1	0.05	0.03	0.12	1.5	1.1	2.72
Rhoicissus tridentata	1	0.05	0.3	1.1	0.5	1.1	2.7
Rhus vulgaris Meikle.	2	0.04	0.08	2.1	3.8	2.1	8
Sesbania sesban (L.) Merr.	2	0.33	0.08	2.7	3.2	2.2	8.1
Syzygium guineense (Willd)	1	0.05	0.02	1.2	2.7	1.1	5
Vachellia abyssinica Hochst.	22	2.56	0.29	7.8	2.19	5.1	15.09
Vachellia etbaica Schweinf.	2	0.19	0.08	2.47	3.28	2.2	7.95
Vachellia sieberiana (DC.)	1	0.28	0.1	1.27	4.45	1.1	6.82
Vernonia amygdalina Del.	16	2	0.32	4.5	3.5	2.1	10.1
Vernonia myriantha Hook.f.	1	0.05	0.08	0.9	2.3	1.1	4.3
Total	22	30.85	5.83	100	100	100	300

Table 12: Parkland woody species data collected from lowland agroecology.

Species name	No	BA (p)	BA (ha)	RF	RDom	RD	IVI
Apodytes dimidiata E. Mey.	12	1.72	0.32	3.9	4.05	4.22	12.17
Clausena anisata (Willd).	2	0.21	0.08	2.2	1.43	2.2	5.83
Celtis africana Burm.f.	2	0.14	0.05	5.2	0.32	2.2	7.72
Cordia africana L.	14	2.78	0.28	6.7	7.93	7.85	22.48
Croton macrostachyus Del.	61	8.6	1.22	30.1	21.09	17.2	68.39
Dodonaea angustifolia L	6	0.47	0.12	6.1	7.83	6.43	20.36
Erythrina abyssinica Lam.	3	0.58	0.08	2.9	3.83	3.12	9.85
Erythrina brucei Schweinf.	6	1.41	0.14	6.2	9.74	6.42	22.36
Euclea schemperi (A.DC).D	3	0.31	0.08	2.8	2	3.03	7.83
Ficus vasta Forssk.	12	2.98	0.24	9.2	9.25	5.6	24.05
Grewia bicolor (A.Juss)	1	0.09	0.1	0.9	0.17	1.01	2.08
Gnidia glauca (Fresen.)	1	0.26	0.1	0.9	1.57	1.01	3.48
Maytenus arbutifolia A.Rich	15	1.55	0.2	2.8	9.9	14.7	27.4
Millettia ferruginea Hochst.	4	0.6	0.11	3.8	2.01	4.03	9.84
Osyris quadripartita Decne	3	0.41	0.08	2.8	2.3	3.03	8.13
Syzygium guineense (Willd.)	3	0.34	0.06	3	2.26	3.21	8.47
Vachellia abyssinica Hochst.	13	1.91	0.42	6.8	8	10.9	25.7
Vachellia etbaica Schweinf.	10	1.55	0.17	3.7	6.32	3.84	13.86
Total	171	25.9	3.85	100	100	100	300

computed for woody species of midland in home garden agroforestry (Table 15). *C. africana, C. macrostachyus*, *Persea americana*, and *S. Campanulata* woody species were the species with the highest basal area, and *S. sesban sinensis* and *C. aurea* were the species with the lowest basal area (Table 16). Total basal areas of home garden woody species in highland, midland, and lowland agroecology were 7.2 $m^2 \cdot ha^{-1}$, 23.2 $m^2 \cdot ha^{-1}$, and 6.3 $m^2 ha^1$, respectively (Tables 14–16).

Table 13: Importance value index of selected woody species under home garden agroforestry.

