

Research Article

Woody Species Composition, Structure, and Soil Seed Bank of the Degraded Parts of the Gera Moist Afromontane Forest, Southwestern Ethiopia

Dereje Egeta ¹, Giche Yadesa ¹, Abeje Eshete ², Hailu Belay ¹, Urge Charu ¹,
and Tensay Teshome ¹

¹Ethiopian Forestry Development Jimma Center, Department of Natural Forest and Climate Change, P.O. Box 10001187, Jimma, Ethiopia

²Ethiopian Forestry Development, Addis Ababa, Ethiopia

Correspondence should be addressed to Dereje Egeta; egetadereje@gmail.com

Received 15 September 2023; Revised 23 June 2024; Accepted 29 June 2024

Academic Editor: Anna Żróbek-Sokolnik

Copyright © 2024 Dereje Egeta et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Ethiopia's forest coverage is decreasing from time to time due to agricultural expansion, settlements, misuse of existing forest resources, and a lack of awareness and sense of ownership among the local population. Not only forest coverage but also species composition and diversity are decreasing in the country. The current study aims to investigate the woody species composition, structure, regeneration, diversity, and distribution of the soil seed bank in a degraded part of the Gera moist Afromontane forest. A systematic random sampling technique was used to collect tree data. Twenty representative sample square plots, each measuring 400 m² for trees and shrubs, were established. Inside the main plots, five subplots measuring 9 m² were assigned for regeneration data collection. Another five subplots were also marked for soil seed bank data collection that are 9 cm deep and 15 cm wide. The forest had twenty-one woody species that belonged to seventeen families. The Shannon–Wiener, Simpson's indices, and evenness of the whole forest were recorded to be 2.17, 0.82, and 0.42, respectively. *Syzygium guineense* had the highest species-specific value indices (68.49), accounting for 22.83 percent of the total. The first DBH and height class patterns encompass over 61.16 and 59.92 percent of the total individuals, respectively. There were two growth phases (seedling and saplings) missing in three tree species (*Allophylus abyssinicus*, *Olea welwitschii*, and *Schefflera abyssinica*). The soil seed bank in the forest contained 77 plant species belonging to 41 families. Compared to other moist Afromontane forests, the Gera forest has a smaller composition of woody species and medium diversity. The soil seed bank did not significantly contribute to the restoration of the forest.

1. Introduction

Ethiopia has distinctive climatic features, wide altitude ranges, and well-known ecological settings that make it the center of biological diversity [1]. Moreover, it is attributed to the existence of different vegetation types ranging from afro-alpine to desert vegetation and is fully separated into 12 categories [2]. Among these vegetation types, Afromontane forests are known for having distinctive fauna and flora and harboring a high proportion of endemic species. Studies revealed six thousand and twenty-seven vascular plant species, which are widely distributed across the vegetation, with ten percent being unique to Ethiopia, especially in the highlands [3].

In the early 20th century, more than 35 percent of Ethiopian land was covered in forest. However, the forest had reduced by 50 percent after five decades. Approximately, around 2.7 percent of the country's land was covered in forests in 1989 [4]. This is the output of agricultural expansion, especially coffee and tea plantations, settlements, misuse of existing forest resources, and a lack of awareness and sense of ownership among the local population [5].

Gera forest is one of the forest patches located in the southwestern part of Ethiopia and Gera-degraded forest is the small portion of the forest located in Dusta Badiya and Muje kebele. The forest is located near Chira town in the Gera district, which is the major reason for the acceleration

of forest degradation. Degraded forests are characterized by a high number of individuals with smaller diameters, low density, low total basal area, and a loss of structural characteristics [6]. The main direct drivers of forest degradation are the illegal expansion of forest coffee plantations, forest roads, timber log collection, and fuelwood. The end outcome of Ethiopia's forest loss typically has detrimental effects on the environment, agriculture, and health, etc.

The Ethiopian government employs various restoration or conservation techniques to reduce forest degradation and destruction. Mainly, it uses sustainable land management, the establishment of area exclosures [7], soil and water conservation [8], afforestation or reforestation, a convention on biological diversity, participatory forest management, the millennium development goals, the national forest priority area, REDD + activities, and the Ethiopian green legacy.

To select restoration or conservation actions, it requires an understanding of the status of the forests, including soil seed banks in each of the natural forests. Datasets on the vegetation composition and structure of forests provide useful information on the status of forest vegetation and population dynamics, which are important for advancing our understanding of forest ecology and management. Few studies on vegetation composition in the degraded area of dry Afromontane forests in Ethiopia have been documented. These studies have, however, limited application to forest management, and hence there is a need to expand and conduct such studies in moist Afromontane forests.

In addition, soil seed bank (below-ground vegetation) studies also offer knowledge on vegetation composition, maintaining vegetation, succession, regenerating ecosystems, and genetic diversity preservation [9]. Soil seed banks are specifically used to map the history of current plant communities as well as forecast new plant communities that emerge in the area [10]. However, the biodiversity of soil seed banks in the Gera-degraded parts of moist Afromontane forest is less known.

In general, whatever the cause of forest degradation and deforestation that affects vegetation composition of above and below ground, developing conservation and management strategies for sustainable use is very important to halt the problem and save the remaining ones. For this purpose, the research used as input for forest conservation is required because it provides relevant scientific information for restoration, silvicultural activities, conservation, management, and policy arenas.

Therefore, the current study aims to investigate the woody species composition, structure, regeneration, diversity, and distribution of the soil seed bank in degraded parts of the Gera moist Afromontane forest.

2. Materials and Methods

2.1. Description of the Study Site. The study was conducted in Dusta Badiya and Muje Kebele's Gera District, Jimma Zone, Oromia Regional State, southwest Ethiopia (Figure 1). The latitudinal and longitudinal locations of the district are 7°45' to 7°50' north and 36°10' to 36° 17' east, respectively, and its elevation ranges from 1300 to 2400 meters above sea level. The

mean annual temperature of the district ranges between 15°C and 22°C, and its annual rainfall covers a large area between 1300 and 1700 millimeters [11]. The district's agroecological zone classification is lowland, midhighland, and highland, with corresponding percentages of 3.7%, 50.19%, and 46.11%, respectively. The forest lies roughly 440 kilometers southwest of Addis Ababa, the capital city of Ethiopia [12].

2.2. Vegetation Data Collection. Initially, a reconnaissance survey was conducted through a field visit to get a general impression of the forest and identify sampling sites. During the field visit, we identified how diverse the environment was, which was homogenous. In a homogenous forest, a few transects and a large distance between consecutive transects are required. By using this as baseline information, the distance between the grid lines was determined to be 500 m, and the spaces between each quadrant were 500 m wide [13]. Data on trees and the environment were gathered using a systematic random sampling technique [14]. Square sample plots with a size of 400 m² were laid out along four grid lines [15] (Figure 2). The total forest area of the degraded part of Gera forest considered under study is approximately 40 hectares. We used two percent of the sampling intensity to determine the plot number of the studied site. By using visual observation and focusing on the forest landscape, parallel lines of transect were laid across the forest. Data on the vegetation, including the height of every tree and shrub and its diameter at breast height (DBH), were collected from twenty sample plots. A hypsometer and a diameter tape were used to measure the individuals' height and DBH, respectively. In current studies, trees are defined as tall, perennial plants with one main woody stem or trunk, and shrubs are medium, bushy plants that have multiple woody stems that rose from the same root [16]. Inside each major plot, five subplots (9 m²), one at the center and four at the corners, totally, one hundred subplots were established for regeneration (seedlings and saplings) data collection. The subplots were used to count the number of seedlings (height less than 0.75 m) and saplings (height = 0.75–2 m and DBH less than 2 cm) [17] (Figure 2). The collected plant species was identified using published field guides on Ethiopian flora. However, plant species that are hard to identify in the field were collected, pressed, and sent to Addis Ababa University's National Herbarium of Ethiopia.

Environmental data such as slope (percentage), altitude, and geographical positions in degrees and UTM were recorded in the center of each major plot using a clinometer and GPS (Global Positioning System), respectively. A compass was also used for the alignment of transects at the time of laying out the plots.

2.3. Soil Seed Bank Data Collection. For the soil seed bank study, already constructed sample plots for vegetation data collection were utilized. Soil samples were collected from five subplots, one at the center and four at the corners of the main plots, to determine the density, diversity, and vertical distribution of seeds (Figure 2). At each subplot, a 9 cm deep and 15 cm wide plot was established using a sharp-edged knife and

