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Research Article

Influence of Elevation and Anthropogenic Disturbance on Woody Species Composition, Diversity, and Stand Structure in Harego Mountain Forest, Northeastern Ethiopia

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Environmental variables like elevation affect species composition, diversity, distribution, density, and horizontal and upward growth. Ecologists are constantly working to better understand how species diversity varies along elevational gradients, particularly in mountainous ecosystems. Therefore, the purpose of this research was to examine the species' horizontal and vertical structural diversity along the Harego Mountain Forest's elevational gradient. The area was categorized into lower, middle, and upper elevations. A total of 67 (20 m × 20 m) plots were created along gradients of elevation 2,079–2,516 meters above sea level (m a.s.l.). Information for floristic composition, diversity, stand structure, and environmental variables were measured and recorded for each plot over the three elevational gradients. Data on anthropogenic disturbances were visually evaluated for every plot in every gradient of elevation. For the diversity analysis, Hill's diversity statistics were employed. To find significant variations between the three elevational gradients in terms of Hill's diversity number, stand structure, and environmental variables, the one-way analysis of variance with SPSS version 26 at the 0.05 level of significance was carried out. The finding revealed that 50 woody plants that belonged to 35 families and 44 genera in the 67 sample plots with an elevation of 2,079 to 2,516 were identified. Shrubs were dominant in each elevational gradient. Species richness, abundance, and Hill's diversity number were all significantly ($p < 0.05$) greater in the upper elevational gradient of the forest. On the other hand, all stand structures were significantly ($p < 0.05$) higher in the middle elevational gradient. The effect of anthropogenic disturbances and environmental variables were clearly observed in the lower and upper elevational gradients than in the middle elevation. As a result, there were fewer seedlings, saplings, trees, and shrubs in the gradients of lower and higher elevations. For the conservation of the forest, it is crucial to pay special attention to biotic elements at lower elevations and abiotic factors at higher elevations. Accordingly, involving the local community in forest management, reducing anthropogenic pressure in and around the Harego Mountain Forest through tree planting in farmlands and woodlots and implementing physical soil and water conservation structures are recommended.

1. Introduction

The three most significant characteristics of the floral ecosystem are structure, composition, and function. Knowing the temporal and spatial fluctuation patterns in species abundance and variety is among the most significant difficulties facing ecologists and biogeographers [1, 2]. The management of forests, particularly in sub-Saharan Africa, is frequently thought to be severely hampered by an absence of comprehension of the characteristics of forest composition and the processes regulating structural diversity [3]. Information on forest conditions, particularly vertical and horizontal structural diversity along environmental gradients [3, 4], is critical for sustainable forest ecosystem management [5]. As a result, environmental gradients like elevation, slope gradient, aspect, soil conditions (e.g., moisture content, soil depth, and nutrient availability), and other factors hampers species distribution, density, and horizontal and upward growth [6–9].

Ecologists always strive to comprehend how species diversity might vary [10] of these ecological gradients, particularly

in mountainous ecosystems [11]. Altitudinal gradients, however, are still served as a starting point for modern studies on different issues in ecology and evolution [12]. It is discovered to be one of the primary environmental factors structuring both the types of plant communities in the forest region [13, 14] and the makeup of plant species [15]. This is due to the fact that elevation affects the spatiotemporal distribution of other environmental factors, such as temperature, precipitation, air pressure, soil, hydrology, and others [16], which either directly or indirectly affect plant growth and development as well as the dispersal configurations of flora in a given area [17]. Elevation therefore has a significant potential to enhance our comprehension of species richness, species distribution patterns, and conservation [13]. Therefore, an examination of the species configuration [18] and its relationship to environmental conditions is useful [19, 20] in the context of the precursor to developing more efficient ways for management and maintainable exploitation of forest resources [21].

As a result of environmental gradients including elevation, slope, and aspect, certain research carried out elsewhere found a substantial association among plant composition and variety [12, 17, 20, 22, 23]. The result of topographic influences on species variety and organization diversity [3, 13, 19, 24] as well as the interaction between environmental variables and plant species diversity and organizational diversity [4] were also demonstrated in a study carried out in Ethiopia. Numerous research have generally examined existence of species variations along gradients of elevation [2], and the majority of them discovered a "hampered" distribution with peak species richness close to the middle gradient [25] even within a little altitudinal variation [20]. Thus, it is not admiring that these intense changes over short distances have led ecologists to articulate many of the basic ecological concepts of elevational gradients [12].

However, instead of looking at the connection between elevation and species richness and diversity, the aforementioned research neglected to consider the effects of environmental gradients, specifically elevation as well as the impact of anthropogenic disturbances on plant diversity and structure. Consequently, less research has been done on how plant species distribution responds to changes in elevation and human caused disturbances in Ethiopia in general and the northern region in particular [26]. As a result, the research region lacks information on plant distributions along elevational gradients, and anthropogenic disturbances which is essential for the effective conservation of biodiversity [13]. Studying how vegetation reacts to environmental conditions [4] is crucial for improving our understanding of and management of forest ecosystems [3]. Thus, research into the distribution and structural arrangements of species in reaction to external conditions [20] contributes to our indulgent of ecological developments and the managing of ecologies [3, 4, 27]. Therefore, the purpose of this research was to examine how elevation and anthropogenic disturbances affected the diversity, composition, and stand structure of woody species in the Harego Mountain Forest in northeastern Ethiopia. We hypothesized that the variability of plant species richness, diversity, and stand structure was significantly influenced by elevation and human caused disturbances.

2. Methods

2.1. Study Site Descriptions. Northeastern Ethiopia's Harego Mountain forest served as the study's location. Harego Mountain Forest is located between latitudes of 11° 4′ 12″ and 11° 6′ and longitudes of 39° 38′ 53″ and 39° 41′ 24″ (Figure 1). Its rough terrain, which spans 341.67 hectares and ranges at elevation from 2,079 to 2,516 meters above sea level (m a.s.l.), is what defines it. It is made up of high mountains, valleys, and plateaus [28]. Cambisols, arenosolsl lithosols, and vertisols are the main soil types in Harego Mountain Forest [29]. The Harego Mountain Forest's average annual temperature was 17.7°C, with mean minimum and maximum temperatures of 7.7°C and 27.6°C, respectively. The climatic information of Harego Mountain forest was gathered from adjacent stations [30]. The Harego Mountain Forest received 1,040 mm of rain on average year, with significant seasonal variations. The research area generally experiences bimodal rainfall (Figure 2), with the major rainy period existence since July to August and low rainfall occurring from November to February [30]. The populations living near and around the study area (Harego Mountain Forest) are estimated to be 85,367, of whom 41,968 are men and 43,399 women. About 58,667 or 68.72% of the total population are inhabits in Kombolcha city, while the remaining people reside in remote kebeles [31]. Different types of land use systems existed around the study area. Most parts of the land is covered by crops which spans 6,065 ha (48.17% of the total land) (Table 1) followed by forest land 3,763 ha (29.88%), grazing land 2,144 ha (17.03%), and others 620 ha (4.92%) [32].

The vegetation of Harego Mountain Forest hosts various species of wild animals. Among the wild animals in the forest, Jib (*Crocuta crocuta*), Nebr (*Panthera pardus*), Tera Kebero (*Canis aureus*), Midakua (*Silvicapra grimmia*), Ses (*Oreotragus oreotragus*), Tera Zingero (*Papio hamadryas*), Tera Tota (*Cercopethicus aethiops*), Shikoko (*Procavia capensis*), Tinchel (*Lepus starckii*), Jart (*Hystrix cristata*), and Kerkero (*Pacochocerus aethiopicus*) are commonly found. It also provides wild edible fruits for humans and one of a beautiful area for cultural and recreational services. Hiking and celebrating different cultural and spiritual festivities are common in Harego Mountain Forest. However, direct poaching and habitat fragmentation brought on by human development pose a serious threat to the forest's wildlife populations. Around the forest, there are various small communities where people generally cut wood illegally. Crop cultivation is frequently practiced in the vicinity of the forest, as is livestock pressure, particularly in and around the forest's margins. Due to the forest's proximity to the cities of Kombolcha and Dessie, trees were illegally harvested for use in building, as lumber, as fuelwood, and for other uses. This last remaining area of forest is on the verge of extinction due to the pressure from the population's growth on other land use systems and the demand for forest products [28].