Agroecology	Species name	BA ($m^2 \cdot ha^{-1}$)	RF	RDom	RD	IVI
Highland	*Cupressus lusitanica* Mill.	1.15	15.1	12.5	12.3	39.9
	Vernonia amygdalina Del.	0.82	13.2	15.2	10.7	39.1
	Azadirachta indica A.Juss	1.25	13.4	14.5	7.5	35.4
	Prunus africana (Hook. f.)	0.25	12.3	9.5	11.5	33.3
	Faidherbia albida Del.	2.13	11.8	6.1	15	32.9
Midland	*Grevillea robusta* (A.Cunn)	0.58	10.6	7.1	4.6	22.3
	Olea europaea L.	0.13	5.9	7.5	6.7	20.1
	Clausena anisata (Willd).	0.75	7.4	4.6	7.4	19.4
	Cordia africana Lam.	2.06	4.1	4.1	10.7	18.9
	Cupressus lusitanica Mill.	0.9	7.2	6.4	5.3	18.9
Lowland	*Croton macrostachyus* Del.	1.4	19.1	20.1	10.5	49.7
	Mangifera indica L.	0.89	5.3	12.6	21.1	39
	Millettia ferruginea Hochst.	0.36	21.3	7.5	9.3	38.1
	Cordia africana Lam.	1.11	13.2	15.5	7.6	36.3
	Calpurnia aurea (Ait.)	0.25	8.4	8.6	17.4	34.4

Note. BA is the basal area, RF is the relative frequency, RDom is the relative dominance, RD is the relative density, and IVI is the importance value index.

Table 14: Home garden basal area BA (m^2) in highland agroecology.

Species name	BA per plot (m^2)	BA (m^2/ha)	RF	RDom	RD	IVI
Azadirachta indica A.Juss	0.23	1.25	13.4	14.5	7.5	35.4
Juniperus procera (Hochst).	0.15	0.16	8.2	13.4	6.2	27.8
Clausena anisata (Willd).	0.08	1	6.1	8.1	14.1	28.3
Cupressus lusitanica Mill.	0.6	1.15	15.1	12.5	12.3	39.9
Faidherbia albida Del.	1.02	2.13	11.8	6.1	15	32.9
Hagenia abyssinica (Bruce)	0.03	0.75	6.3	7.3	7.4	21
Millettia ferruginea Hochst.	0.35	0.65	5.4	6.3	5.7	17.4
Sesbania sesban (L.) Merr.	0.05	0.31	8.2	7.1	9.6	24.9
Prunus africana (Hook. f.)	0.01	0.25	12.3	9.5	11.5	33.3
Vernonia amygdalina Del.	1.05	0.82	13.2	15.2	10.7	39.1
Total	3.57	8.47	100	100	100	300

Table 15: Home garden basal area BA (m^2) in midland agroecology.

Species name	BA/plot (m^2)	BA (m^2/ha)	RF	RDom	RD	IVI
Azadirachta indica A.Juss	1.67	2.8	5.6	6.5	4.6	16.7
Calpurnia aurea (Ait.)	0.56	3.5	3.6	5.8	3.4	12.8
Casuarina equisetifolia L.	0.03	0.75	3.1	1.7	1.1	5.9
Celtis africana Burm.f.	0.05	1.25	1.7	1	8.1	10.8
Citrus sinensis (L.)	0.56	0.54	6.8	10.1	0.9	17.8
Clausena anisata (Willd).	0.09	0.75	7.4	4.6	7.4	19.4
Cordia africana Lam.	2.23	2.06	4.1	4.1	10.7	18.9
Croton macrostachyus Del.	2.06	1.72	3.2	5.8	7.6	16.6
Cupressus lusitanica Mill.	0.65	0.9	7.2	6.4	5.3	18.9
Faidherbia albida Del.	1.2	1.5	5.3	9.6	2.1	17
Grevillea robusta (A.Cunn)	0.07	0.58	10.6	7.1	4.6	22.3
Juniperus procera Hochst	0.06	0.3	2.3	5.5	6.7	14.5
Olea europaea L. *subsp. cuspidata*	0.02	0.13	5.9	7.5	6.7	20.1
Persea americana Mill.	0.82	0.89	6.2	3.7	2.5	12.4
Podocarpus falcatus Thunb.	0.01	0.25	3.7	6.1	8.3	18.1
Prunus africana (Hook. f.)	0.02	0.5	0.9	7.3	5.8	14
Pinus patula Schiede Ex.	0.46	1.6	6.9	2.4	0.9	10.2
Sesbania sesban (L.) Merr.	0.92	1.04	3.9	3.6	4	11.5
Spathodea campanulata P.	0.12	0.5	7.9	0.7	6.2	14.8
Vernonia amygdalina Del.	2.28	1.6	3.7	0.5	3.1	7.3
Total	13.88	23.16	100	100	100	300