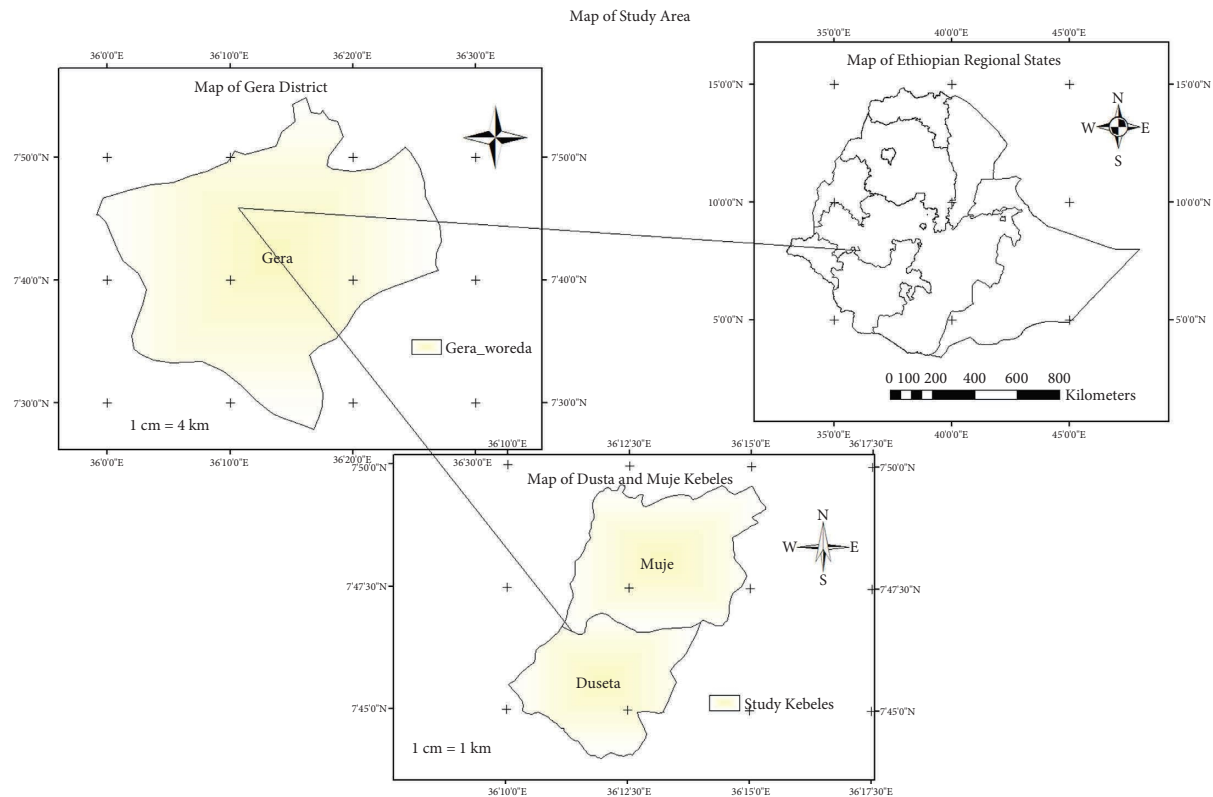


FIGURE 1: Map of the study area.

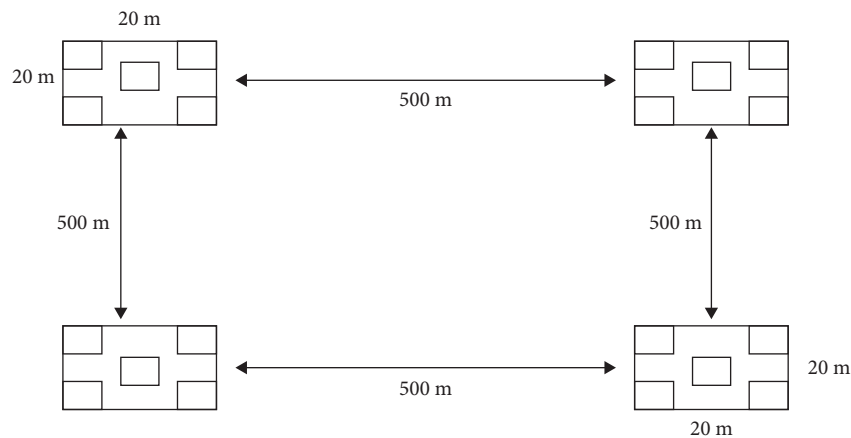


FIGURE 2: Sampling design for data collection.

ruler in line with the procedure outlined in Lemenih and Teketay [9]. From three sequential soil layers, each measuring three centimeters thick, soil samples were collected. The corresponding layers from each subplot were mixed to form a composite sample to reduce variability within the quadrants. The three composite samples from each subplot were kept separately. The composite sample for each soil layer was again divided into four equal parts, of which one was randomly selected for further study. The density, diversity, and vertical distribution of seeds were determined from the collected soil samples in the germination experiment in the greenhouse of Jimma University College of Agriculture and Veterinary Medicine for 6–12 months [9]. Each seedling was identified

using photos and plant specimens in the herbarium, using Flora of Ethiopia and Eritrea [18]. The seedlings that were challenging to identify during the seedling stage were tallied and kept in their pots until their identity was ascertained. In the end, plants that were challenging to identify were pressed and identified at Addis Ababa University's National Herbarium in Ethiopia.

3. Statistical Analysis

3.1. Diversity Analysis. The collected vegetation data were analyzed using past statistical software version 4.03 and Microsoft Excel version 2016, especially for determining

species diversity index and ecologically important species in the forest.

The diversity of species in the degraded parts of the Gera forest was determined using the common diversity index, or Shannon–Wiener diversity index, because it gives information statistic indices, which means it assumes all species are represented in a sample and that they are randomly sampled.

The Shannon–Wiener diversity was calculated as

$$H' = - \sum_{i=1}^s p_i \ln p_i, \quad (1)$$

where H' is the Shannon diversity index, S is the number of species in quantity, $\ln$ is the log base e , p_i is the proportion of individuals found in the species and is estimated using the maximum likelihood estimator, and $p_i = n_i/N$, where n_i is the number of individuals in the species and N is the total number of individuals in all species.

Shannon's equitability (EH) or evenness was determined by [19] using the following equation:

$$EH = \frac{H}{H_{\max}} = \frac{H}{\ln s}. \quad (2)$$

The other diversity information is the Simpson diversity index (opposite to the Shannon–Wiener diversity index), which gives more weight to common or dominant species.

Simpson's diversity index was estimated by using the following formula:

$$D = 1 - \sum_{i=1}^s \left(\frac{n_i}{N} \right)^2, \quad (3)$$

where n_i is the number of individuals of species i , N is the total number of individuals in the plot, and S is the number of species in the plot.

3.2. Analysis of Vegetation Structure. The degraded parts of the Gera forest structure were analyzed based on the abundance, density, frequency, basal area, and ecologically significant species (the sum of relative densities, frequencies, and dominance) for each species. In addition, the DBH and height class distribution of various species were examined. According to Kent and Coker [14], the following formulas are used to compute density, frequency, dominance, and their relatives.

Basal area is an important component for understanding vegetation structure. Basal area is a measurement, expressed in square meters, of the cross-sectional area at the breast height of a single tree, including the bark.

It is calculated as

$$BA = \pi \times \frac{(DBH)^2}{4}, \quad (4)$$

where BA is the basal area in square meters per hectare, DBH is the diameter at breast height in meters, and $\pi = 3.14$.

The important value index (IVI) is an interesting term due to its statistical quantity, which gives an overall picture of the species in the vegetative community. It is estimated from three terms (relative density, relative frequency, and relative dominance).

$$\text{Density of a species} = \frac{\text{total number of individuals of species in all plots}}{\text{sample size in hectare}}; \quad (5)$$

$$\text{Relative density} = \frac{\text{density of } i\text{th species}}{\text{total density of all species}} \times 100; \quad (6)$$

$$\text{Frequency} = \frac{\text{number of quadrates of occurrence of a species}}{\text{total number of quadrates sampled}}; \quad (7)$$

$$\text{Relative frequency} = \frac{\text{frequency of a species}}{\text{total frequency of all species}} \times 100; \quad (8)$$

$$\text{Dominance} = \frac{\text{basal area of } i\text{th species}}{\text{basal area of quadrates in hectare}}; \quad (9)$$

$$\text{Relative dominance} = \frac{\text{basal area of a species}}{\text{basal area of all the species}} \times 100. \quad (10)$$

3.3. Regeneration Status Analysis. The regeneration status of a certain forest is a core point for deciding the conservation and silvicultural management required for the forest. Regeneration was determined based on the population

dynamics of mature trees or shrubs, saplings, and seedlings. When the population dynamics of seedlings are greater than saplings and mature trees or shrubs, the regeneration status is good, whereas when all the population dynamics of all

lifeforms (seedlings, saplings, and mature trees or shrubs) are equal, the regeneration status is fair. Nevertheless, if the population dynamics of seedlings were less than those of saplings and mature trees or shrubs, the regeneration status is poor [20]. To see the natural regeneration of the forest, histograms were constructed using the number of individuals and the growth stage of the species.

3.4. Soil Seed Bank Data Analysis. As used in Tesfaye et al. [21] and Perera [22], methodologies to examine the species richness (S) and evenness (E) of the soil seed bank composition in each soil profile are calculated as follows:

$$E = \frac{H'}{\ln S}, \quad (11)$$

where E stands for evenness and S stands for species richness.

$$S = \frac{H'}{\ln(E)}, \quad (12)$$

where H' is the Shannon diversity index, S stands for species richness, and $\ln$ is the natural logarithm of evenness.

3.5. Similarity of Species. Jaccard's coefficient of similarity was used to determine how closely related the species of soil seed banks (below ground) and aboveground plants are to one another.

$$JCS = \frac{c}{c + b + a}, \quad (13)$$

where a is the number of plant species found above ground, b is the number of plant species found below ground, and c is the number of species found in both.

4. Results

4.1. Woody Species Compositions. The forest is made up of twenty-one woody species that belong to seventeen families (Table 1). Among these, 15 species (71.43% of them) were trees, while 5 species (23.81%) were shrubs, and the remaining one was a tree or a shrub. We found that there were only a few species in each family. Fabaceae is the most dominant, with three species, followed by Asteraceae and Rutaceae with two species, and the remaining families had only one species for each (Araliaceae, Celastraceae, Cupressaceae, Euphorbiaceae, Icacinaeae, Melianthaceae, Moraceae, Myrtaceae, Oleaceae, Rosaceae, Rubiaceae, Sapindaceae, Simaroubaceae, and Solanaceae). All of the species that were identified were native, with the exception of *Cupressus lusitanica* (different seed dispersal agents may have brought it into the forest from another location).