2.2. Vegetation Data Collection. From September to November 2018, reconnaissance surveys were conducted in and around the forest area to obtain an overview of the site

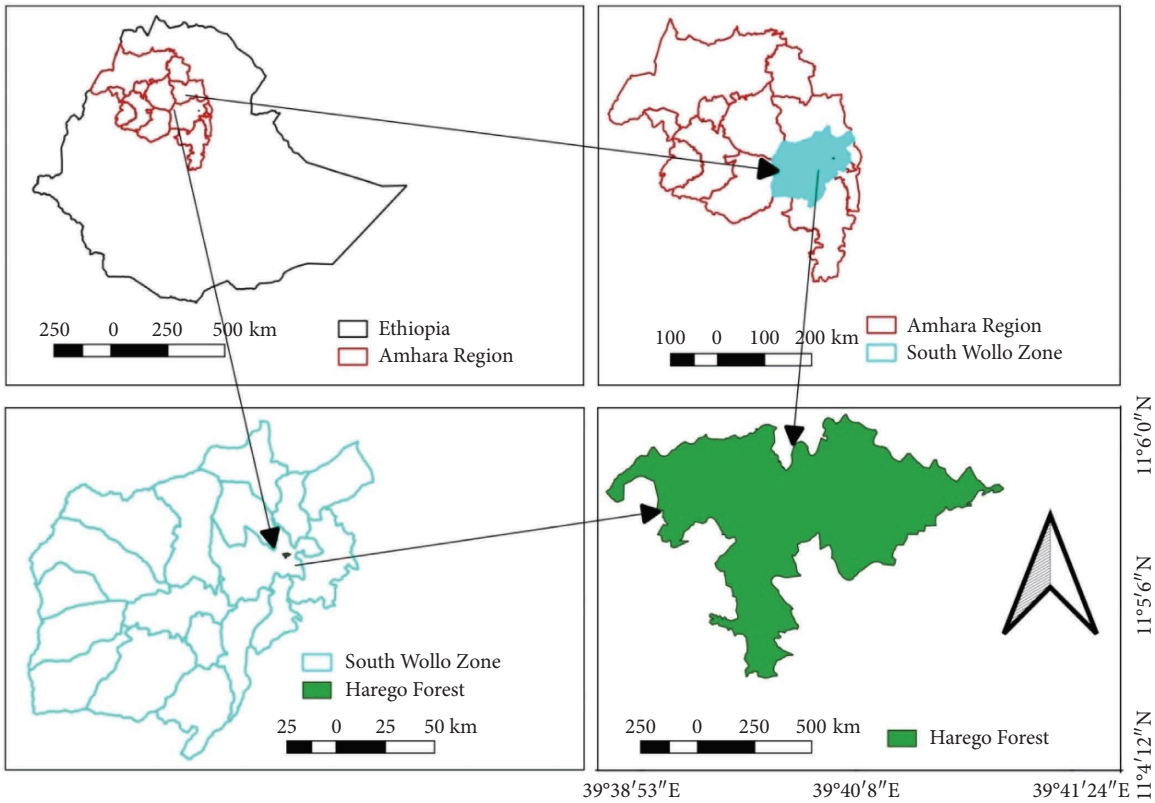

Figure 1: Location of Harego Mountain Forest, South Wollo, Northeastern Ethiopia. Figure 1 is reproduced from Worku et al. [28] (under the creative commons attribution license/public domain).

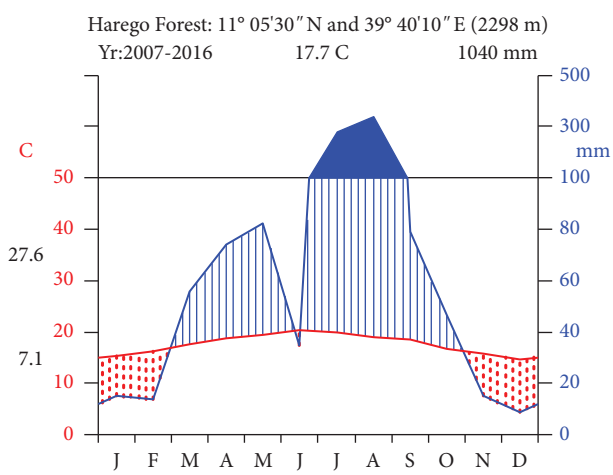

Figure 2: Climatic diagram of Harego Mountain Forest between 2007 and 2016. Data were obtained from the National Meteorological Service Agency, Kombolcha Station.

conditions, identify potential sampling sites, and obtain pertinent information regarding the distribution of vegetation. A geographical map was then used to classify the forest into three elevational gradients: lower [2,079–2,225], middle (2,225–2,347), and upper (2,347–2,516] elevations with equal distances. Data from the real field was gathered between December 2018 and April 2019. Following Worku et al. [28], diameter at breast height (DBH) and height in 67 plots (20 m × 20 m) were measured for all woody plants with a diameter of ≥2 cm and a height of ≥2 m along the gradient. Plots and transects were spaced an average of 100 and 500 meters apart in each elevational gradient, respectively, in accordance with the procedures that Worku et al. [28] and Yineger et al. [33] advised for mountainous areas. The scientific names of all the woody species in each plot were then noted, and references to the published volumes 1–7 of Flora of Ethiopia and Eritrea [34–41] and useful trees and shrubs for Ethiopia [42] were made.

Table 1: List of the collected plant species in Harego Mountain Forest, including their vernacular name, family, life form, and origin.

Scientific name	Local name (Amharic)	Family	Life form	To Ethiopia
Acacia abyssinica Hochst.	Bazra Girar	Fabaceae	Tree	Indigenous
Acacia etbaica Schweinf.	Dere	Fabaceae	Tree	Indigenous
Acacia seyal Del.	Nech Girar	Fabaceae	Tree	Indigenous
Asparagus africanus Lam.	Yeset Kest	Asparagaceae	Liana	Indigenous
Berberis holstii Engl.	Zinkila	Berberidaceae	Shrub	Indigenous
Buddleja polystachya Fresen.	Atquar	Loganiaceae	Shrub	Indigenous
Calpurnia aurea (Ait.) Benth.	Digta	Fabaceae	Shrub	Indigenous
Carissa edulis (Forssk.) Vahl	Agam	Apocynaceae	Shrub	Indigenous
Clematis hirsuta Perr. and Guill.	Nech Yeazo Hareg	Ranunculaceae	Liana	Endemic
Clerodendrum myricoides (Hochst.) Vatke	Misirich	Lamiaceae	Shrub	Indigenous
Clutia abyssinica Jaub. and Spach.	Fyele Fejj	Euphorbiaceae	Shrub	Indigenous
Crateva adansonii Gilg.	Dingay Seber	Capparidaceae	Tree	Indigenous
Cupressus lusitanica Mill.	Yeferenj Tsid	Cupressaceae	Tree	Introduced
Dodonaea angustifolia L. f.	Kitkita	Sapindaceae	Shrub	Indigenous
Dombeya torrida (J. F. Gmel.) P. Bamps	Wulkfa	Sterculiaceae	Tree	Indigenous
Echinops macrochaetus Fresen.	Kosheshila	Asteraceae	Shrub	Indigenous
Ekebergia capensis Sparrm.	Lol	Meliaceae	Tree	Indigenous
Erica arborea L.	Asta	Ericaceae	Tree	Indigenous
Eucalyptus globulus Labill	Nech Bahir Zaf	Myrtaceae	Tree	Introduced
Euclea racemosa Murr. (*subsp. chimperi*)	Dedeho	Ebenaceae	Shrub	Indigenous
Euphorbia candelabrum Kotschy.	Kulkual	Euphorbiaceae	Tree	Indigenous
Euphorbia tirucalli L.	Kinchib	Euphorbiaceae	Tree	Indigenous
Festuca simensis Hochst ex. A. Rich.	Lancha	Poaceae	Shrub	Indigenous
Grewia ferruginea Hochst. ex A. Rich.	Alenkoza	Tiliaceae	Shrub	Indigenous
Heteromorpha arborescens (Spreng.)	Yejib Mirkuz	Apiaceae	Shrub	Indigenous
Jasminum grandiflorum P.S.Green	Tembelel	Oleaceae	Liana	Indigenous
Juniperus procera Hochst. ex Endl.	Yehabesha Tsid	Cupressaceae	Tree	Indigenous
Lippia adoensis Hochst. ex Walp.	Kesse	Verbenaceae	Shrub	Endemic
Maytenus arbutifolia (A. Rich.) Wilczek	Wend atat	Celastraceae	Shrub	Endemic
Maytenus senegalensis (Lam.)	Sete atat	Celastraceae	Shrub	Indigenous
Mimusops kummel A. DC.	Isheh	Sapotaceae	Tree	Introduced
Myrsine africana L.	Qechemo	Myrsinaceae	Shrub	Indigenous
Ocimum lamiifolium Hochst. ex. Benth.	Dama Kese	Lamiaceae	Shrub	Indigenous
Olea europaea L. *subsp. Cuspidata*	Weira	Oleaceae	Tree	Indigenous
Olinia rochetiana A. Juss.	Beye	Oliniaceae	Tree	Indigenous
Opuntia ficus-indica (L.) Miller.	Kulkual	Cactaceae	Tree	Introduced
Osyris quadripartita Decn.	Keret	Santalaceae	Shrub	Indigenous
Pinus patula Schiede ex Schltdl	Pachula	Pinaceae	Tree	Indigenous
Pittosporum viridiflorum Sims.	Kefeta	Pittosporaceae	Tree	Indigenous
Premna schimperi Engl.	Chocho	Lamiaceae	Shrub	Indigenous
Prunus africana (Hook.f.) Kalkm.	Tiqur Inchet	Rosaceae	Tree	Indigenous
Pterolobium stellatum (Forssk.) Brenan	Kentafa	Fabaceae	Liana	Indigenous
Rhus glutinosa A. Rich.	Embs	Anacardiaceae	Shrub	Endemic
Rhus natalensis Krauss	Taquama	Anacardiaceae	Shrub	Indigenous
Rhus retinorrhoea Oliv.	Tilem	Anacardiaceae	Shrub	Indigenous
Rosa abyssincia Lindley.	Kega	Rosaceae	Shrub	Indigenous
Rumex nervosus Vahl	Embuacho	Polygonaceae	Shrub	Indigenous
Abutilon longicuspe Hochst. ex A. Rich.	Nechlo	Malvaceae	Shrub	Indigenous
Solanum marginatum Lam.	Embuay	Solanaceae	Shrub	Endemic
Otostegia integrifolia Benth.	Tinjut	Lamiaceae	Shrub	Indigenous