Table 16: Home garden basal in lowland agroecology.

Species name	BA per plot (m^2)	BA (m^2/ha)	RF	RDom	RD	IVI
Calpurnia aurea (Ait.)	0.05	0.25	8.4	8.6	17.4	34.4
Citrus sinensis (L.)	0.08	0.2	7.2	6.4	6.3	19.9
Cordia africana Lam.	1.02	1.11	13.2	15.5	7.6	36.3
Croton macrostachyus Del.	1.32	1.4	19.1	20.1	10.5	49.7
Mangifera indica L.	0.89	0.89	5.3	12.6	21.1	39
Millettia ferruginea Hochst.	0.1	0.36	21.3	7.5	9.3	38.1
Persea americana Mill.	0.85	1.06	10.4	10.1	8.6	29.1
Sesbania sesban (L.) Merr.	0.04	0.05	8.9	7.5	6.7	23.1
Spathodea campanulata	0.2	1	6.2	11.7	12.5	30.4
Total	4.55	6.32	100	100	100	300

3.3. Importance Value Index of Woody Species

3.3.1. Importance Value Index of Selected Woody Species in Parkland Agroforestry. The importance value index of parkland woody species among highland, midland, and lowland agroecology of the study sites was evaluated. The IVI value-dominating tree species that grew under the three agroecologies are presented in Table (3). Among these, *P. africana* (60.6), *F. sur* (45.9), *F. albida* (36.9), and *O. europaea* subsp. *cuspidata* (19.0) were the species with the highest IVI of woody species in highland agroecology, whereas *Osyris quadripartite* (3.8), *Premna schimperi* (6.9), *Maesa lanceolata* (5.7), and *J. procera* (6.2) woody species were the lowest IVI of highland agroecology in parkland agroforestry practice (Table 10). *Faidherbia albida* (18.4), *Vachellia abyssinica* (15.1), *P. africana* (14.5), and *Albizia gummifera* (11.35) were the highest IVI for woody species in midland agroecology, whereas *O. quadripartite* (2.3), *Pinus patula* (4.6), *Rhoicissus tridentata* (2.7), and *Vernonia myriantha* (4.3) were the lowest IVI woody species in midland agroecology (Table 11). Meanwhile, the highest value of IVI was computed under lowland agroecology for *Croton macrostachyus* (68.4), *F. vasta* (24.1), and *Maytenus arbutifolia* (27.4), and *A. abyssinica* (25.7) had the highest IVI of woody species for lowland agroecology. But *C. anisata* (5.83), *G. bicolor* (2.08), and *Gnidia glauca* (3.48) had the lowest IVI for woody species in lowland agroecology (Table 12).