A summary of plant families and the number of individuals investigated in the studied forest are presented in Figure 3. The maximum number of individuals in the studied forest was recorded for the Asteraceae family (153 individuals). The second-highest number of individuals was recorded for Melianthaceae (57 individuals). The

least number of individuals (1) was recorded in the Celastraceae, Oleaceae, Sapindaceae, and Solanaceae families.

4.2. Ecological Diversity Indices. Diversity information about the degraded parts of the Gera forest under different lifeforms and the whole forest is presented in Table 2. Seedlings had the most species-rich lifeforms in the forest as compared to saplings and mature trees. The diversity indices result showed that a higher value of diversity index was recorded for seedlings than saplings and mature trees. The mature trees were more evenly distributed than the other two lifeforms in the forest, and a high equitability was recorded for them. The Shannon–Wiener, Simpson's indices, and evenness of the whole forest were recorded to be 2.17, 0.82, and 0.42, respectively.

4.3. Vegetation Structure. The basal area, density, and frequency of every woody species found in the studied forest are presented in Table 3. *Syzygium guineense* has the largest basal area (8.59 meters squared per ha), accounting for 40.85% of the total basal area of the woody species under investigation. *Apodytes dimidiata* has the second-highest basal area (2.97 meters squared per ha), accounting for 14.12% of the total basal area of the species under analysis. Out of all the documented species, two species accounted for nearly 54% of the basal area: *Syzygium guineense* and *Apodytes dimidiata*. *Brucea antidysenterica*, *Calpurnia aurea*, *Clausena anisata*, *Senna didymobotrya*, and *Teclea nobilis* had the lowest basal areas in the forest.

Of the species under investigation, *Vernonia auriculifera* (2275) had the highest density, accounting for 37.60 percent of the total. With 875 records, *Syzygium guineense* had the second-highest density nearly 14.46 percent of the species' overall density. *Syzygium guineense* and *Vernonia auriculifera* accounted for 52.06 percent of the total density. *Allophylus abyssinicus*, *Calpurnia aurea*, *Cupressus lusitanica*, *Olea welwitschii*, *Teclea nobilis*, and *Vernonia amygdalina* had the lowest density found.

Vernonia auriculifera had the greatest frequency (0.75), accounting for 17.86 percent of the overall frequency. *Syzygium guineense* (0.55) had the next greatest frequency, accounting for 13.10 of the total frequency. Approximately 30.96 percent of the overall frequency is made up of these two species. *Allophylus abyssinicus*, *Calpurnia aurea*, *Cupressus lusitanica*, *Olea welwitschii*, *Senna didymobotrya*, *Teclea nobilis*, and *Vernonia amygdalina* were the species with the lowest frequencies in the forest.

The important value index of the investigated woody species of the studied forest is accessible in Table 4. There were differences among species in terms of relative dominance, relative frequency, and relative density. *Syzygium guineense* had the highest species-specific value indices (68.49), accounting for 22.83 percent of the total. *Vernonia auriculifera*, with a value index of 58.40, or 19.47 percent of the total important value index (IVI), was the next highest. Of the overall IVI, these two species accounted for about 42.30 percent. *Teclea nobilis* and *Calpurnia aurea* had the lowest IVI ever noted.

TABLE 1: List of woody species, their families, and growth habits in the forest.

No	Species scientific name	Family	Growth type
1	<i>Allophylus abyssinicus</i> (Hochst.) Radlkofer	Sapindaceae	T
2	<i>Apodytes dimidiata</i> E. Mey. Ex arm	Icacinaeae	T
3	<i>Bersama abyssinica</i> Fresen	Melanthaceae	T
4	<i>Brucea antidysenterica</i> J.F. Mill	Simaroubaceae	S
5	<i>Calpurnia aurea</i> (Ait.) Benth	Fabaceae	S
6	<i>Clausena anisata</i> (Willd.) Hook.f. ex Benth	Rutaceae	T/S
7	<i>Croton macrostachyus</i> Del	Euphorbiaceae	T
8	<i>Cupressus lusitanica</i>	Cupressaceae	T
9	<i>Ficus sur</i> Forssk	Moraceae	T
10	<i>Galiniera saxifrage</i> (Hochst.) Bridson	Rubiaceae	T
11	<i>Maytenus senegalensis</i>	Celastraceae	T
12	<i>Millettia ferruginea</i> (Hochst.) Bak	Fabaceae	T
13	<i>Olea welwitschii</i> (Knohl.) Gilg & Schellenb	Oleaceae	T
14	<i>Prunus africana</i> (Hook.f.) Kalkman	Rosaceae	T
15	<i>Schefflera abyssinica</i> (Hochst. Ex A. Rich.) Harms	Araliaceae	T
16	<i>Senna septemtrionalis</i> (Viv.) Irwin & Barney	Fabaceae	S
17	<i>Solanum incanum</i> L	Solanaceae	S
18	<i>Syzygium guineense</i> (Willd.) DC. subsp. <i>afromontanum</i> F. White	Myrtaceae	T
19	<i>Teclea nobilis</i> Del	Rutaceae	T
20	<i>Vernonia amygdalina</i> Del	Asteraceae	T
21	<i>Vernonia auriculifera</i> Hiern	Asteraceae	S

T, tree; S, shrub.

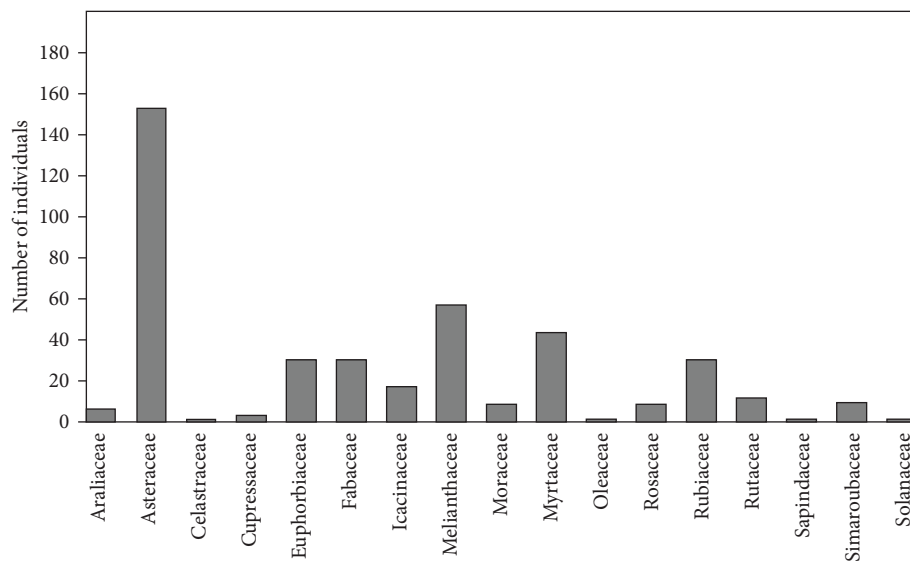


FIGURE 3: Summary of plant families and number of individuals in the study area.

TABLE 2: Diversity of mature trees or shrubs, saplings, and seedlings of species growing in the forest.

Woody species under different growing stages	Species richness	Abundances	Shannon diversity	Simpson	Evenness	Equitability
Mature trees	13	95	2.11	0.83	0.63	0.82
Saplings	13	147	1.50	0.62	0.34	0.58
Seedlings	18	165	2.20	0.82	0.50	0.76
Total	21	407	2.17	0.82	0.42	0.71

4.3.1. *Diameter at Breast Height Distribution of Species in Forest.* We created eight DBH classes based on the DBH of every species found in the forest in order to visualize the vegetation structure of the area. All required information

about the DBH classes and the number of individuals falling into each DBH class of woody species in the degraded blocks of the Gera forest is shown in Figure 4. The first pattern of DBH classes has the highest number of individuals (148), or

TABLE 3: Basal area, density, and frequency of individual woody species in the studied forest.

Species name	BA (m ²)/ha	Density	Frequency
<i>Allophylus abyssinicus</i>	0.03	25	0.05
<i>Apodytes dimidiata</i>	2.97	200	0.25
<i>Bersama abyssinica</i>	1.38	775	0.4
<i>Bucea antidysenterica</i>	0.00	75	0.1
<i>Calpurnia aurea</i>	0.00	25	0.05
<i>Clausena anisata</i>	0.00	75	0.1
<i>Croton macrostachyus</i>	1.40	425	0.45
<i>Cupressus lusitanica</i>	0.01	25	0.05
<i>Ficus sur</i>	1.76	150	0.15
<i>Galiniera saxifrage</i>	0.03	400	0.4
<i>Millettia ferruginea</i>	1.94	350	0.3
<i>Olea welwitschii</i>	0.23	25	0.05
<i>Prunus africana</i>	1.09	100	0.15
<i>Schefflera abyssinica</i>	0.87	150	0.25
<i>Senna didymobotrya</i>	0.00	50	0.05
<i>Syzygium guineense</i>	8.59	875	0.55
<i>Teclea nobilis</i>	0.00	25	0.05
<i>Vernonia amygdalina</i>	0.11	25	0.05
<i>Vernonia auriculifera</i>	0.62	2275	0.75

The values that appear as zero in the table are actually very small numbers that are nearly equal to zero.

TABLE 4: The forest's species' relatives, ecologically significant value indexes, and level of significance in the forest.