A caliper and a Suunto Clinometer have been used to quantity the diameter and height, respectively. The DBH of each stem was measured and averaged for plants with more than one stem that were less than 1.3 meters in height [43]. The diameter of trees that were aberrant at 1.3 m and buttressed was measured directly above the buttress, at the point where the stem almost takes on a cylindrical shape [43]. A diameter tape was used to measure trees that were too big to measure with the calipers. With a graded stick, the heights of small trees and plants were determined. Tree and shrub heights were assessed visually in areas where topography made measurement challenging. Additionally, five 1 m × 1 m subplots (four at the corners and one in the middle) were used to count the seedlings and saplings in each plot. According to Sighal [44], Temesgen and Werkineh [45], and Worku et al. [28], individual stems with DBH <2 cm and height <1.5 m were counted by species as seedlings, while individuals with DBH <2 and height between 1.5 and 2 m were counted as

saplings. Individuals with BDH ≥2 cm and height ≥2 m were considered trees and shrubs. Next, a density calculation was performed for trees and shrubs, saplings, and seedlings.

2.3. Environmental Variables Data Collection. Measurements of environmental variables were made in addition to vegetation data. Elevation, slope, aspect, soil depth, and litter concentration (depth) are among the environmental variables that are measured in each plot. We measured elevation with a portable GPS unit (GARMIN 72). A GPS compass was used to measure the aspect, and a clinometer was used to measure the slope. The aspect was classified using the codes found in [46] as a potential measure of solar energy overall. As a result, the following values are obtained: North (N) = 0, Northeast (NE) = 1, Southeast (SE) = 3, Southwest (SW) = 3.3, Northwest (NW) = 1.3, East (E) = 2, South (S) = 4, and West (W) = 2.5. Plastic metric tape was used to measure the thickness (depth) of the litter. Using a metallic stick, the soil depth was measured in the center and at each of the four corners. The stand soil depth was then determined by averaging these measurements. In accordance with Woldemichael et al. [21], the measured depth was then categorized as follows: ≤20 cm = very shallow, >20–50 cm = shallow, >50–100 cm = moderately deep, and >100 cm = deep.

2.4. Anthropogenic Disturbances Data Collection. In the same way, information on anthropogenic disturbances like footpaths, stem cutting, and grazing pressure was gathered from the study area. Thus, the amount of bare ground or ground vegetation cover, the quantity of faecal matter droppings left by herbivores, and the presence of animal trails and signs of trampling and browsing were used to estimate the intensity of grazing. According to Tekle et al. [47] and Woldemichael et al. [21], the grazing rate was then visually categorized as 0 = nil, 1 = slightly grazed, 2 = moderately grazed, and 3 = highly grazed. By evaluating and documenting the existence or lack of stumps, logs, and indications of firewood gathering at each sample plot, the degree of human intervention was also estimated. As a result, in accordance with Woldemichael et al. [21], the impact's magnitude was scaled as follows: 0 = negligible, 1 = low, 2 = moderate, and 3 = heavy. Additionally, the footpath's presence and absence were ascertained, and the frequency and intensity of the footpath were recorded using 0–3 scales. Ultimately, the degree of disturbance was classified into four (0–3) categories as stated by Aynekulu [48] by taking into account the intensity of the grazing, human impact, and the footpath: 0 = nil, 1 = slightly disturbed, 2 = moderately disturbed, and 3 = highly disturbed.

2.5. Data Analysis. The diversity of woody species throughout the three elevation gradients (lower, middle, and upper) was evaluated using the following metrics: Fisher alpha, the Simpson diversity index [49], and the Shannon–Wiener diversity and equitability index [50, 51]. To ascertain the effectively existing species in each elevational gradient, Hill's diversity, or true diversity (true Shannon, true evenness, and true Simpson) [52, 53], was also examined. It was determined that the Shannon diversity index was as follows:

$$H' = -\sum_{i=1}^{s} \mathrm{Pi} \ln \mathrm{Pi}, \tag{1}$$

where H' = Shannon–Wiener diversity index, S = the number of species, Pi = the proportion of individuals in the ith species, and ln = natural logarithm = logarithm of the base e

The Shannon–Wiener index has values ranging from 0 to large numbers, which characterize communities with numerous individuals of a single species and communities with numerous species nevertheless few individuals [51, 52, 54].

The value of evenness (Shannon equitability index) was calculated as follows:

$$\begin{aligned} E &= \frac{H'}{H\max} \\ &= \frac{H'}{\ln S \text{ or } \ln N_0}, \end{aligned} \tag{2}$$

where E = Shannon equitability, $H'_{\max} = S$, or N_0 = the number of species.

The value of evenness lies in between 0 and 1, with 1 being comprehensive evenness [55].

The diversity of Simpson index (λ) was computed as follows:

$$\lambda = 1 - \sum \mathrm{Pi}^2, \tag{3}$$

where λ = Simpson's diversity index and Pi is labeled in equation (1).

Its value ranges from 0 (low diversity) to a maximum of $(1 - 1/S)$, where S is the number of species [54].

The Shannon–Wiener and Simpson diversity indices, however, are entropies or indexes rather than diversity in and of itself [56]. Since the index is based on probabilities of occurrence and measures the uncertainty in predicting the species of a given randomly selected individual from a community, they should be converted into effective numbers of species (true diversities) [52, 53]. The effective number of species produces a consistent and credible similarity measure [53].

The value of true Shannon was calculated by exponential altering of the results gained from Shannon entropy as follows:

$$\begin{aligned} N_1 &= {}^1D \\ &= e^{H'}, \end{aligned} \tag{4}$$

where ${}^1D$ or N_1 = True Shannon and e = the inverse of LN, the natural logarithm of a number.

The value of true evenness (E') [57] was gained from the exponential result of evenness:

$$\begin{aligned} E1 &= e^{E}\frac{{}^1D}{S} \\ &= \frac{N_1}{N_0}. \end{aligned} \tag{5}$$

Table 2: Endemic woody species recorded in the three elevational gradients of Harego Mountain Forest.

Scientific name	Family	Life form	IUCN red list category	Lower elevation	Middle elevation	Upper elevation
Rhus glutinosa	Anacardiaceae	S	VU	X	X	X
Clematis hirsuta	Ranunculaceae	S	NA	X	X	A
Maytenus arbutifolia	Celastraceae	S	NT	X	X	X
Lippia adoensis	Verbenaceae	S	LC	X	X	X
Solanum marginatum	Solanaceae	S	LC	X	A	A

A is absent, LC is the least concern, NA data is not available, NT is near threatened, S is a shrub, VU is vulnerable, and X is present.

The value of true Simpson was gained by inverting the result of Simpson entropy.

$$N2 = \frac{1}{\lambda} = {}^{2}D = \left[\frac{1}{1-\left(1-\sum_{i=1}^{S} Pi^{2}\right)}\right] = \frac{1}{\sum_{i=1}^{S} Pi^{2}}, \quad (6)$$

where $1/\lambda = {}^{2}D =$ is true Simpson diversity index

The study of species frequency and abundance frequency ratio (A/F) [58], density and basal area [59], and Important Value Index (IVI) [55] was used to explain the structural analysis of the vegetation along the gradients.

$$\begin{aligned}
\text{Frequency}\,(F) &= \frac{\text{The total number of quadrats in which a species occurred}}{\text{Total number of sampled quadrats}} * 100,\\
\text{Abundance}\,(A) &= \frac{\text{The total number of individuals of a species}}{\text{The total number of Quadrats in which the species occurred}},\\
\text{Density}\,(D) &= \frac{\text{The total number of individuals of a species}}{\text{The total number of quadrats studied}},\\
\text{Basal Area}\,(\text{BA}) &= \frac{\pi \text{DBH}^{2}}{4},
\end{aligned} \quad (7)$$

where $\pi = 3.14$ and DBH = diameter measured at breast height.

$$\text{Important Value Index}\,(\text{IVI}) = \text{RD} + \text{RBA} + \text{RF}, \quad (8)$$

where RD = relative density, RBA = relative basal area, and RF = relative frequency.

To discover significant variations among the elevational gradients in terms of the mean of the diversity indices, stand structure, and environmental parameters, a one-way analysis of variance (ANOVA) was done using SPSS version 26 at the 0.05 level of significance. To identify which gradient had the significant difference, a post hoc test was performed using the Tukey Honestly Significant Difference (Tukey HSD).