3.3.2. Importance Value Index of Selected Woody Species in Home Garden Agroforestry. The importance value index woody species in highland, midland, and lowland agroecologies of home garden agroforestry in the study area were evaluated. Among recorded woody species, 5 species with the highest importance value index were selected from three agroecologies (Table 13). From those woody species, *Vernonia amygdalina* (39), *C. lusitanica* (39.9), *Azadirachta indica* (35.4), *P. africana* (33.3), and *F. albida* (32.9) were the highest IVI from highland agroecology (Table 14). *G. robusta* (22.3), *O. europaea* (20.1), *C. anisata* (19.4), and *C. africana* (18.9) were woody species with the highest IVI in midland agroecology. *Casuarina equisetifolia* (5.9) was the species with the lowest IVI from midland agroecology (Table 15), whereas *M. ferruginea* (38), *H. abyssinica* (21), and *S. sesban* (24.9) were the lowest IVI woody species identified from lowland agroecology (Table 16). *C. macrostachyus* (49.7), *Mangifera indica* (39), *Millettia ferruginea* (38), *C. africana* (36.3), and *Calpurnia aurea* (34.4) were the species with the highest IVI from lowland agroecology. But *S. sesban* (23.1) was woody species with the lowest IVI in lowland agroecology (Table 16).

3.3.3. Diameter Class Distribution of Woody Species in Parkland Agroforestry. Woody species in parkland were classified into six diameter classes based on their stem thickness. These classes included 20–50 cm, 51–80 cm, 81–110 cm, 111–140 cm, 141–170 cm, and 171–200 cm diameter as shown in graphical representation. Distribution of diameter classes between 111 and 140 cm had the highest number of species in parkland agroforestry followed by 81–110 cm diameter classes (Figure 2). In this class distribution, the most dominant woody species that existed were *V. etbaica*, *N. congesta*, *C. macrostachyus*, *V. abyssinica*, *P. africana*, *F. albida*, *P. falcatus*, and *O. europaea*,.

The diameter classes' distribution between 171 and 200 cm has the lowest number of tree species in parkland followed by 20–50 cm diameter class distribution. The biggest tree species which had the highest diameter DBH were found sparsely in this diameter class distribution in parkland agroforestry. *C. macrostachyus*, *V. abyssinica*, *P. africana*, *C. africana*, *F. vasta*, *C. africana*, and *F. albida* were the most dominant tree species in this class distribution. The diameter classes' distribution between 51 and 80 cm had a medium number of tree species followed by a 141–170 cm diameter class distribution. These were dominated by *V. abyssinica*, *O. europaea*, *P. africana*, *Nuxia congesta*, *F. sur*, *F. albida*, *P. falcatus*, and *E. capensis* woody species in parkland agroforestry.

3.4. Class Distribution of the Size of Woody Species

3.4.1. Diameter Class Distribution of Woody Species in Home Garden Agroforestry. In this study, only the diameter class distribution for woody species was presented. Species in the home garden were classified into six diameter classes based on their stem thickness. These classes include 10–30 cm, 31–60 cm, 61–90 cm, 91–120 cm, 121–150 cm, and >151 cm diameter as shown in graphical representation. Diameter

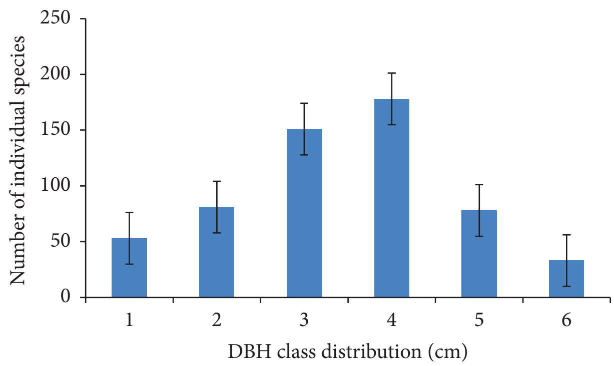

FIGURE 2: Diameter class distribution of woody species in parkland agroforestry (1 = 20–50 cm, 2 = 51–80 cm, 3 = 81–110 cm, 4 = 111–140 cm, 5 = 141–170 cm, and 6 = 171–200 cm).