Species name	R. dominance	R. density	R. frequency	IVI	Level of significance
<i>Allophylus abyssinicus</i>	0.14	0.41	1.19	1.75	15
<i>Apodytes dimidiata</i>	14.15	3.31	5.95	23.41	5
<i>Bersama abyssinica</i>	6.59	12.81	9.52	28.93	3
<i>Bucea antidysenterica</i>	0.01	1.24	2.38	3.63	11
<i>Calpurnia aurea</i>	0.00	0.41	1.19	1.61	17
<i>Clausena anisata</i>	0.01	1.24	2.38	3.63	11
<i>Croton macrostachyus</i>	6.48	7.03	10.71	24.22	4
<i>Cupressus lusitanica</i>	0.04	0.41	1.19	1.64	16
<i>Ficus sur</i>	8.41	2.48	3.57	14.46	8
<i>Galiniera saxifrage</i>	0.12	6.61	9.52	16.26	7
<i>Millettia ferruginea</i>	9.25	5.79	7.14	22.17	6
<i>Olea welwitschii</i>	1.11	0.41	1.19	2.72	12
<i>Prunus africana</i>	5.17	1.65	3.57	10.40	10
<i>Schefflera abyssinica</i>	4.13	2.48	5.95	12.56	9
<i>Senna didymobotrya</i>	0.00	0.83	1.19	2.02	14
<i>Syzygium guineense</i>	40.93	14.46	13.10	68.49	1
<i>Teclea nobilis</i>	0.00	0.41	1.19	1.61	17
<i>Vernonia amygdalina</i>	0.53	0.41	1.19	2.13	13
<i>Vernonia auriculifera</i>	2.94	37.60	17.86	58.40	2
Total	100	100	100	300	—

R denotes relative dominance, density, and frequency, and IVI is the important value index.

they cover more than 61.16 percent of total individuals. The sixth DBH class has the lowest number of individuals (7), or 2.89 percent of the total. The highest DBH was recorded for two species, *Apodytes dimidiata* (93.5 cm) and *Syzygium guineense* (92.5 cm), in the forest. The majority of the *Vernonia auriculifera* species are located in the DBH classes' initial pattern. Somewhat, the DBH class distribution exhibits an inverted J-shaped distribution. DBH classes starting from the third up to the seventh classes have an inconsistent distribution.

4.3.2. Height Class Distribution of Species in the Forest. For the woody species present in the research area, eight height classes of individuals were assigned (Figure 5). Out of all the height classes, the first pattern has the most individuals (145), accounting for 59.92 percent of the total classes. The height classes of third comprised the lowest numbers (11 individuals), or 4.55 percent of the total. In the forest, *Apodytes dimidiata* reached 34.2 meters, while *Syzygium guineense* was the next largest tree at 33.4 meters. Three species of trees were

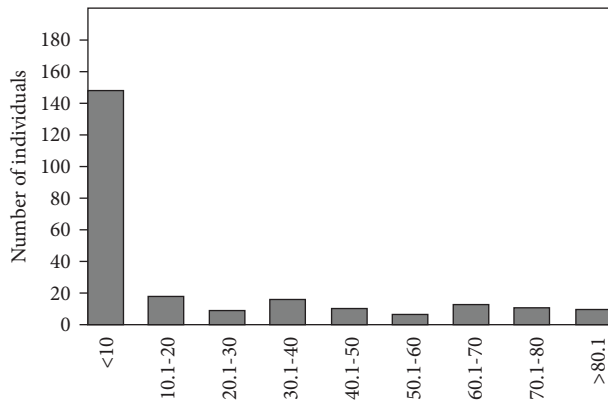


FIGURE 4: The distribution of woody plant species across various DBH classes.

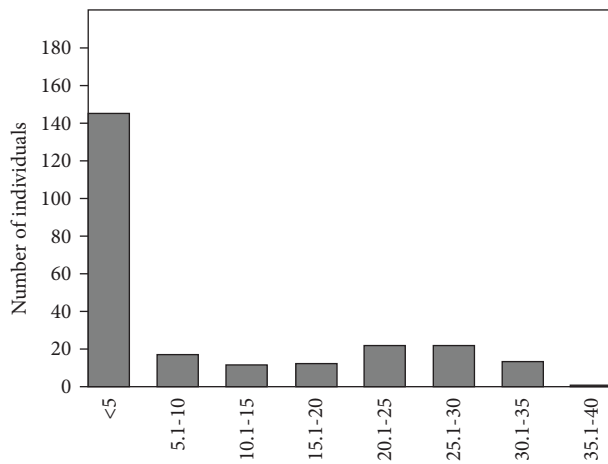


FIGURE 5: The height classes' distribution of tree species recorded in the forest.

found to be the shortest: *Vernonia auriculifera*, *Bersama abyssinica*, and *Schefflera abyssinica*. The distribution of height classes probably reflects an inverted J-shaped pattern. There is no consistent distribution or a changing distribution for height classes, ranging from the third to the seventh.

4.4. Regeneration Status of the Forest. During an overview of the vegetation structure (diameter at breast height and height classes), distribution saplings were mixed with adult woody plants. However, for the regeneration status of the forest saplings, they stood separately as one component. The species composition of adult woody plants, saplings, and seedlings was used to evaluate the regeneration status of the forest. Figure 6 shows the number of mature individuals, which totaled 95, as well as the number of saplings (147) and seedlings (165). The proportion of saplings and seedlings to mature woody plants was 1.55 and 1.74, respectively. The forest's seedling composition is outstanding when compared to the two other compositions (saplings and mature trees). This suggested that the forest had undergone a good regeneration.

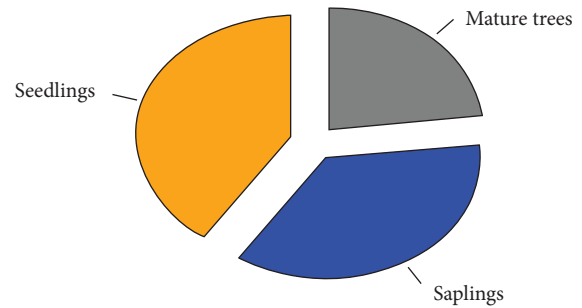


FIGURE 6: The number of mature tree species, saplings, and seedlings in the forest.

Seedlings are the fundamental element for the regeneration of certain forests. However, in the Gera forest, *Allophylus abyssinicus*, *Olea welwitschii*, and *Schefflera abyssinica* were missed in this stage. In addition, mature tree species and saplings of certain species were lacking in the studied forest (Table 5).

4.5. Soil Seed Banks

4.5.1. Species Composition of Soil Seed Banks. The soil seed bank in the forest contained 1462 individuals' or 77 plant species belonging to 41 families (Figure 7 and Supplementary File 1). Out of all the plant species that were recovered from soil seed banks, herbs make up the majority, with 1280 individuals, or 87.53 percent. Herbaceous plants' inclusion in soil seed banks makes it simple to comprehend the vegetation's composition and determine the best conservation strategies for the area under study. While 39 individuals (2.67%) represented shrubs, 7 individuals (0.48%) represented grass and 11 individuals (0.75%) represented herbs or shrubs; these indicate that certain plant species can grow as herbs or shrubs, depending on the environmental suitability for their growth. From the total plant species that emerged from the soil seed bank, climbers occupy 0.07%, 7.60%, and subshrubs 0.89% (Supplementary File 1). Only two native tree species, *Croton macrostachyus* and *Ficus sur*, were found in the soil seed bank. Brassicaceae is the third richest family, with six species, after Lamiaceae and Asteraceae, which have seven species each (Supplementary File 1).

4.5.2. Species Diversity of Soil Seed Bank. Across the depth layers, there is a fluctuation in the species richness of the seedlings that emerged from the soil seed banks (Table 6). The highest species richness was found in the first layer (0–3 centimeters), and the lowest species richness was found in the second layer (3–6 centimeters). The maximum number of individuals, or abundance, is found in the first layer, and the lowest abundance is found in the third layer (6–9 centimeters). The lowest layer has the most species diversity, whereas the middle layer has the least (Table 6).

The highest seed density was registered for the top layer (28,977.78 seeds per meter squared) and the lowest was found in the bottom layer (14,755.56 seeds per meter squared). In the middle layer, we found 21,200 seeds per

TABLE 5: List of species that are missed in different growing stages (mature, saplings, and seedlings).

Species without mature trees or shrubs	Species without saplings	Species without seedlings
<i>Brucea antidysenterica</i>	<i>Allophylus abyssinicus</i>	<i>Allophylus abyssinicus</i>
<i>Calpurnia aurea</i>	<i>Apodytes dimidiata</i>	<i>Olea welwitschii</i>
<i>Clausena anisata</i>	<i>Olea welwitschii</i>	<i>Schefflera abyssinica</i>
<i>Cupressus lusitanica</i>	<i>Prunus africana</i>	
<i>Senna didymobotrya</i>	<i>Schefflera abyssinica</i>	
<i>Teclea nobilis</i>	<i>Vernonia amygdalina</i>	
<i>Maytenus senegalensis</i>	<i>Maytenus senegalensis</i>	
<i>Solanum incanum</i> L	<i>Solanum incanum</i> L	

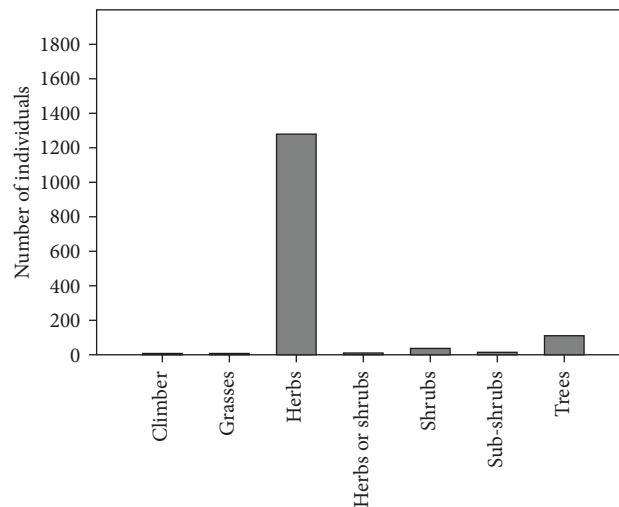


FIGURE 7: Growing stages of plant species and number of individuals germinating from the soil seed bank.