3. Results

3.1. Floristic Composition along Elevational Gradients. In all, 50 woody species that belongs to thirty-five families and forty-four genera were found and documented in the 67 sample plots that ranged in elevation from 2,079 to 2,516 m a.s.l. (Table 1). There were 40, 45, and 30 species found in the lower, middle, and upper elevational gradients, respectively. The medium elevation had the most documented number of species, while the upper level had the fewest. Similarly, the middle elevation took the uppermost number of genus ($n = 40$) and families ($n = 31$), while the upper elevation contained the lowest number of genus ($n = 24$) and families ($n = 23$) (Figure 3). *Fabaceae* was the greatest species-rich family in each elevation gradient, and the majority of families were exemplified by one species each. *Lamiaceae* was also an equally dominant family in the middle elevation, while *Anacardiaceae* was the second maximum species-rich family in each elevation gradient. In the lower elevation, *Fabaceae* was denoted by five species, followed by *Anacardiaceae* and *Lamiaceae*, each with three species. *Celastraceae*, *Cupressaceae*, *Euphorbiaceae*, *Oleaceae*, and *Rosaceae* were represented with two species each at the same elevation. Each of the remaining 17 families was represented by a single species in this elevational gradient. In the middle elevation, *Fabaceae* and *Lamiaceae* were embodied each by four species, followed by *Anacardiaceae* (three species), and *Celastraceae, Cupressaceae, Euphorbiaceae, Oleaceae, and Rosaceae* (each with two species). Each of the remaining 23 families was represented by a single species in this elevational gradient. Four species of *Fabaceae* were found in the upper elevation, followed by *Anacardiaceae*, *Celastraceae*, *Oleaceae*, and *Rosaceae* each with two species. Each of the remaining 18 families was represented by a single species in this elevational gradient.

In each elevation gradient, shrubs were the predominant life form, accounting for 21, 23, and 18 species of the total species recorded in the lower, middle, and upper elevations, respectively. In the lower, middle, and upper elevation

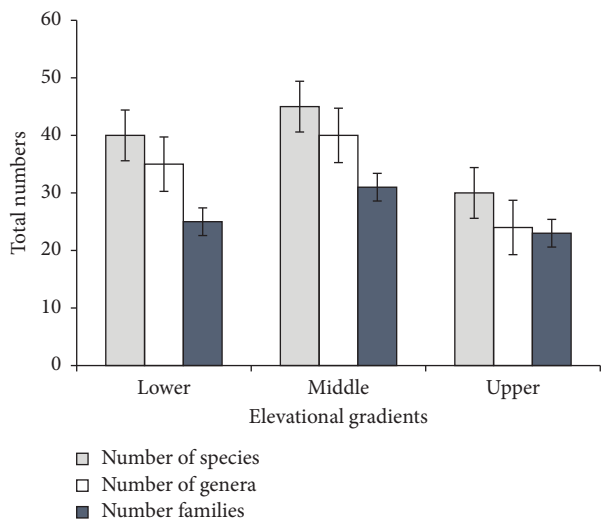

Figure 3: Floristic composition of collected woody species in the three elevational gradients of Harego Mountain Forest.

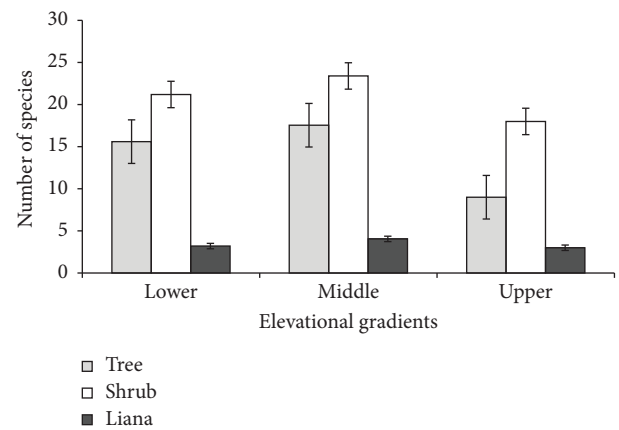

Figure 4: Growth habit of collected woody species in the three elevational gradients of Harego Mountain Forest.

gradients, trees made up roughly 16, 18, and 9 species of all the species, respectively. Conversely, lianas represent 3, 4, and 3 species of the total species in the lower, middle, and upper elevation gradients, respectively (Figure 4).

Five of the total species found in the research region were endemic to Ethiopia (Table 2). Every known endemic species in the study area has a shrubby growth habit. Three out of the total endemic species, namely, *Lippia adoensis*, *Rhus glutinosa*, and *Maytenus arbutifolia*, were found in the entire elevational gradients. *Clematis hirsuta* was found in both the lower and middle elevation gradients, whereas *Solanum marginatum* was only found in the lower elevation.

Structural values of woody species in this research area across the three elevational gradients are presented in Table 3. The three abundant species in the lower elevation in decreasing direction were *Dodonaea angustifolia* (12.82%), *Myrsine africana* (9.91%), and *Rhus natalensis* (6.77%), while *Lippia adoensis* (8.84%), *Dodonaea angustifolia* (7.71%) and *Rhus natalensis* (7.09%) were in the middle elevation. In contrary, *Dodonaea angustifolia* (9.55%), *Myrsine africana* (8.23%), and *Maytenus arbutifolia* (7.55%) were the three abundant species in the upper elevation. In the lower elevation, *Euclea racemosa* was occurred in all plots (100% of the plots) followed by *Rhus natalensis* (95.83% of the plots) and *Carissa spinarum* (87.50% of the plots), while *Ekebergia capensis*, *Prunus africana*, *Rosa abyssincia*, and *Acacia seyal* (each with 8.33% of the plots) were among the least frequent species. In the middle elevation, *Olea europaea* (90.91%), *Dodonaea angustifolia*, and *Rhus natalensis* (each with 84.85% of the plots) were among the utmost frequent species, while *Rhus retinorrhoea* and *Olinia rochetiana* (each with 3.03% of the plots) were among the minimum frequent species. In the upper elevation, *Carissa spinarum*, *Myrsine africana*, *Dodonaea angustifolia*, *Rhus natalensis,* and *Jasminum abyssinicum* (occurred each in 90% of the plots) were the utmost frequent species, while *Acacia etbaica*, *Dombeya torrida*, and *Grewia ferruginea* (occurred each in 10% of the plots) were among the least frequent species. The furthermost densely populated species in the lower, middle, and upper elevational gradients was *Dodonaea angustifolia*, accounting for 22.21, 15.63, and 16.46% of the total density, respectively. Species like *Euphorbia candelabrum*, *Olea europaea*, and *Juniperus procera* were accounting for 37.44, 34.37, and 34.55% of the total basal area, in the lower, middle and upper elevation, respectively. Based on the species important value index (IVI), *Euphorbia candelabrum* (49.67% of the total IVI value), *Olea europaea* (36.89%), and *Juniperus procera* (45.95%) were also the furthermost ecologically important species in the lower, middle, and upper elevation, respectively. *Clerodendrum myricoides*, *Prunus africana*, *Rhus glutinosa*, and *Rosa abyssincia* were the rare species recorded in the three elevational gradients. Species like *Acacia seyal, Echinops macrochaetus*, *Pinus patula*, and *Solanum marginatum* were recorded only in the lower elevation, while *Clematis hirsuta, Clutia abyssinica, Erica arborea, Festuca simensis, Otostegia integrifolia, Mimusops kummel* and *Berberis holstii* were documented only in the middle elevation. On contrary, *Rumex nervosus* was only present in the upper elevation. However, *Acacia abyssinica*, *Acacia etbaica*, *Asparagus africanus*, *Buddleja polystachya*, *Calpurnia aurea*, *Carissa spinarum*, *Clerodendrum myricoides*, *Dodonaea angustifolia*, *Eucalyptus globulus*, *Euclea racemosa*, *Grewia ferruginea*, *Heteromorpha arborescens*, *Jasminum abyssinicum*, *Juniperus procera*, *Maytenus arbutifolia*, *Maytenus senegalensis*, *Myrsine africana*, *Olea europaea*, *Osyris quadripartita*, *Pittosporum viridiflorum*, *Prunus africana*, *Pterolobium stellatum*, *Rhus glutinosa*, *Rhus natalensis*, and *Rosa abyssincia* were existed in the entire elevational gradients.

3.2. Species Diversity and Stand Structure along Elevational Gradients

3.2.1. Woody Species Diversity. The richness, abundance, and diversity indices of woody species' ANOVA findings are reported in Table 4. The overall mean woody species richness and

Table 3: The RF, RBA, RD, and IVI values of each species encountered in the three elevational gradients of Harego Mountain Forest.