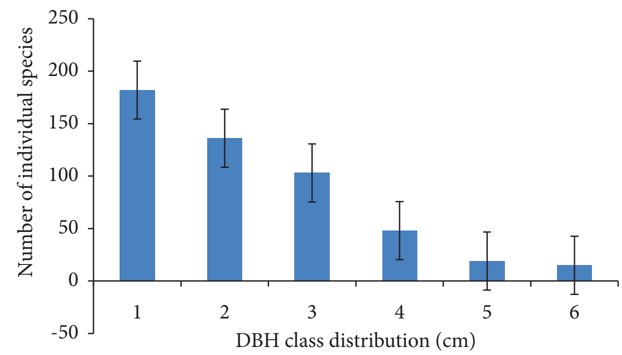

FIGURE 3: Diameter class distribution of tree species in home garden agroforestry (1 = 10–30 cm, 2 = 31–60 cm, 3 = 61–90 cm, 4 = 91–120 cm, 5 = 121–150 cm, and 6 = ≥151 cm).

classes between 10 and 30 cm have the highest number of trees and shrubs followed by 31–60 cm diameter classes and 61–90 cm diameter classes in the home garden, which is dominated by woody species of *C. sinensis, M. indica, P. americana, S. sesban, V. amygdalina,* and *A. indica* (Figure 3).

3.5. Carbon Stock Estimation. The aboveground and belowground carbon stocks and total carbon storage of woody species in both parkland and home garden agroforestry were calculated in the study area.

3.5.1. Biomass of Woody Species in Parkland Agroforestry. The average aboveground, belowground, and total biomass of woody species in highland, midland, and lowland agroecologies was 30.47 $MgCha^{-1}$, 6.1 $MgCha^{-1}$, and 36.57 $MgCha^{-1}$, respectively (Figure 4). The aboveground biomass of woody species in highland, midland, and lowland agroecology was 32.9 $MgCha^{-1}$, 29.2 $MgCha^{-1}$, and 29.3 $MgCha^{-1}$, respectively. The belowground biomass of woody species in highland, midland, and lowland agroecology was 6.6 $MgCha^{-1}$, 5.8 $MgCha^{-1}$, and 5.9 $MgCha^{-1}$, respectively. The total biomass of woody species in highland, midland, and lowland agroecology was 39.5 $MgCha^{-1}$, 35 $MgCha^{-1}$, and 35.2 $MgCha^{-1}$, respectively (Figure 4).

3.5.2. Estimation of Carbon Sequestration under Parkland Woody Species. Carbon dioxide is sequestered in woody species depending on the total biomass of woody species. The mean of carbon stored and carbon dioxide sequestered in parkland woody species were 18.3 $MgCha^{-1}$ and 67.1 tha^{-1}, respectively. The value of carbon stored in highland, midland, and lowland woody species in parkland was 19.8 $MgCha^{-1}$, 17.6 $MgCha^{-1}$, and 17.5 $MgCha^{-1}$, respectively (Figure 5). These resulted in carbon dioxide sequestered in highland, midland, and lowland woody species that were 144.9 CO_2 equivalent (tha^{-1}), 129.2 CO_2 equivalent (tha^{-1}), and 128.9 CO_2 equivalent (tha^{-1}), respectively (Figure 5).

3.5.3. Aboveground, Belowground, and Total Biomass of Wood Species in the Home Garden. The average aboveground, belowground, and total biomass of woody species in highland, midland, and lowland agroecology was 26.07 $MgCha^{-1}$, 6.77 $MgCha^{-1}$, and 32.83 $MgCha^{-1}$, respectively. The aboveground biomass of home garden woody species in highland, midland, and lowland agroecology was 25.9 $MgCha^{-1}$, 27.5 $MgCha^{-1}$, and 24.8 $MgCha^{-1}$, respectively. Meanwhile, the belowground biomass of woody species in highland, midland, and lowland agroecology was 6.7 $MgCha^{-1}$, 7.2 $MgCha^{-1}$, and 6.4 $MgCha^{-1}$, respectively. Thus, the total biomass of midland woody species in the home garden was 32.6 Mg/ha, 34.7 $MgCha^{-1}$, and 31.2 $MgCha^{-1}$, respectively (Figure 4).