TABLE 6: Diversity information of soil seed banks.

Soil depth	Species richness	Abundance	Dominance	Shannon index	Simpson index	Evenness	Equitability
0–3 cm	52	652	0.08	3.00	0.92	0.39	0.76
3–6 cm	43	477	0.07	2.98	0.93	0.46	0.79
6–9 cm	47	332	0.08	3.07	0.92	0.46	0.80
Overall	77	1462	0.06	3.21	0.94	0.32	0.74

meter squared (Figure 8). The first layer, for example, covers approximately 44.60 percent of the population in the soil seed bank, the second layer covers 32.63 percent, and 22.71 percent is covered by the third layer (Figure 8).

4.5.3. Similarity between Aboveground Flora and Soil Seed Bank. Only four species of plants, out of 77 plant species, were present in the aboveground vegetation. The seedlings that emerged from the soil seed bank and the aboveground plants had a very low Jaccard's coefficient of similarity ($JCS = 0.04$). Therefore, a very low number denotes a significant difference between aboveground vegetation and the soil seed bank.

5. Discussion

5.1. Woody Species Compositions. We investigated a few woody plant species from the degraded parts of the Gera forest that belonged to particular families (Table 1). This is

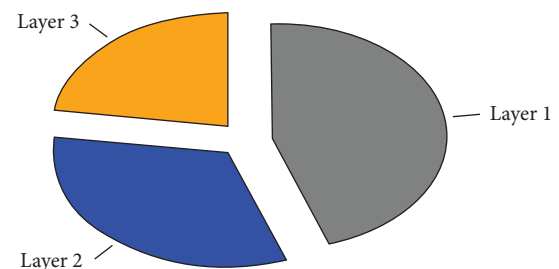


FIGURE 8: The vertical distribution of soil seed banks in the forest.

a smaller number than the woody species composition found in some moist Afromontane forests, such as the Hereje natural forest (44 woody plant species), Anamo et al. [23]; Abbo Sacred forest (63 woody plant species), Yigeremu and Woldearegay [1]; Wurg forest (76 woody plant species), Boz and Maryo [24]; Gurra Farda forest (66 woody species),

Hundera and Deboch [25]; Sirso moist evergreen Afromontane forest (74 woody species), Mewded et al. [26]; Gera moist Afromontane forest (132 plant species), Mulugeta et al. [27]; the Agama forest (72 woody plant species), Dibaba et al. [28]; and the Belete natural forest (55 woody plant species). The reason for the discrepancy in our results could be attributed to the highest levels of forest disturbance (57,987 m³ of logs were removed from the Gera forest between 1982 and 1993), the growth of coffee and tea plantations in recent decades, overexploitation, and the merciless destruction of the selected natural forests (Belete-Gera forest lost about 82.8 percent of its closed high forest areas from 1976 to 1990). The plant species that were studied (woody plant species and nonwoody plant species) are additional sources of inconsistencies in our findings.

Our result was similar to the findings of Eddy et al., reference [29], who found that the Air Telang Protected Forest consisted of 20 species of plants belonging to 14 families. In addition, similar to Sharma and Chaudhry [30], who found 17 tree species distributed across 11 families in the mining-disrupted tropical thorn forest of Asola-Bhatti Wildlife Sanctuary, Northern India, our results are also similar to those of Al-Sagheer et al. [31], who found 22 species in the moist deciduous forest in the Thithimathi Range of Western Ghats, India. It might have a comparable history of disruptions.

Trees were the most common woody plant species in the studied forest (Table 1). Our results confirm that trees are the predominant species in the area, as reported by Tenzin and Hasenauer [32], Yakob and Fekadu [33], Boz and Maryo [24], and Gurmesssa et al. [34]. On the other hand, prior studies conducted in their respective study areas by Gurmesssa et al. [35], Gebrehiwot and Hundera [36], Tekle and Maryo [37], and Kefalew et al. [38] reported a restricted quantity of trees.

Based on our observations, the Fabaceae family was the most prosperous in the area under study (Table 1).

Our results support the findings of Gurmesssa et al. [35], Ahmedin and Eliasb [39], Yasin et al. [40], Tekle and Maryo [37], Gurmesssa et al. [34], and Yigeremu and Woldearegay [1] who found that the Fabaceae family was the most prevalent in the area under study. The reason for these similarities is that the Fabaceae family has stronger systems for adapting to a variety of environmental conditions than other families [41]. Our research contradicts the conclusions of Lulekal et al. [42], Tegene et al. [43], Assefa et al. [44], and Dibaba et al. [28, 45], who found that Fabaceae is not the dominant family in the forest under investigation.

Understanding the species makeup of a forest and implementing significant efforts to maintain low species diversity depend on scientific information. Assessing the distribution of species in the forest requires not only an awareness of species richness but also of evenness. Diversity information for woody species under three growing stages is presented in Table 2. The overall values of the Shannon–Wiener diversity index were 2.17, and the evenness of the forest was 0.42. Our results were lower than those reported for Wurg forest by Boz and Maryo [24]; Abbo Sacred forest by Yigeremu and Woldearegay [1]; and Agama forest

by Dibaba et al. [28]. The edaphic conditions of the forest, the vast range of climatic qualities, the fragmentation of habitats, and geological history might cause these differences. Generally, different scholars divide a given forest's diversity into four categories: very low (below 1.0), low (between 1.0 and 2.0), medium (between 2.0 and 3.0), and high (beyond 3.0) [46]. Therefore, Gera forest's diversity is classified as medium.

5.2. Vegetation Structure. Important aspects of a forest's vegetation structure, such as its basal area, density, and frequency, are crucial for deciding how to manage its silvicultural environment and calculating its productivity in terms of producing timber and carbon stocking. In the examined forest, the total basal area of the studied species was 21.03 meters squared per hectare (Table 3). Our results are lower than those of other moist Afromontane forests such as Abbo Sacred forest (basal area = 67.85 m² per ha), Yigeremu and Woldearegay [1]; Bonga forest (basal area = 47 m² per ha), Senbeta [47]; Harena forest (basal area = 49 m² per ha); and Berhane-Kontir forest (basal area = 54 m² per ha), Negesse and Woldearegay [48]. This discrepancy could be caused by the rapid rate of deforestation in Gera forest (high demand for logs and illegal expansion of coffee plantations). Our results are also higher than those of other forests such as Ambericho forest (3.40 m²/ha) [37].

The observed woody species in the forest had a total stem density of 6050 individuals with a DBH greater than or equal to 1.5 cm within sampled plots (Table 3). This value was higher than other Afromontane forests such as Gurra Farda forest (1373 individuals per ha), Hundera and Deboch [25]; Wurg forest (1745.27 individuals per ha), Boz and Maryo [24]; Abbo Sacred forest (1319.17 individuals per ha), Yigeremu and Woldearegay [1]; Werganbula forest (1012.35 individuals per ha), Zeleke et al. [49] and Upadhaya et al. [50], who found (938–1476 stems per ha) woody species in subtropical humid forests; and Doshke forest (1288 individuals per hectare), Tegene et al. [43]. The variation may result from the diameter ranges that are employed in investigations of vegetation structure and the rate of forest degradation among the studied forests.

Vernonia auriculifera and *Syzygium guineense* cover about thirty percent of the frequency in our research forest (Table 3). Our observation was different from that of other scholars, such as Yigeremu and Woldearegay [1], who found that *Croton macrostachyus* Del. and *Brucea antidysenterica* J.F. Mill were the most frequented species in Abbo Sacred forest. Bogale et al. [51] also discovered that *Warburgia ugandensis* and *Filicium decipiens* were the first two most frequented species in Berbere Afromontane moist forest. Nigatu et al. [52] investigated that *Celtis africana* and *Dioscorea abyssinica* were the two most frequented species in Wabero forest [53] and found that *Hagenia abyssinica*, *Ilex mitis*, and *Prunus africana* were the three most frequently observed species in Debelle forest. There could be a reason for this discrepancy in results, such as the demands of local communities place on species and the suitability of the

environments for species growth. On the other hand, our results agree with the findings of Tegene et al. [43], Bayissa [54], and Amenu et al. [55], who found that *Syzygium guineense* is a frequently encountered species in the Chencha forest, Setema natural forest, and Shoti forest, respectively.