Species	Lower elevation				Middle elevation				Upper elevation			
	RF	RBA	RD	IVI	RF	RBA	RD	IVI	RF	RBA	RD	IVI
Acacia abyssinica	1.49	0.62	0.16	2.27	0.72	2.49	0.10	3.31	2.65	9.95	0.53	13.14
Acacia etbaica	1.12	0.55	0.20	1.87	1.92	1.20	0.31	3.43	0.88	0.80	0.29	1.98
Acacia seyal	0.76	0.00	0.06	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Asparagus africanus	0.76	0.00	0.72	1.48	0.72	0.00	0.32	1.04	0.88	0.00	0.39	1.27
Berberis holstii	0.00	0.00	0.02	0.02	0.48	0.00	0.10	0.58	0.00	0.00	0.00	0.00
Buddleja polystachya	0.76	0.02	0.13	0.91	0.72	0.08	0.20	1.01	0.88	0.08	0.15	1.11
Calpurnia aurea	4.43	0.71	2.30	7.44	3.13	0.53	2.33	5.98	3.54	0.81	2.14	6.49
Carissa spinarum	7.74	1.97	9.65	19.36	6.25	1.89	7.98	16.13	7.96	5.10	10.59	23.65
Clematis hirsuta	0.00	0.00	0.02	0.02	1.44	0.13	0.83	2.40	0.00	0.00	0.00	0.00
Clerodendrum myricoides	1.49	0.02	0.30	1.82	2.64	0.41	0.79	3.83	2.65	0.94	0.68	4.27
Clutia abyssinica	0.00	0.00	0.02	0.02	0.72	0.00	0.13	0.85	0.00	0.00	0.00	0.00
Crateva adansonii	0.76	0.08	0.20	1.03	1.44	0.82	0.93	3.19	0.00	0.00	0.00	0.00
Cupressus lusitanica	1.49	2.57	0.62	4.68	1.44	1.63	0.22	3.29	0.00	0.00	0.00	0.00
Dodonaea angustifolia	7.37	6.81	22.21	36.39	6.73	4.48	15.63	26.84	7.96	9.60	16.46	34.02
Dombeya torrida	0.00	0.00	0.02	0.02	3.13	1.46	1.67	6.26	0.88	0.34	0.44	1.66
Echinops macrochaetus	2.59	0.00	2.16	4.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ekebergia capensis	0.76	0.56	0.13	1.45	0.24	1.51	0.13	1.88	0.00	0.00	0.00	0.00
Erica arborea	0.00	0.00	0.02	0.02	0.24	0.00	0.01	0.26	0.00	0.00	0.00	0.00
Eucalyptus globulus	0.76	1.27	0.06	2.09	1.20	11.87	0.16	13.23	0.88	4.12	0.05	5.05
Euclea racemosa	9.21	2.10	7.34	18.65	4.09	0.56	2.52	7.16	2.65	0.50	1.51	4.66
Euphorbia candelabrum	5.90	37.44	6.32	49.67	2.64	18.41	2.08	23.13	0.00	0.00	0.00	0.00
Euphorbia tirucalli	0.76	0.00	0.16	0.92	0.24	0.00	0.03	0.27	0.00	0.00	0.00	0.00
Festuca simensis	0.00	0.00	0.02	0.02	0.96	0.00	0.52	1.48	0.00	0.00	0.00	0.00
Grewia ferruginea	1.12	2.37	0.72	4.22	2.40	0.47	1.19	4.06	0.88	0.03	0.10	1.01
Heteromorpha arborescens	1.12	0.01	0.34	1.48	2.64	0.04	2.30	4.99	2.65	0.14	1.99	4.78
Jasminum abyssinicum	5.54	0.26	4.43	10.23	5.53	0.22	5.93	11.68	7.96	0.63	7.72	16.32
Juniperus procera	1.86	4.47	0.93	7.26	3.85	9.25	1.48	14.57	7.08	34.55	4.32	45.95
Lippia adoensis	0.00	0.00	0.02	0.02	0.48	0.00	1.28	1.76	1.77	0.00	2.38	4.15
Maytenus arbutifolia	2.23	0.42	1.98	4.63	2.16	0.45	2.72	5.33	3.54	1.22	5.78	10.54
Maytenus senegalensis	2.23	0.04	1.39	3.65	2.16	0.59	1.77	4.53	3.54	0.58	1.99	6.11
Mimusops kummel	0.00	0.00	0.02	0.02	0.48	0.53	0.19	1.20	0.00	0.00	0.00	0.00
Myrsine africana	3.70	0.91	8.60	13.21	6.01	0.96	12.55	19.52	7.96	2.82	14.18	24.96
Ocimum lamiifolium	0.76	0.00	0.16	0.92	0.24	0.00	0.03	0.27	0.00	0.00	0.00	0.00
Olea europaea	6.27	21.00	7.09	34.37	7.21	21.18	8.51	36.89	7.08	14.61	7.67	29.36
Olinia rochetiana	0.00	0.00	0.02	0.02	0.24	0.01	0.06	0.31	0.88	0.84	0.15	1.87
Opuntia ficus-indica	0.76	0.69	0.13	1.57	0.96	3.30	0.63	4.88	0.00	0.00	0.00	0.00
Osyris quadripartita	2.96	0.72	1.81	5.49	5.77	1.55	5.09	12.41	3.54	1.05	2.48	7.06
Otostegia integrifolia	0.00	0.00	0.02	0.02	0.24	0.00	0.32	0.56	0.00	0.00	0.00	0.00
Pinus patula	0.76	1.97	0.20	2.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pittosporum viridiflorum	3.33	3.74	2.47	9.54	4.09	1.68	1.89	7.66	2.65	1.40	0.73	4.78
Premna schimperi	1.12	0.46	0.83	2.41	0.96	0.10	0.36	1.42	0.00	0.00	0.00	0.00
Prunus africana	0.76	0.22	0.16	1.13	0.72	1.47	0.38	2.57	0.88	0.03	0.05	0.96
Pterolobium stellatum	1.86	0.19	0.76	2.80	1.44	0.11	0.63	2.18	0.88	0.32	0.63	1.84
Rhus glutinosa	4.07	0.51	1.42	5.99	3.13	0.47	1.02	4.61	6.19	1.84	2.72	10.76
Rhus natalensis	8.48	6.98	13.50	28.95	6.73	10.13	14.36	31.22	7.96	7.44	11.70	27.11
Rhus retinorrhoea	1.49	0.26	0.65	2.40	0.24	0.00	0.04	0.28	0.00	0.00	0.00	0.00
Rosa abyssincia	0.76	0.06	0.34	1.16	0.72	0.04	0.23	0.99	0.88	0.29	1.31	2.48
Rumex nervosus	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.88	0.00	0.58	1.47
Senra incana	0.00	0.00	0.02	0.02	0.48	0.00	0.06	0.54	0.88	0.00	0.29	1.18
Solanum marginatum	0.76	0.00	0.20	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

RF = relative frequency, RD = relative density, RBA = relative basal area, and IVI = important value index.

abundance of the forest under study were 11.37 ± 0.47 and 176.03 ± 11.19, respectively. The overall Shannon–Wiener diversity, evenness, and Simpson diversity indices of the woody species in the studied forest were 2.04 ± 0.04, 0.86 ± 0.01, and 0.83 ± 0.01, respectively. The mean woody species richness (observed) in the higher elevation was substantially higher than the lower and middle elevation ($p < 0.05$). However, the difference in woody species richness (observed) of the forest between the lower and middle elevation was not substantial. Woody species richness or Chao-1 richness (observed plus undetected) in the middle elevation was significantly ($p < 0.05$) higher than that of the lower elevation but not higher elevation. The variation in woody species richness (observed plus undetected) between lower and upper elevations was not

Table 4: The mean (mean ± SE) richness, abundance, and diversity indices of woody species in the three elevational gradients of Harego Mountain Forest.

Species diversity	Lower (24) Mean ± SE	Middle (33) Mean	Upper (10) Mean	Overall (67) Mean	F	P
Hill's N0	$10.25^{a} \pm 0.66$	$11.39^{a} \pm 0.64$	$14.00^{b} \pm 1.55$	11.37 ± 0.47	3.601	0.033
Abundance	$114.71^{a} \pm 11.82$	$207.36^{b} \pm 16.49$	$219.8^{b} \pm 11.19$	176.03 ± 11.19	11.008	<0.001
Simpson (λ)	$0.83^{a} \pm 0.01$	$0.81^{a} \pm 0.02$	$0.88^{b} \pm 0.01$	0.83 ± 0.01	4.019	0.014
Shannon (H')	$2.00^{a} \pm 0.06$	$1.98^{a} \pm 0.07$	$2.31^{b} \pm 0.06$	2.04 ± 0.04	3.781	0.028
Equitability (J)	$0.88^{b} \pm 0.01$	$0.83^{a} \pm 0.02$	$0.89^{b} \pm 0.01$	0.86 ± 0.01	3.087	0.052
Hill's E1	$0.77^{b} \pm 0.02$	$0.69^{a} \pm 0.02$	$0.76^{b} \pm 0.03$	0.73 ± 0.02	3.150	0.040
Hill's N1	$7.73^{a} \pm 0.46$	$7.70^{a} \pm 0.39$	$10.24^{b} \pm 0.72$	8.09 ± 0.29	5.264	0.008
Hill's N2	$6.41^{a} \pm 0.40$	$6.27^{a} \pm 0.32$	$8.37^{b} \pm 0.37$	6.63 ± 0.23	5.538	0.006
Fisher alpha	$2.88^{a} \pm 0.16$	$2.67^{a} \pm 0.17$	$3.38^{b} \pm 0.41$	2.85 ± 0.12	4.098	0.013
Chao-1	$9.79^{a} \pm 0.64$	$12.91^{b} \pm 0.85$	$11.50^{ab} \pm 0.78$	11.58 ± 0.52	4.121	0.021

Values represented with different letters revealed significant difference at 0.05 level of significance tests. The plus-minus (±) sign used to separate standard error from the value of mean. Hill's N0 stands for species richness (observed), Hill's E1 stands for true evenness, Hill's N1 stands for true Shannon, Hill's N2 stands for true Simpson, and Chao-1 stands for species richness (observed plus undetected).

significant. This implies that undetected species during data collection were high in number than the species in the lower and upper elevation. The abundance of woody species in the higher and middle elevations were significantly ($p < 0.001$) higher than that in the lower elevation. Generally, woody species richness (observed) and abundance increased as elevation increased. Woody species diversity (Shannon, Simpson, and Fisher alpha) and Hill's diversity number (Hill's N1 and Hill's N2) in the higher elevation was significantly ($p < 0.05$) higher than the diversity at the lower and middle elevation. A least Shannon and Simpson, and their true diversity, in addition to Fisher alpha, were detected in the middle elevation. However, evenness and its true evenness were significantly ($p < 0.01$) lower in the middle elevation than those in the lower and higher elevational gradient.