3.5.4. Carbon Sequestration in Home Garden Woody Species. In this study, 16.43 $MgCha^{-1}$ storage of carbon and 120.13 tha^{-1} of carbon dioxide were sequestered in home garden woody species. The value of carbon stored in highland, midland, and lowland woody species in the home garden was 16.3 $MgCha^{-1}$, 17.6 $MgCha^{-1}$, and 17.5 $MgCha^{-1}$, respectively. The value of carbon dioxide sequestered in highland, midland, and lowland woody species was 59.76 tha^{-1}, 63.79 tha^{-1}, and 57.19 tha^{-1}, respectively (Table 17).

4. Discussion

4.1. Woody Species Composition and Diversity. In this study, a significant amount of species belonging to various families and genera was recorded from study agroecology in the parkland and home garden practices of agroforestry. For example, our study indicated that a higher number of species and families were recorded than the result reported by Molla and Kewessa [50] in Dellomenna of the Oromia region in southeast Ethiopia. The reason for the highest species richness in midland might be due to the availability of suitable conditions for growing different woody species, while lowland has low species richness because many woody species cannot easily adapt or tolerate the condition of lowland agroecology. This result is in line with Gochera et al. [51] who reported that species richness was higher in the

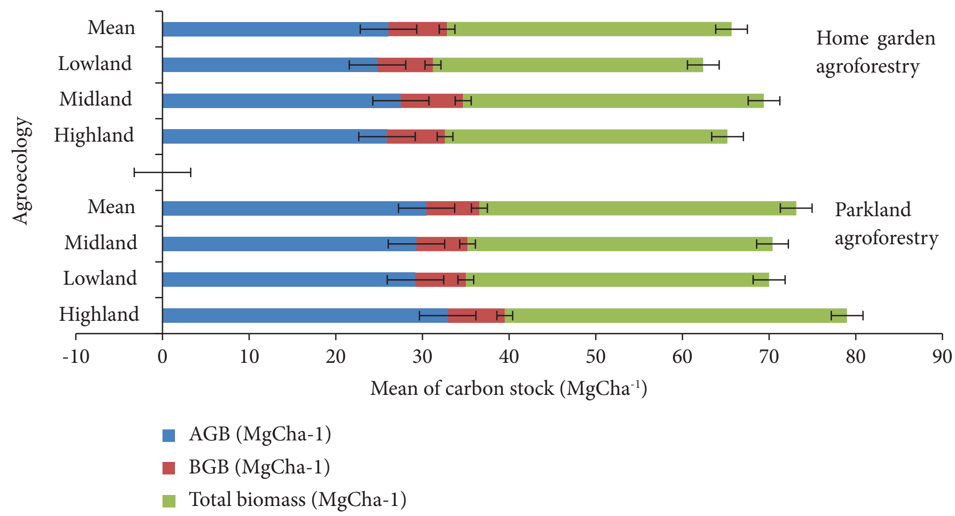

FIGURE 4: The aboveground, belowground, and total biomass of woody species for parkland and home garden practices.

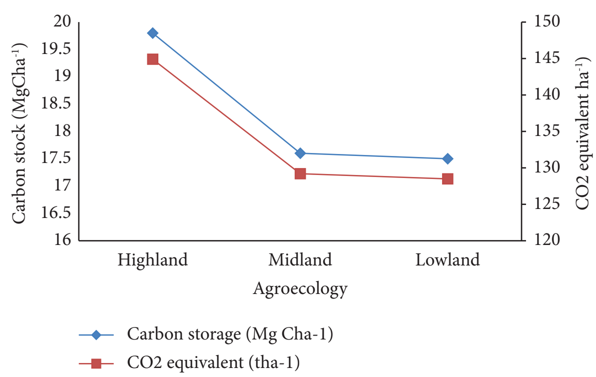

FIGURE 5: Carbon stored and carbon dioxide sequestered in parkland agroforestry practice.