The important value index values play a key role in understanding the ecological significance of the specific tree species in the forest. In the Gera forest, the *Syzygium guineense* tree has the highest important value index (Table 4). Our output contradicts the findings of other researchers. For instance, *Warburgia ugandensis* has the highest IVI (33.91) in Berbere Afromontane moist forest, Bogale et al. [51]; *Schefflera abyssinica* (Hochst. ex A. Rich.) Harms (31.08%) in Bong forest, *Argomuellera macrophylla* Pax. (34.29%) in Berhane-Kontir forest; *Coffea arabica* L. (52.82%, 78.02%) in Harenna and Maji forests, respectively; *Dracaena fragrans* L. (20.76%) in Yayu forest, Senbeta [47]; *Cordia africana* (43.85%) in Setema natural forest, Bayissa [54]; *Coffea arabica* L. (79.93%) in Gera forest, Mulugeta et al. [27]; *Diospyros mespiliformis* (27.40%) in Wabero forest, Nigatu et al. [52]; *Prunus africana* (9.35%) in Shoti forest, Amenu et al. [55], *Podocarpus falcatus* (IVI = 32.99) in the Kenech forest, Balemlay and Siraj [56]; and *Arundinaria alpina* (IVI = 27.53) in Ambericho forest, Tekle and Maryo [37]. Mewded et al. found that *Syzygium guineense* has the highest IVI (29) in Sirso moist evergreen Afromontane forest [26].

Multiple canopy layers and stems with different diameters are characteristics of forest structures that are crucial for assessing the forest's ecological sustainability and function. Understanding the diameter distribution of individual trees at different intervals and the necessary silvicultural management for a stand or particular forest is important. According to our research, a large portion of woody species' diameters fall into the DBH classes' initial pattern (Figure 4). It appeared that the forest had just been disturbed because of the abundance of trees with small diameters. This outcome is consistent with the research conducted by Girma and Mosandl [57], who discovered that small-diameter trees dominated the forest under study. Furthermore, Mesfin et al. [58] discovered that 56% of the diameter in the study area was found to be in the lowest DBH class. Another researcher investigated the highest frequency found in the lowest diameter classes in South Africa (Mensah et al. [59] and Addo-Fordjour et al. [60]); the largest number of individuals found in the lowest class of DBH in the studied forest. Aydagnehum et al. [61] found that above 66% of the vegetation had a DBH class <5 cm in Geresse highland forest complex, Gamo Zone, in the southwestern part of Ethiopia.

The first pattern of height classes contained the majority of the height of woody species (Figure 5). Our results are in line with those of Burju et al. [62], who revealed that over 65% of the individuals in Jibat forest were under 9 meters height tall. One sign of a high rate of regeneration in the forest was its abundance of small-sized individuals. The two forests, Jibat and Gera, are adjacent to the town and can be accessed by road for harvesting logs and collecting fuel wood from large trees. Our results also align with those of Gebrehiwot et al. [34], who reported that 62.8% of the first

class (1–5 m) in Hurubu natural forest, Northern Shewa, was accounted for. Dibaba et al. [28] also discovered that in the Agama forest in southwest Ethiopia, over 63% of individuals were in the first height class (2.5–5 m).

5.3. Regeneration Status of the Forest. Regeneration was evaluated by comparing the three growth stages of the plant species in the forest: seedlings, saplings, and mature plants. This is an important method for understanding an ecosystem's future nature and acting quickly to conserve its resources. According to the results of the current study, the forest's regeneration state is good because there are more seedlings than saplings and mature trees (Figure 6). However, during vegetation data collection, we have seen a high number of stumps in the forest due to the forest being located near Chira town. The other characteristics of degraded forests are a high number of individuals with smaller diameters, low density, low total basal area, and a loss of structural characteristics. Similar findings were made by Gebrehiwot and Hundera [36], Ahmedin and Eliasb [39], and Gurmessa et al. [63], who discovered that the forest under study successfully regenerates with seedlings > saplings > adults. This may result from human actions such as harvesting large-diameter commercial species, which create canopy gaps that can be used to accelerate forest regeneration. Our result is also similar to the findings of Girma and Mosandl [57] for the Munessa-Shashamane forest, Ethiopia.

5.4. Species Composition of Soil Seed Banks. Understanding the composition and density of soil seed banks can aid in improving our awareness of how a degraded forest ecosystem recovers and regenerates itself. In this study, 77 plant species were germinated from the soil seed bank. This result is similar to the research from other Afromontane forests in Ethiopia. In the case of Munessa-Shashamane (south-central Ethiopia) and Gara Ades (southeastern Ethiopia), Teketay [74] found that the 0–9 cm soil layers contained 58–92 species of flowering plants, respectively. Asteraceae and Lamiaceae were the two major families in the forest's Gera-degraded parts. Comparable outcomes have been documented at Munessa-Shashamane and Gara Ades Afromontane forests, where Asteraceae was dominant. According to our research, soil seed banks had a higher herbaceous content than other forms of growth (Figure 7). This conclusion confirms the findings of other researchers, who found that herbaceous species predominated in the examined area, including Dainou et al. [64], Teklu and Bekele [65], Birhanu et al. [66], Girmay et al. [67], and Bekele et al. [68]. The soil seed bank of heavily disturbed forest consists largely of herbs and grasses [69]. Due to tiny seeds that are easily spread by different agents, they regenerate more quickly than woody species. In addition, the majority of woody species' seeds are big, easily damaged by many substances, and especially vulnerable to fungal infections because of the high moisture content in the surrounding air.

The first soil layers had the maximum seed density, which declined as depth increased (Figure 8). Our results support the inverse relationship between seed density and soil depth discovered by Dalling et al. [70], Decocq et al. [71], Tessema et al. [72], Birhanu et al. [66], and Berihun et al. [73], who reported that the Arjo-Diga Humid Afromontane forest observed the following outcomes in various layers: first layer: 39,333 seedlings per square meter; somewhat lower densities were found in the middle and bottom levels, which were 3–6 cm and 6–9 cm. Furthermore, our research results confirm Teketay's [74] findings, which indicated that in Munessa-Shashamane forests, the highest densities were found in the top three centimeters of the soil and that densities progressively decreased as depth increased. These may result from an environment that is more conducive to the germination of various soil seeds in the first layer than others are.

5.4.1. Species Diversity, Richness, and Evenness of Seedlings in the Soil Seed Banks. We discovered that the Shannon–Wiener diversity index was greater than three and the Shannon evenness index was 0.32 for species that were the subject of our analysis (Table 6). We found that the bottom layer had the maximum diversity than the upper layer in our results. This suggests that there is an inverse relationship between species diversity and soil depth. This outcome is in contrast to the results of Shibru et al. [13], who discovered that in the southern Ethiopian Gerese Gegha forest, the upper layer has the greatest species diversity ($H' = 2.7$), followed by the middle layer ($H' = 2.44$). This might be due to the fact that some species may have adapted to flourish and germinate their seeds at deeper soil depths. In comparison with the findings of Berihun et al. [73] for the Arjo-Diga Humid Afromontane forest, our result was lower ($E = 0.71 \pm 0.04$) and higher ($H' = 2.52 \pm 0.14$). This discrepancy may be the result of watering frequency twice a day (morning and evening) or daily throughout the week, as opposed to three times per week as reported by Berihun et al. [73]. Furthermore, we have obtained better results than Weerasinghe and Singhakumara [75] in the soil seed bank in the Tropical moist forest lands of the Southwest lowlands of Sri Lanka ($H' = 1.37$).

5.4.2. Similarity between Aboveground Flora and Soil Seed Bank. The value of similarity between above- and below-ground species was found between zero and one. The value very close to one indicates a high similarity, and the value 0 indicates two species sources (above and below ground) that are completely different or have no intersection species. In our study, the calculated value of Jaccard's coefficient of similarity was very low. This shows that the regeneration of woody species from soil seed bank samples is poor. Our investigation is far from the findings of Shibru et al. [13], who found 0.55 for the Gerese Gegha natural forest in southern Ethiopia. One possible explanation for this could be the variations in seed characteristics and dispersal abilities of the species in the area. In addition, our result differs from that of Mamo Kebede et al. [76], who discovered that Wondo

Genet natural forest in south-central Ethiopia had a 0.16 Jaccard's coefficient of similarity. The degree of forest degradation, seed size, and dormancy behavior may be the cause of this discrepancy. Our result coincides with the findings of Lemenih and Teketay [9], who found a JCS value ranging from 0.032 to 0.06 in Munessa-Shashamane forest.

6. Conclusions and Recommendations

Compared to other moist Afromontane forests, the Gera forest has a smaller composition of woody species and medium diversity. Among the forest's species, only the *Syzygium guineense* tree species held greater ecological significance. Approximately fifty-nine percent of DBH and height classes fall into the first classification class. There were two growth phases (seedling and saplings) missing in three tree species (*Allophylus abyssinicus*, *Olea welwitschii*, and *Schefflera abyssinica*) that needed to be immediately conserved. We discovered in the degraded parts of the Gera forest soil seed bank study that more than 85% of species seedlings showed seasonal patterns of growth or herbs that had no significant impact on forest revival. The soil seed bank did not significantly contribute to the restoration of the forest; therefore, planting seedlings of native tree species that are appropriate for the area and implementing onsite conservation measures will be ideal alternatives. For long-term forest vegetation composition management and knowing regeneration status, permanent plots will be preferable to temporary plots.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was funded by the Ethiopian Forestry Development Jimma Center for data collection. The authors are grateful to the Jimma University College of Agriculture and Veterinary Medicine for research equipment or field material support and green house for soil seed bank germination test.