The highest number of woody species (Hill's $N_0 = 26$) was documented in the upper elevation at 2378 m, while the lowest number of woody species (Hill's $N_0 = 4$) was verified in the middle elevational gradient at 2276 m (Figure 5(a)). Similarly, the upper elevational gradient had the highest Shannon diversity index ($H' = 2.74$) at elevation of 2378 m, while the middle elevation had the lowest Shannon diversity index ($H' = 0.72$) at elevation 2231 m (Figure 5(b)). In contrast, the highest ($J = 0.95$) and the lowest ($J = 0.29$) species evenness were recorded in the middle elevational gradient at 2164 m and 2231 m, respectively (Figure 5(c)). The overall trend of species richness and the Shannon diversity index over an elevation gradient demonstrates that these parameters grew with elevation until it reached 2378 m, at which point they progressively decreased as elevation increased. On the contrary, as elevation rose, the species evenness distribution pattern shrank.

3.2.2. Stand Structure. The stand configurations of Harego Mountain Forest over each elevational gradient are described in Table 5. The mean value of tree density and basal area of the studied forest were 4,400.75 ± 279.83 stems ha^{-1} and 9.75 ± 1.29 m^2 ha^{-1}, respectively. The entire three elevational gradients showed a substantial difference ($p < 0.05$) in the stand structures. All stand structures were higher in the middle elevational gradient. The greatest basal area was documented (13.24 m^2 ha^{-1}) in the middle elevation, while the lowest (4.88 m^2 ha^{-1}) was at the upper elevation. At the middle elevation, the basal area was twofold and threefold higher than the values of the lower and the upper elevation, respectively. Similarly, the basal area in the lower elevation was twofold greater than the basal area of the upper elevational gradient. The overall stem number (i.e., a combination of seedling, sapling, and tree and shrub density) was significantly ($p < 0.01$) varied by elevation. A comparable stem number was recorded at the middle and upper elevation, while the number of individual increased greatly from lower (2,976 stems ha^{-1}) to middle (5,211 stems ha^{-1}), but decreased to upper (5,148 stems ha^{-1}) elevation. This means the stem number in the lower elevation was substantially ($p < 0.01$) 43% and 41% lower than the stem number in the middle and upper elevation, respectively. The stem number of trees and shrubs in the lower elevation was substantially ($p < 0.01$) lower by 34% and 21% of the stem number of trees and shrubs in the middle and upper elevation.

The density and basal area of stems augmented as elevation increased (Figures 6(a) and 6(b)). The uppermost stem density (10,950 stems ha^{-1}) in the Harego Mountain Forest was estimated in the middle elevational gradient at 2,316 m, while the lowermost stem density (400 stems ha^{-1}) was estimated in the lower elevational gradient at 2,092 m. Similarly, the greatest basal area (57.19 m^2 ha^{-1}) was estimated in the middle elevation at 2,286 m, while the lowest basal area (0.85 m^2 ha^{-1}) was estimated in the lower elevation at 2,134 m. The basal area and stem density over the gradient of elevation show an increasing pattern as elevation increased.

3.3. Environmental Variables along Elevational Gradients. The environmental variables of the Harego Mountain Forest for each elevational gradient are described in Table 6. Except for aspect; all environmental variables had revealed a substantial difference ($p < 0.05$) along the three elevational gradients. In contrast to the middle elevation, the slope's steepness was substantially ($p < 0.05$) higher in the lower and upper elevation. Soil depth in the lower and middle

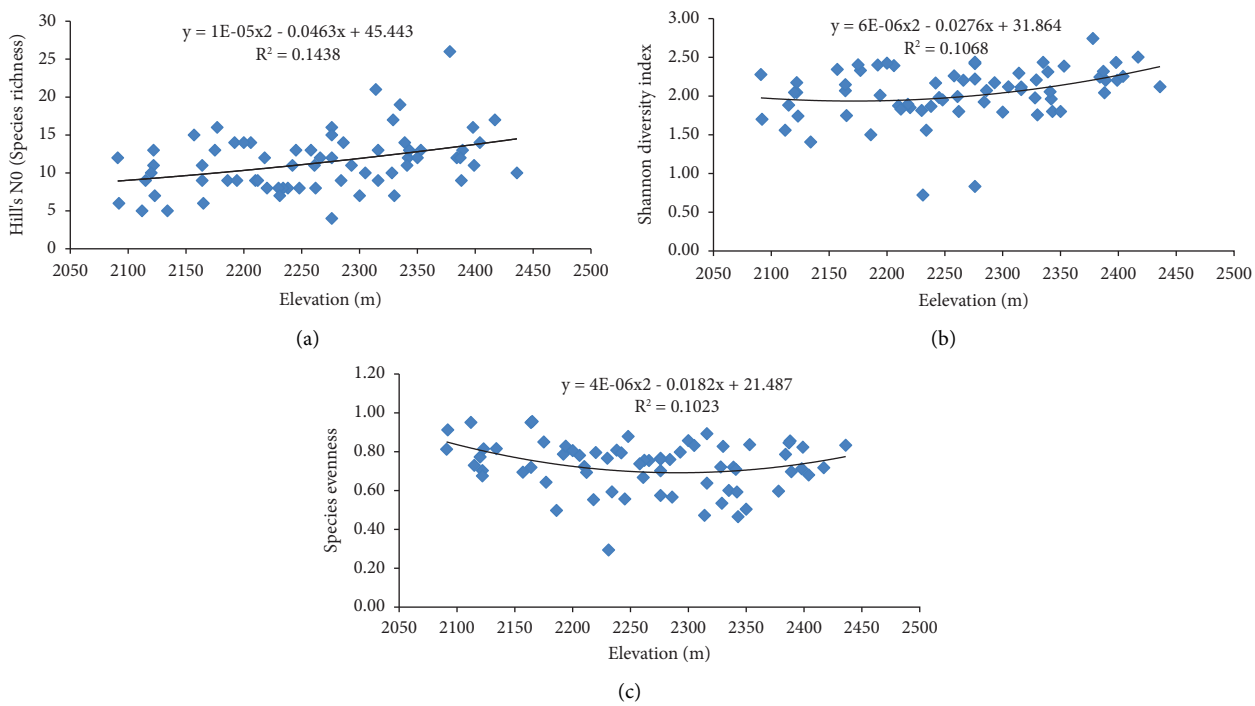

Figure 5: Species richness (a), Shannon diversity index (b), and species evenness (c) patterns over elevational gradients of Harego Mountain Forest.

Table 5: Mean (±SE) DBH, height, basal area, density of seedlings, saplings, trees and shrubs, and overall woody species for each elevational gradient in Harego Mountain Forest.

Stand structure	Elevation					
	Lower	Middle	Upper	Overall	F	p value
Seedling ha^{-1}	668.75 ± 72.268^{a}	1767.50 ± 366.54^{b}	1494.70 ± 217.75^{b}	1239.55 ± 132.64^{b}	6.28	0.003
Sapling ha^{-1}	359.37 ± 56.42^{a}	907.50 ± 170.66^{b}	772.73 ± 114.30^{b}	644.78 ± 69.50^{b}	5.61	0.006
Tree and shrub ha^{-1}	1947.92 ± 274.22^{a}	2943.18 ± 242.54^{b}	2472.50 ± 356.81^{b}	2516.42 ± 170.72^{ab}	3.83	0.03
Total density ha^{-1}	2976 ± 346.05^{a}	5210.61 ± 384.17^{b}	5147.50 ± 733.20^{b}	4400.75 ± 279.83^{b}	8.99	<0.001
BA (m^{2} ha^{-1})	7.00 ± 1.57^{a}	13.24 ± 2.18^{b}	4.88 ± 1.29^{a}	9.75 ± 1.29^{a}	4.01	0.02
Mean DBH (cm)	4.70 ± 0.52^{a}	6.24 ± 0.40^{b}	6.10 ± 0.45^{b}	5.67 ± 0.29^{a}	3.30	0.043
Mean height (m)	3.09 ± 0.29^{a}	4.28 ± 0.24^{b}	4.03 ± 0.21^{ab}	3.82 ± 0.17^{a}	5.89	0.004

The difference between elevational gradients was investigated by analysis of variance, followed by Tukey's HSD test. Values represented with different letters revealed significant difference at 0.05 level of significance tests. The plus-minus (±) sign used to separate standard error from the value of mean.