TABLE 17: Carbon stored and carbon dioxide sequestered in home garden agroforestry.

Agroecology	Carbon storage ($MgCha^{-1}$)	CO_2 equivalent (tha^{-1})
Highland	16.3	59.76
Midland	17.4	63.79
Lowland	15.6	57.19
Total	16.43	60.25

midland followed by highland and lowland. However, our study was in disagreement with Tefera [52] who reported that lowland has high species diversity followed by highland and midland agroecology.

The Shannon evenness diversity of midland species in parkland and home garden was higher than in highland and lowland agroecology. This indicated that woody species in midland agroecology were sparsely growing or retained in both parkland and home garden agroforestry practices. The higher the Shannon evenness index, the more even distribution within the given area [53], and the lower evenness index dominates one or few species in the community. A report by Motuma et al. [54] revealed that the Shannon diversity index of woody species in crop fields was 2.22, and Guyassa et al. [55] revealed also that the woody species diversity index in cropland was 2.32 in Ethiopia. In the present study, the value of Shannon diversity in parkland agroforestry was higher when compared with [54, 55] reports.

4.2. Structure of Woody Species. In this study, results indicated that midland agroecology for woody species had the highest basal area followed by lowland and highland agroecology. The results were similar to Gochera et al. [51] who reported that woody species in parkland agroecology had the highest basal area in lowland followed by midland and highland agroecology. Results showed that the basal area of midland woody species was found to be the basal area of woody species in order of midland > highland > lowland. These results were in agreement with the reports of Latamo and Wondmagegn [24] who reported that a higher basal area was obtained in midland agroecology as many numbers of trees with the higher DBH class. Wood species that had the highest basal area provided multiple benefits like shade and improved soil fertility, fodder, and fuel wood for a household in the study area. Asfaw et al. [56] reported that *C. africana* had significantly higher nutrients in the topsoil underneath its canopy. This improves soil fertility and is used for soil and water conservation purposes in the farmland.

According to Senbeta et al. [57], woody species had the lowest importance value which may be due to adverse environmental conditions and selective disturbance of humans for resource uses and computation in the study sites. *P. africana, F. albida, and C. macrostachyus* had the highest importance value index in the three agroecologies of parkland agroforestry. Woody species which had the highest importance value index was the most dominant in the three agroecologies. This study was similar to Shibru and Balcha [58] who reported that woody species with the highest IVI are the dominant species in given vegetation. Woody species which had the highest importance value provide shade, timber production, construction material, fuel wood, and as livestock feeds that were benefited by local farmers in study areas. *C. africana* is one of the best-known indigenous wood species that was used for quality timber in Ethiopia [23, 24].

The highest importance value species in the home garden were ecologically and socioeconomically important for local farmers. Those woody species were shown in the results of the three agroecologies of the study areas. Mekonnen et al. [15] reveal that woody species with the greatest importance value index were the most dominant species of particular vegetation. Farmers obtained benefits such as fuel wood, livestock fodder, construction material, shade, soil fertility improvement, and human food consumption from important species in their home gardens. According to Gindaba et al. [59], tree species such as *C. macrostachyus* whose leaves decompose rapidly could supply nutrients in the short term for uptake nutrients by crops.

In this study, results showed that with the increase of total biomass in woody species, there was an increase in carbon dioxide sequestration in woody species in the study agroforestry practices in different agroecologies. Carbon dioxide sequestered in the highland was higher followed by midland and lowland agroecologies for woody species. On the other hand, the carbon stored in highland woody species was higher followed by midland and lowland agroecology woody species. The aboveground, belowground, and total biomass of woody species in the home garden was higher in midland woody species followed by highland and lowland woody species in the study area. It indicates that the midland agroecology of home gardens accumulated a high amount of total biomass followed by highland and lowland agroecologies. In the midland agroecology, woody species had the highest carbon storage and carbon dioxide sequestration followed by woody species of highland and lowland.