Supplementary Materials

The attached supplementary material shows a list of species, growth habits, and individual numbers of seedlings that germinated from the soil seed bank of Gera-degraded parts of moist Afromontane forest obtained during the germination test at Jimma University's greenhouse in Ethiopia. Botanists at Jimma University in Ethiopia identified a plant species that germinated from soil depth (0–9 cm). We used the first letter of the words for simplification as indicated, where H stands for herbs, S for shrubs, T for trees, C for climbers, G for grass, and TPL, where T is the transect, P is

the plot where the soil seed bank sample was obtained, and L is the soil layer for the soil seed bank sample obtained. L1 represents the soil depth of 0–3 centimeters, L2 represents the soil depth of 3–6 centimeters, and L3 represents the soil depth of 6–9 centimeters. (*Supplementary Materials*)

References

- [1] A. Yigeremu and M. Woldearegay, “Woody species diversity, composition, and regeneration status of Abbo sacred forest, southern Ethiopia,” *Science World Journal*, vol. 2022, Article ID 9112578, 10 pages, 2022.
- [2] I. Friis and S. Demissew, *Atlas of the Potential Vegetation of Ethiopia*, EFAP, Addis Ababa, Ethiopia, 2010.
- [3] E. Kelbessa and S. Demissew, “Diversity of vascular plant taxa of the flora of Ethiopia and Eritrea,” *Ethiopian Journal of Biological Sciences*, vol. 13, 2014.
- [4] EFAP, *Ethiopian Forestry Action Program*, EFAP, Addis Ababa, Ethiopia, 1994.
- [5] B. Babiso Badesso, A. Bajigo Madalcho, and M. Mesene Mena, “Trends in forest cover change and degradation in Duguna Fango, Southern Ethiopia,” *Cogent Environmental Science*, vol. 6, 2020.
- [6] A. Vásquez-Grandón, P. Donoso, and V. Gerding, “Forest degradation: when is a forest degraded?” *Forests*, vol. 9, p. 726, 2018.
- [7] B. Nedessa, J. Ali, and I. Nyborg, “Exploring ecological and socioeconomic issues for the improvement of area enclosures management: a case study from Ethiopia,” Report No. 38, Dry Lands Coordination Group, Oslo, Norway, 2005.
- [8] S. Hishe, J. Lyimo, and W. Bewket, “Soil and water conservation effects on soil properties in the Middle Silluh Valley, northern Ethiopia,” *International Soil and Water Conservation Research*, vol. 5, pp. 231–240, 2017.
- [9] M. Lemenih and D. Teketay, “Changes in soil seed bank composition and density following deforestation and subsequent cultivation of a tropical dry Afromontane forest in Ethiopia,” *Tropical Ecology*, vol. 47, no. 1, pp. 1–12, 2006.
- [10] Q. Li, H. Fang, and Q. Cai, “Persistent soil seed banks along altitudinal gradients in the Qilian Mountains in China and their significance for conservation management,” *African Journal of Agricultural*, vol. 6, 2017.
- [11] S. Diro, B. Erko, and K. Fikirie, “Production and adoption constraints of improved coffee varieties in Jimma zone, southwest Ethiopia,” *Agriculture and Food Sciences Research*, vol. 6, pp. 41–49, 2019.
- [12] A. Arage, M. Ketema, and A. Gemechu, “Factors affecting honey market outlet choices in Gera district, Jimma zone, Oromia region of Ethiopia,” *International Journal For Innovative Research In Multidisciplinary Field*, vol. 86, 2020.
- [13] S. Shibru, H. Asres, S. Getaneh, and S. Gatew, “Aboveground and soil seed bank woody flora comparison in plantation and natural forest, southern Ethiopia: an implication for forest ecosystem sustainability,” *Journal of Sustainable Forestry*, vol. 41, pp. 829–846, 2022.
- [14] M. Kent and P. Coker, *Vegetation Description and Analysis: A Practical Approach*, John Wiley and Sons Ltd, England, UK, 1992.
- [15] B. Sewale and S. Mammo, “Analysis of floristic composition and plant community types in Kenech natural forest, kaffa zone, Ethiopia,” *Trees For. People*, vol. 7, 2022.
- [16] K. Jurisch, K. Hahn, R. Wittig, and M. Bernhardt-Römermann, “Population structure of woody plants in relation to land use in a semi-arid savanna, west Africa,” *Biotropica*, vol. 44, pp. 744–751, 2012.
- [17] A. Alelign, D. Teketay, Y. Yemshaw, and S. Edwards, “Diversity and status of regeneration of woody plants on the peninsula of Zegie, northwestern Ethiopia,” 2007.
- [18] S. Edwards, T. Mesfin, and I. Hedeberg, *Flora of Ethiopia and Eritrea, Volume 2, Part 2 the National Herbarium*, Addis Ababa University, Ethiopia, 1995.
- [19] C. E. Shannon and W. Weaver, *The Mathematical Theory of Communication*, The University of Illinois Press, Urbana, IL, USA, 1949.
- [20] P. Pokhriyal, P. Uniyal, D. S. Chauhan, and N. P. Todaria, “Regeneration status of tree species in forest of phakot and pathri rao watersheds in garhwal himalaya,” *Current Science*, vol. 98, 2010.
- [21] G. Tesfaye, D. Teketay, Y. Assefa, and M. Fetene, “The impact of fire on the soil seed bank and regeneration of Hareenna forest, southeastern Ethiopia,” *Mountain Research and Development*, vol. 24, pp. 354–361, 2004.
- [22] G. A. D. Perera, “Diversity and dynamics of the soil seed bank in tropical semi-deciduous forests of Sri Lanka,” *Tropical Ecology*, vol. 46, 2005.
- [23] A. Anamo, S. Mammo, and M. Temesgen, “Floristic composition and community analysis of woody species in Hereje Natural Forest, southwest Ethiopia,” *SN Applied Sciences*, vol. 5, p. 48, 2023.
- [24] G. Boz and M. Maryo, “Woody species diversity and vegetation structure of Wurg forest, southwest Ethiopia,” *International Journal of Forestry Research*, vol. 2020, Article ID 8823990, 17 pages, 2020.
- [25] K. Hundera and B. Deboch, “Woody species composition and structure of the Gurra Farda forest, snnp, south western Ethiopia,” *Ethiopian Journal of Education and Sciences*, vol. 3, 2008.
- [26] B. Mewded, M. Negash, and T. Awas, “Woody species composition, structure and environmental determinants in a moist evergreen Afromontane forest, southern Ethiopia,” *Journal of Forestry Research*, vol. 31, pp. 1173–1186, 2020.
- [27] Y. Mulugeta, T. Bekele, and E. Kelbessa, “Floristic composition, species diversity and vegetation structure of Gera moist montane forest, Jimma zone of oromia national regional state, southwest Ethiopia,” *Ethiopian Journal of Biological Sciences*, vol. 14, 2015.
- [28] A. Dibaba, T. Soromessa, A. Kefalew, and A. Addi, “Woody species diversity, vegetation structure, and regeneration status of the moist afromontane forest of Agama in southwestern Ethiopia,” *International Journal of Ecology*, vol. 2020, Article ID 1629624, 10 pages, 2020.
- [29] S. Eddy, M. Rasyid Ridho, I. Iskandar, and A. Mulyana, “Species composition and structure of degraded mangrove vegetation in the air Telang protected forest, south sumatra, Indonesia,” *Biodiversitas Journal of Biological Diversity*, vol. 20, 2019.
- [30] V. Sharma and S. Chaudhry, “Vegetation composition and plant diversity in mining disturbed tropical thorn forest of Asola-Bhatti Wildlife Sanctuary, Northern India,” *Taiwania*, vol. 63, 2018.
- [31] N. A. Al-Sagheer, A. G. D. Prasad, and N. A. Prakash, “Impact of anthropogenic pressures on forest structure and species composition of moist deciduous forest in Thithimathi range of western Ghats, India,” *International Journal of Applied Agricultural Research*, vol. 4, 2009.
- [32] J. Tenzin and H. Hasenauer, “Tree species composition and diversity in relation to anthropogenic disturbances in broad-