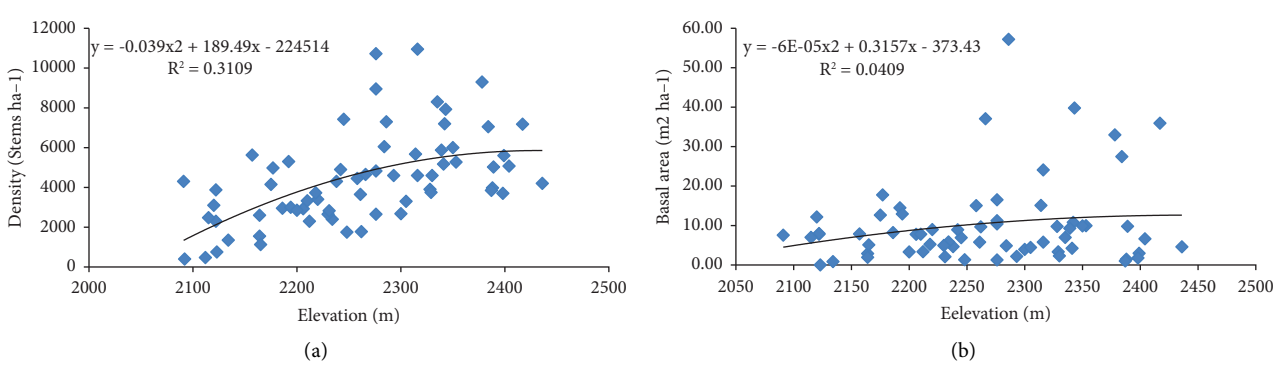

Figure 6: Stem density (a) and basal area patterns (b) of woody species over elevational gradients in the Harego Mountain Forest.

elevational gradients was substantially ($p < 0.05$) higher than that in the higher elevation. The concentration of litter was substantially ($p < 0.001$) different in the entire three elevational gradients. Litter in the middle and higher elevation was four-times and two-times higher than the concentration at the lower elevation. The moisture content (humidity) of Harego Mountain Forest was also significantly ($p < 0.05$) different among the entire three elevational gradients. The humidity of the middle elevation was higher by 45% and 61% of the lower and higher elevation, respectively while, the humidity in the higher elevation was higher by 28% of the lower elevation.

3.4. Anthropogenic Disturbance along Elevational Gradients. The Kruskal–Wallis test of anthropogenic disturbance in the three elevational gradients was also described in Table 7. The extent of grazing pressure and illegal stem cutting showed significant ($p < 0.01$) differences in the entire three elevational gradients. Grazing pressure and illegal stem cutting were higher and moderate at the lower and higher elevational gradient, respectively, but slight at the middle elevation. The extent of the footpath at the lower elevation was moderate, but it was slight at the middle and higher elevation. Generally, the level of anthropogenic disturbance (a combination of grazing pressure, stem cutting, and footpath) was moderate at the lower and higher elevation, while a slight disturbance in the middle elevation.

4. Discussion

4.1. Floristic Composition along Elevational Gradients. Obviously, floristic composition can be expressed in terms of species richness, genera, families, and life forms. Within 2,079 to 2,516 m a.s.l. elevational ranges, about 50 woody species were recorded and documented in the Harego Mountain Forest. The finding of this study is generally in agreement with the Afromontane forest species richness, such as at Jibat mountain forest, with 52 species [60], and Wof-Washa forest, with 51 species [61] in the elevational range of 1,500–3,000 m. Studies also reported elsewhere at Mount Elgon and Mau forest in Kenya also reported 49 and 50 tree species, respectively, at the elevations of 1,200–2,400 m and 2,100–2,700 m [62, 63], which are comparable numbers of species to the study area. Then again, the number of species found in the present study was higher than that of the species stated at Bale mountain (Rira) forest, 16 woody species, in the elevation range of 3,074–3,274 m [4], at Menagesha forest, 30 species [60], at Naran Valley, Pakistan, 32 woody species, in the gradient range of 2,450–4,100 m [23], at Dawsura exclosure forests, 34 woody species, in the gradient range of 1,670–2,138 m [64]. However, it was less than the number of species reported in Mana Angetu forest (117 species) in the elevation range of 1500–3000 m [65], the Great Rift Valley of Tigray, northern Ethiopia (108 species) in the elevation range of 1,000–2,760 m [13], in the Eastern Escarpment of Wollo, Ethiopia (104 species) in the elevation range of 750–1,750 m [19], in the remnant moist Afromontane forest of Wondo Genet, south central Ethiopia, 72 species in the elevation range of 1,800–2,500 m [3], and Harenna forest, 61 species, in the elevation range of 1,500–3,000 m [66]. Species number presented here in the current study is lower than species number documented elsewhere, such as at Southern Norway grassland with 141 species in the elevation range of 530–1,230 m [67], at Baihua mountain reserve, Bejing, with 171 species [14]. The possible reason for this variation might be due to the difference in elevation range, which in turn governs other environmental variables such as temperature, precipitation, air pressure, soil, and hydrology [16], which directly or indirectly control the growth and development of plants and the patterns of vegetation distribution in an area [17]. Many authors, including Brinkmann et al. [20], Chawla et al. [68], Yirdaw et al. [4], and Zhang et al. [69], have reported on the number of species variations, even in a small elevational range differences.

Along the elevational gradient of Harego Mountain Forest, the number of species, genera, and families were highest at the middle elevation. Species genera and families were found the highest in the middle elevational gradient, as also reported in the Eastern Escarpment of Wollo [19], in the Great Rift Valley of Tigray, northern Ethiopia [17], in the remnant moist Afromontane forest of Wondo Genet, south central Ethiopia [3], and in the Bhabha Valley in the western Himalaya [68]. According to Berhanu et al. [70], the diversity of species, genera, and families in the dry Afromontane forests of Ethiopia in general, are higher at the middle elevational gradient. The maximum diversity in species, genera, and families in the middle elevational gradient could be explained by the minimum disturbance, which states that the minimum disturbance maximizes the diversity of species, genera, and families [68]. As a result of agricultural expansion and road construction in the lower elevational gradient, species distribution in the disturbed area was declined to a minimum figure. Besides, the species, genera, and families which are found in the transition stage from the disturbance of higher and lower elevational gradients are confined to the middle elevational gradient [68].

Similar to the present study, the dominance of *Fabaceae* and *Lamiaceae* along an elevational gradient was reported in the Great Rift Valley of Tigray, northern Ethiopia [13]. Furthermore, the dominance of *Fabaceae* in the forest along an elevation gradient was reported in the Eastern Escarpment of Wollo, Ethiopia, representing 28 species [19], in the Dawsura exclosure forests, Tigray, 8 species [64], in the Yegof mountain forest, 9 species [71], and in the Wof-Washa forest, 6 species [72]. The highest representation of species from the family *Fabaceae* across the three elevational gradients could be related to the fact that it is the first largest family in the woody plants of the Afromontane forests of Ethiopia [70]. Besides, *Fabaceae* has the largest number of woody species in the flora of Ethiopia and Eritrea, next to the family *Asteraceae* [40, 73]. This could also be attributed to its successful dispersal strategies and adaptation potential to the diverse agroecologies of the country [28]. In line with this, Chawla et al. [68] reported families that have the potential to grow in a wide range of environmental conditions and had higher recruitment capability with resource limitations would dominate the vegetation areas.

Table 6: Environmental variables (mean ± SE) of the three elevational gradients located in Harego Mountain Forest.

Environmental variable	Lower (24)	Middle (33)	Upper (10)	Overall (67)	F	P
Slope (%)	52.71 ± 4.08^{b}	40.06 ± 3.01^{a}	47.50 ± 4.17^{b}	45.70 ± 2.26	3.554	0.034
Aspect	1.96 ± 0.26^{a}	1.76 ± 0.19^{a}	2.10 ± 0.28^{a}	1.88 ± 0.14	0.440	0.646
Soil depth (m)	56.04 ± 11.22^{b}	62.27 ± 9.50^{b}	43.00 ± 10.86^{a}	57.16 ± 6.35	5.290	0.012
ALD (cm)	0.42 ± 0.13^{a}	1.52 ± 0.16^{c}	0.8 ± 0.25^{b}	1.01 ± 0.12	12.682	<0.001
Moisture content	81.74 ± 620.76^{b}	149.91 ± 31.70^{c}	59.21 ± 20.35^{a}	111.95 ± 18.00	4.987	0.010

ALD = average litter depth (accumulation).

Table 7: Anthropogenic disturbance along the three elevational gradients in the Harego Mountain Forest.