Under both agroforestry practices, the largest DBH of tree species in the study area were scarce. The reason could be due to selective cutting of the trees for different uses. This study is in agreement with the finding of Tamirat [60], who reported that the proportion of individual woody species in higher diameter classes was smallest in parkland agroforestry. The most dominant species in the home garden were small trees because some tree species might be regenerated and other species sprouted were from old trees. Trees and shrubs greater than 151 cm diameter classes had the biggest size and smallest in number followed by 121–150 diameter classes and 91–120 cm diameter classes. In these diameter classes, species *C. africana*, *C. macrostachyus*, and *F. albida* were the most dominant species. The number of individual species decreased with the increase in the distribution of diameter classes in home garden agroforestry. In this case, the results are in line with Misgana et al. [61] who reported that the total number of woody species in each DBH class decreased with the increasing diameter classes.

4.3. Carbon Stock of Woody Species. Diameter at breast height is commonly used for aboveground biomass estimation because it is simple to be repeatedly measured with high accuracy and generally follows commonly acknowledged forestry conventions [61]. The higher total biomass of woody species in the highlands for parklands was observed than in midlands and lowlands. These results were in contrast to reports by Tsedeke et al. [62] who reported that the mean biomass in midland was higher than in lowland agroecology. The average aboveground, belowground, and total biomass of woody species in highland agroecology was higher followed by midland and lowland agroecology. The reason could be likely highland agroecology dominant with evergreen woody species due to this reason ABG of woody species in the highland was significantly higher than in other agroecology. The AGB depends on the height and diameter of woody species because the AGB increases with an increase in the diameter and height of the tree. The relationship between height and diameter is also related to species, climate, soil characteristics, region, and even tree diversity [63]. BGB of woody species measured from AGB, due to this AGB of woody species increases with BGB in the parkland study area. The AGB of woody species increases with increasing altitude. This study was in disagreement with Misgana et al. [61] who reported that the aboveground biomass of vegetation decreased with increasing altitude. The total biomass of woody species in agroecology was higher in highland than in midland and lowland agroecology, because highland agroecology is always dominated by evergreen woody species.

5. Conclusions

The present study identified the availability of 45 woody species belonging to 29 families in three agroecologies of parkland and 35 woody species which were belonging to 24 families identified in the three agroecologies for home garden agroforestry practice. The three agroecologies in the study area had different woody species composition, richness, and diversity in both parkland and home garden practices. Midland agroecology had the highest species richness in both parkland and home garden followed by highland and lowland agroecology in the parkland agroforestry practices implying the development of more woody species in farmers' farmlands in the midland. The basal area of trees in midland agroecology both in parkland and home garden was higher in highland and lower in lowland agroecology. Midland agroecology was more dominated by the biggest tree woody species than by highland and lowland agroecologies. The total biomass carbon stored in highland agroecology of parkland woody species was higher in midland and lowland agroecologies which showed that higher sequestering potential of CO_2 of woody species in the highland than the later agroecologies. The improvement of woody species diversification and sustainability in parkland agroforestry practices needed high awareness of local farmers in the study area. Local farmers who managed woody species in their parkland and homestead can be aware of farmers who had low management abilities. As a result, the cut of trees may be carried out with sufficient regeneration of other woody species. Farmers in the study areas cut woody species only to obtain benefits like fuel wood, charcoal, and construction. However, farmers would have to understand the ecological, economic, and social effects before cutting woody species in the parkland and home garden. Communities have to also predict the environmental consequence of the destruction of woody species. Thus, to transfer the economic, ecological, cultural, and social benefits of woody species in parkland and homestead agroforestry practices to the next generation, farmers should conserve and manage woody species in the parkland and home garden.

Data Availability

All data are available in the manuscript.

Ethical Approval

During data collections, all ethics are permitted by concerned bodies between the researchers and farmers in the study areas.

Conflicts of Interest

The authors declare that they have no conflicts of interest

Authors' Contributions

All the authors have contributed equally to writing and data analysis.

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