- leaved forests of Bhutan,” *International Journal of Biodiversity Science, Ecosystem Services & Management*, vol. 17, 2016.
- [33] G. Yakob and A. Fekadu, “Diversity and regeneration status of woody species: the case of keja araba and tula forests, south west Ethiopia,” *OALib*, vol. 03, pp. 1–15, 2016.
- [34] F. Gurmesssa, B. Warkineh, T. Soromessa, and S. Demissew, “Structure and regeneration status of tulu lafto forest, horo guduru wollega zone, west Ethiopia,” *Trees For. People*, vol. 11, 2023.
- [35] F. Gurmesssa, T. Soromessa, and E. Kelbessa, “Structure and regeneration status of komto afromontane moist forest, east wollega zone, west Ethiopia,” *Journal of Forestry Research*, vol. 23, pp. 205–216, 2012.
- [36] K. Gebrehiwot and K. Hundera, “Species composition, plant community structure and natural regeneration status of Belete moist evergreen montane forest, oromia regional state, southwestern Ethiopia. Momona ethiop,” *Journal of Sciences*, vol. 6, p. 97, 2014.
- [37] T. Tekle and M. Maryo, “Ecological assessment of woody plant diversity and the associated threats in afromontane forest of Ambericho, southern Ethiopia,” *Journal of Landscape Ecology*, vol. 15, pp. 102–126, 2022.
- [38] A. Kefalew, T. Soromessa, and S. Demissew, “Plant diversity and community analysis of Sele-Nono forest, Southwest Ethiopia: implication for conservation planning,” *Botanische Studien*, vol. 63, p. 23, 2022.
- [39] A. Ahmedin and E. Eliasb, “Tree species composition, structure and regeneration status in Munessa natural forest, Southeastern Ethiopia,” *Eurasian Journal of Science and Technology*, vol. 8, pp. 21–39, 2020.
- [40] H. Yasin, Z. Kebebew, and K. Hundera, “Woody species diversity, regeneration and socioeconomic benefits under natural forest and adjacent coffee agroforests at Belete forest, southwest Ethiopia,” *Ekológia Bratisl*, vol. 37, pp. 380–391, 2018.
- [41] E. Kelbessa and T. Soromessa, “Interfaces of regeneration, structure, diversity and uses of some plant species in Bonga Forest: a reservoir for wild coffee gene pool. SINET Ethio,” *Journal of Sciences*, vol. 31, pp. 121–134, 2008.
- [42] E. Lulekal, E. Kelbessa, T. Bekele, and H. Yineger, “Plant species composition and structure of the mana angetu moist montane forest, south-eastern Ethiopia,” *Journal of East African Natural History*, vol. 97, pp. 165–185, 2008.
- [43] A. S. Tegene, F. W. Gamo, and S. S. Cheche, “Woody vegetation composition, structure, and community types of Doshke forest in Chencha, Gamo gofa zone, Ethiopia,” *International Journal of Biodiversity*, vol. 2018, Article ID 4614790, 16 pages, 2018.
- [44] A. Assefa, S. Demissew, and Z. Woldu, “Floristic composition, structure and regeneration status of M asha forest, south-west E thioia,” *African Journal of Ecology*, vol. 52, pp. 151–162, 2014.
- [45] A. Dibaba, T. Soromessa, and B. Warkineh, “Plant community analysis along environmental gradients in moist afromontane forest of Gerba Dima, Southwestern Ethiopia,” *BMC Ecol. Evol.*, vol. 22, p. 12, 2022.
- [46] E. A. H. Cavalcanti and M. Eduarda Lacerda de Larrazábal, “Macrozooplâncton da Zona Econômica Exclusiva do Nordeste do Brasil (segunda expedição oceanográfica-REVIZEE/NE II) com ênfase em Copepoda (Crustacea),” *Revista Brasileira de Zoologia*, vol. 21, pp. 467–475, 2004.
- [47] F. Senbeta, “An analysis of vegetation structure of the moist evergreen Afromontane forests of Ethiopia,” *Ethiopian Journal of Applied Sciences and Technologies*, vol. 7, 2016.
- [48] G. Negesse and M. Woldearegay, “Floristic diversity, structure and regeneration status of menfeskidus monastery forest in berehet district, north shoa, central Ethiopia,” *Trees For. People*, vol. 7, 2022.
- [49] G. S. Zeleke, A. Tesfaye, and F. Sileshi, “Diversity, structure and regeneration status of woody species along altitudinal gradient of Werganbula forest at sude district, arsi zone, oromia region, Ethiopia (preprint),” *Review*, 2022.
- [50] K. Upadhaya, H. N. Pandey, P. S. Law, and R. S. Tripathi, “Diversity and population characteristics of woody species in subtropical humid forests exposed to cultural disturbances in Meghalaya, Northeast, India,” 2004, <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=c0683e5919c2c32cc5de5f89ef684e9338454e57>.
- [51] T. Bogale, D. Datiko, and S. Belachew, “Structure and natural regeneration status of woody plants of Berbere afromontane moist forest, bale zone, south east Ethiopia; implication to biodiversity conservation,” *Open Journal of Forestry*, vol. 07, pp. 352–371, 2017.
- [52] D. Nigatu, K. Firew, and K. Mulugeta, “Floristic composition, vegetation structure and regeneration status of Wabero forest, Oromia Regional State, Southeastern Ethiopia,” *International Journal of Biodiversity and Conservation*, vol. 11, pp. 272–279, 2019.
- [53] M. Kumar, “Structure and regeneration status of woody species in the Debelle forest,” *Central Highlands of Ethiopia*, vol. 11, 2023.
- [54] B. T. Bayissa, “Assessment of woody species diversity, structure and regeneration status of Setema natural forest, Setema district, southwest Ethiopia,” *International Journal of Agriculture Innovations and Research*, vol. 9, 2020.
- [55] B. T. Amenu, G. S. Mamo, B. A. Amamo, and T. T. Doko, “Woody species structure and regeneration status of shoti,” *Ukrainian Journal of Ecology*, vol. 4, 2022.
- [56] S. Balemlay and M. Siraj, “Population structure and regeneration status of woody species in Kenech forest, southwest Ethiopia,” *International Journal of Forestry Research*, vol. 2021, Article ID 6640285, 14 pages, 2021.
- [57] A. Girma and R. Mosandl, “Structure and potential regeneration of degraded secondary stands in Munessa-Shashemene Forest, Ethiopia,” *Journal of Tropical Forest Science*, 2012.
- [58] S. Mesfin, F. Christine, and Y. Kumelachew, “Plant diversity analysis for conservation of Afromontane vegetation in socio-ecological mountain landscape of Gurage, South Central Ethiopia,” *International Journal of Biodiversity and Conservation*, vol. 10, pp. 161–171, 2018.
- [59] S. Mensah, A. Egeru, A. E. Assogbadjo, and R. Glèlè Kakai, “Vegetation structure, dominance patterns and height growth in an Afromontane forest, Southern Africa,” *Journal of Forestry Research*, vol. 31, pp. 453–462, 2020.
- [60] P. Addo-Fordjour, S. Obeng, A. K. Anning, and M. G. Addo, “Floristic composition, structure and natural regeneration in a moist semi-deciduous forest following anthropogenic disturbances and plant invasion,” *Tropical Restoration Library*, vol. 1, 2009.
- [61] S. G. Aydagnehum, Y. Ugo, S. Shibu, O. Honnay, and B. Muys, “Composition and structure of woody plant communities as a function of altitude and human degradation in

- Afromontane moist evergreen forests SW Ethiopia,” *African Journal of Ecology*, vol. 60, pp. 668–681, 2022.
- [62] T. Burju, K. Hundera, and E. Kelbessa, “Floristic composition and structural analysis,” 2013, <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=a0cd23574f65715d97575aa3cb0d24a3747a3da1>.
- [63] F. Gurmessa, B. Warkineh, T. Soromessa, and S. Demissew, “Vegetation structure and regeneration status of tulu lafto forest, horo guduru wollega zone, west Ethiopia,” *SSRN Electronic Journal*, 2022.
- [64] K. Daïnou, A. Bauduin, N. Bourland, J.-F. Gillet, F. Fétéké, and J.-L. Doucet, “Soil seed bank characteristics in Cameroonian rainforests and implications for post-logging forest recovery,” *Ecological Engineering*, vol. 37, pp. 1499–1506, 2011.
- [65] Y. Teklu and T. Bekele, “Composition study of soil seed bank at Gera moist evergreen afromontane forest,” *Jimma Zone of Oromia Regional State, Southwest Ethiopia*, vol. 10, 2019.
- [66] L. Birhanu, T. Bekele, B. Tesfaw, and S. Demissew, “Soil seed bank composition and aboveground vegetation in dry Afromontane forest patches of Northwestern Ethiopia,” *Trees For. People*, vol. 9, 2022.
- [67] M. Girmay, T. Bekele, E. Lulekal, and S. Demissew, “Soil seed bank study of Hirmi woodland vegetation: implications for restoration and conservation of natural vegetation,” *Tigray, Northern Ethiopia. Trees For. People*, vol. 8, 2022.
- [68] M. Bekele, S. Demissew, T. Bekele, and F. Woldeyes, “Soil seed bank distribution and restoration potential in the vegetation of Buska Mountain range, Hamar district, southwestern Ethiopia,” *Heliyon*, vol. 8, 2022.
- [69] P. Rungrojtrakool, P. Tiansawat, A. Jampeetong, D. P. Shannon, and S. Chairuangsi, “Soil seed banks of tree species from natural forests, restoration sites, and abandoned areas in Chiang Mai,” *Thailand. For. SOC*, pp. 167–180, 2021.
- [70] J. W. Dalling, M. D. Swaine, and N. C. Garwood, “Soil seed bank community dynamics in seasonally moist lowland tropical forest, Panama,” *Journal of Tropical Ecology*, vol. 13, pp. 659–680, 1997.
- [71] G. Decocq, B. Valentin, B. Toussaint, F. Hendoux, R. Saguez, and J. Bardat, “Soil seed bank composition and diversity in a managed temperate deciduous forest,” *Biodiversity & Conservation*, vol. 13, pp. 2485–2509, 2004.
- [72] Z. K. Tessema, B. Ejigu, and L. Nigatu, “Tree species determine soil seed bank composition and its similarity with understory vegetation in a semi-arid African savanna,” *Ecol. Process.*, vol. 6, p. 9, 2017.
- [73] T. Berihun, T. Bekele, E. Lulekal, and Z. Asfaw, “Study of the soil seed bank composition in arjo-diga humid afromontane forest under different land use types and its implications for the restoration of degraded lands in western Ethiopia,” *International Journal of Ecology*, 2024.
- [74] D. Teketay, “Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production-population structures,” *Tropical Ecology*, vol. 46, 2005.
- [75] W. H. M. S. N. Weerasinghe and B. M. P. Singhakumara, “Composition of soil seed banks in relation to four different land use patterns in tropical moist forest lands of Southwest Lowlands, Sri Lanka,” *ICAO Environmental Symposium*, vol. 20, 2015.
- [76] K. Mamo, K. Markku, Y. Eshetu, and L. Mulugeta, “Soil seed bank and Seedlings bank Composition and diversity of Wondo genet moist Afromontane forest South Central Ethiopia,” *International Journal of Botany*, vol. 8, no. 4, pp. 170–180, 2012.