Anthropogenic activity	Lower (24)	Middle (33)	Upper (10)	Overall (67)	X^2	P
LGP	High^{c}	Slight^{a}	Moderate^{b}	Moderate	9.181	0.002
LISC	High^{c}	Slight^{a}	Moderate^{b}	Moderate	7.570	0.004
LFP	Moderate^{b}	Slight^{a}	Slight^{a}	Slight	4.415	0.035
LGD	Moderate^{b}	Slighta	Moderate^{b}	Moderate	5.952	0.015

LGP = level of grazing pressure, LISC = level of illegal stem cut, FP = level of the footpath, and LGD = level of general anthropogenic disturbance.

In the current study, the biggest proportion (54%) of life forms was shrubs. A higher proportion of shrubs was also presented in other similar vegetation studies along elevational gradients, such as the Great Rift Valley of Tigray, northern Ethiopia, representing 55% [13], in the Eastern Escarpment of Wollo, Ethiopia, 43% [19], in Yegof mountain forest, 51.3% [71], and in Gra-Kahsu natural vegetation, 39.53% of the total species recorded [74]. Additionally, it was observed by that shrub species predominate in Ethiopia's Afromontane forest [70]. The abundance of shrub species was also presented in the vegetation area of the Bhahala Valley in Western Himalaya, with 52% of the total woody species [68]. Presence of high shrub species composition was because heavy duty logging of useful woody species used for fuelwood and timber [75]. Consequently, the predominance of pioneers and shrubs changed their species composition dramatically [48, 76]. Furthermore, shrub species can establish themselves early in damaged areas [28, 71]. Chawla et al. [68] draw the conclusion that although trees are restricted to specific height gradients, shrubs can potentially be found across a larger geographic range. In the research area, five endemic plant species that are unique to Ethiopia, cannot be found anywhere else in the world, and require immediate conservation action. *Rhus glutinosa* was classified as vulnerable in the IUCN Red List, whereas *Maytenus arbutifolia* was classified as near threatened [77]. *Clematis hirsuta* is not affected, while the other two species: *Solanum marginatum* and *Lippia adoensis* were the least.

4.2. Species Diversity and Stand Structure of Woody Species along the Elevational Gradients. The results of the current study showed that stand structure, species richness, and diversity are all significantly influenced by elevation. Several studies have shown that elevation is a significant factor influencing species diversity in mountains regions [28, 67, 78–87]. The result of the current study also supports the results given by Zhang et al. [87], Cui and Zheng [86], Zhang et al. [14] and Woldu et al. [64], who reported elevation was among the most important factors that influenced species distribution and diversity in the six subtropical mountain forests, Yunnan Province, in the subtropical Broadleaf Forests in Southern China, in the Baihua Mountain Reserve, China, and in the Dawsura exclosure, Tigray, respectively. The highest value of woody species richness and diversity was found in the highest elevation in this study. Inversely, Austrheim [67] found that the species diversity of vascular plants on a small scale area peaked at midelevation, but diversity on a broad scale decreased continuously with elevation. Likewise, Gracia et al. [82] in the central Pyrenees, Lleida, Spain, Kebede et al. [85] in Wondo Genet forest, and Zhang et al. [69] in Mount Tai and Mount Lao, China, found that species richness and Shannon diversity index decreased continuously as elevation increased. On the other hand, Vetaas and Grytnes [78] in the Himalayan forest in Nepal, Chawla et al. [68] in the Bhabha Valley of the western Himalaya in India, and Khan et al. [23] in the Narran Valley, Pakistan, found that species diversity was higher at the middle elevation than at either the lower or higher elevation. The difference in species richness along an elevational gradient among the vegetation areas might be due to the variation in elevation range, climatic condition, and anthropogenic disturbance. Species diversity reduction in the lower elevational gradient was mainly due to the existence of high anthropogenic disturbance [68]. However, the higher effective number of species for Shannon and Simpson indices at higher and lower elevation might be due to the even distribution of species; while in the middle elevation, high species richness was encountered because of the dominance of *Olea europaea* and the occurrence of many rare species provides a less effective number of species. In agreement with the current study, Aynekulu [6] found a lower Shannon index within the gradient where the existence of a better dominance of *Juniperus procera*, which reduces the even distribution of species. In the lower and upper elevational gradients, on the other hand, shrub species that could have dense stems were abundant. This may have to do with past

disturbances in the upper and lower elevational gradients as well as the secondary succession of plants, which includes many shrub species that are among the first to emerge and survive in the region. Consequently, there are fewer species in the lower and upper elevational gradients but higher species diversity due to past disruption and current protection of the area; in contrast, this was not the case in the middle elevational gradient. In line to this, Chawla et al. [68] reported in an area where human disturbances like road building, habitation, and agricultural operations are prevalent, species richness decreases while species diversity increases. Furthermore, Austrheim [67] and Wondie et al. [79] strengthened land use processes such as farming, grazing, and fuelwood cutting and have leveled out the effects of other variables along the gradient. In line to this, Chawla et al. [68] reported that the lower species richness at the highest elevational gradient might be due to the loss of habitat diversity.

The presence of elevational variation had also shown a significant difference in stand structure, in which high density of seedlings, saplings, tree, and shrubs were found and high basal area, DBH, and height in the middle elevation, followed by the upper elevation, while low in the lower elevation. This portrays that the forest had lower DBH of trees at lower and higher elevations. This might be due to the high human-caused impacts like expansion of agriculture, grazing pressure, and selective stem cutting in the lower and upper elevational gradients which influence the survival of seedlings and saplings and reduction of the frequency of larger diameter trees. A similar result was also obtained in the northeastern escarpment of Ethiopia [6] and in the subalpine zone of west Himalaya [88]. The previous study [89] showed that the stand structure and diversity indices could vary as a result of the variation in species composition and the magnitude of disturbance involved. Therefore, in the study site, the high tree parameters in the middle elevation might be due to the dominance of *Olea europaea* and *Eucalyptus globulus* which can provide larger stem diameter and height. By contrast, low in lower elevational gradient could be due to the dominance of shrub species despite the presence of *Euphorbia candelabrum* tree species. In terms of stem density, the lowest in lower elevation could be mainly due to the disturbance effect. As a result, the stem number of seedlings and sapling in the lower elevation was threefold and twofold lower than that in the middle and upper elevation, respectively. In consistent with our finding, the lower stem number at the lower elevation was also reported by a previous study [4] from the Rira forest. Livestock pressure was also stated to have an adverse impact on the natural regeneration of native woody species and ought to be managed to reverse the current trend [90]. In the study area, grazing was not continuous meanwhile, high in the lower and upper elevation, but it had a slight effect in the middle elevation, which led to lower density in all developmental stages at the lower and upper elevational gradients. Besides, stem cutting for firewood and construction purposes was also higher (common) at the lower elevation of Harego Mountain Forest and reduced in the middle elevation. The lower stem number due to the higher effect of stem cutting in the lower elevation was also reported from Bale mountain (Rira) forest in [4].

Furthermore, Hegazy [83] strengthened that the intricate interface of diverse ecological elements in relative to elevation results in a variety of plant communities, vegetation belts, and habitat types. Environmental gradients like slope, aspect, moisture content, soil depth, and nutrient availability are hindering factors of species distribution, density, and population structure [7, 64, 91]. Deep soil depth and high moisture content, slight grazing effect and illegal stem cutting, and the low frequency of footpaths in the middle elevation of the studied site resulted in better stand structure and species richness compared to the other two elevational gradients. As the range of elevation increases, the climatic condition will be also changed and the species coping mechanism will vary with a reduced climate [4], which in turn leads to a lower density of seedlings and saplings. Certain species' distribution might be restricted at the higher elevation due to comparatively damp climatic conditions [13, 92]. Therefore, giving high concern for biotic factors in the lower elevation while for abiotic factors in the upper elevation should be important for the conservation of the forest.

5. Conclusion

Harego Mountain Forest's woody species composition is noticeably similar to most of the forest of Ethiopian dry Afromontane. The findings revealed that elevation has a significant effect on the species composition, diversity, and stand configuration of the forest. The effect of anthropogenic disturbance is clearly observed in the lower and upper elevational gradients, which results in a lower stem number of seedlings, saplings, and trees and shrubs and a low basal area than in the middle elevation. The steepness of the slope, low soil moisture content, and shallowness of soil depth in the lower and upper elevations also contributed to the reduction of diversity and stand structure in these elevational gradients. Engaging the local community in forest management through participatory forest management system would raise the awareness of forest ownership, reduce illegal activities in the forest, and improve the regeneration process of indigenous species. Besides, reducing human pressure on forest areas through tree planting in farmlands and woodlots, as well as implementing physical soil and water conservation structures are recommended. Further investigation on seed banks of soil and the result of other physical and human factors not yet investigated on the forest are required.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Disclosure

The funders had no involvement in the study's design, data collection, analysis, or interpretation, article preparation, or decision to publish the results.

Conflicts of Interest

The authors declare that they do not have any conflicts of interest.

Authors' Contributions

Belachew Bogale Worku was responsible for the study's conception, design, material preparation, and data collection. Belachew Bogale Worku, Melese Genete Muluneh, and Tesfaye Molla handled the data analysis and manuscript drafting. The manuscript was revised by all authors. After reading the published version of the manuscript, all authors have given their approval.

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