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Research Article

Plant Diversity and Relationship between Plant Communities and Environmental Variables in Combretum-Terminalia Woodland, Western Ethiopia

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The aim of the study was to determine plant community types and species distribution patterns and their relationships with environmental variables in Dabena woodland in western Ethiopia. A systematic sampling design was used. Representative and relatively homogeneous vegetation units of sampling sites were selected on the basis of physiognomy. Vegetation and environmental data were collected from a total of 92 plots (each 20 m × 20 m) which were placed at intervals of 200 m along the established transect lines. All vascular plant species in the plots were recorded. Floristic richness, diversity, evenness indices, and similarity of the plant communities were analyzed using R Package 3.2. Classification and ordination methods were used to describe community types and to examine the relationship between community type and environmental variables. Five plant communities were identified in the vegetation of Dabena woodland, namely, *Clerodendrum myricoides-Vernonia hymenolepis*, *Erythrina brucei-Entada abyssinica*, *Combretum molle-Gardenia ternifolia*, *Galiniera saxifraga-Flacourtia indica*, and *Dracaena afromontana-Landolphia buchananii.* All community types showed a high diversity index. The highest similarity coefficient was 0.49 between community types two and three, reflecting 0.51 dissimilarity in their species richness. Disturbance, altitude, CEC, phosphorous, OC, clay, and TN are the environmental factors that most influenced the distribution of the plant communities. The CCA diagram revealed that disturbance and silt strongly influenced the distribution of species in *Clerodendrum myricoides-Vernonia hymenolepis* community, *Combretum molle-Gardenia ternifolia* community, and *Erythrina brucei-Entada abyssinica* community. Altitude, clay, and total nitrogen axes strongly influenced the distribution of species in *Galiniera saxifraga-Flacourtia indica* and *Dracaena afromontana-Landolphia buchananii* community. Therefore, it can be concluded that some other environmental variables may influence the distribution of the plant communities, which needs to be further investigated.

1. Introduction

The decline in natural vegetation cover and the resulting biodiversity loss is today a global problem seeking a global solution. Woodlands are important sources of fuel wood and construction materials for the rural as well as for the urban community [1]. Forests and woodland vegetation have been declining both in size and quality as a result of anthropogenic pressures [2]. Land degradation and deforestation are the two most important causes of the decline of both the vegetation size and quality in the woodland area [3]. Geographical gradients such as altitude can play a significant role in determining the general occurrence and distribution patterns of plant communities [4, 5].

The vegetation cover of a given area has a definite structure and composition [6, 7]. In order to have a good mental image of the vegetation of an area and to recognize the distribution of plant species, vegetation composition and vegetation community study are very important. Both vegetation structure and vegetation composition are typically measured or estimated on the basis of plant community [6]. Plant communities are largely based on the appearance or the growth form of the given vegetation type. This is due to their similar requirements for existence in terms of

environmental variables such as light, temperature, water, drainage, and soil. Consequently, the description of plant communities involves the analysis of the species diversity index, species evenness, and similarity index [7]. Environmental variable analysis provides the underlying reasons for the pattern and distribution of plant communities on landscapes. Thus, the assessment of the spatial variation of environmental variables is important to recognize the factors leading to the distribution of plant communities.

Classification of natural vegetation types into possible plant communities is a vital tool for the appropriate management of woodland vegetation. Recognition of plant communities helps in recommending appropriate management regimes for the community types as separate units deserve separate management regimes [8]. This further helps in planning and implementing conservation strategies and sustainable utilization of natural vegetation resources. Plant communities are determined as a collection of functionally alike species populations that occur together in time and space. One of the features of the community is its physiognomy, which means the way it appears. Consequently, the relationship between the distribution of plant communities and environmental variables is one of the most significant research problems in vegetation ecology.

Dabena woodland is found in the Buno Bedele zone, Western Ethiopia and it is one of the most diverse areas inhabited by a great diversity of both animals and plants. However, the area is seriously declining in its vegetation cover due to resettlement and illegal usage of vegetation resources by the nearby communities [9]. The availability of accurate data on vegetation resources is an important requirement for woodland vegetation management [10]. The vascular plant species of Dabena woodland vegetation have not been studied previously; the plant communities that exist in the woodland have not been identified; and there is also low information and poor management system of the Dabena woodland vegetation which lead to the mismanagement of plant species [9]. In light of this, the generation of sound biodiversity and ecological data on the remaining vegetation is necessary for subsequent conservation activities. Thus, the present study aims to assess the diversity of vascular plant species, identify and classify the plant community types found in the study area, study the relationship between plant communities and environmental variables, and describe the major environmental factors which affect the vegetation of Dabena woodland in Western Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area. The Dabena woodland vegetation is found in the Meko and Dabo Hana districts in the Buno Bedele zone, Western Oromia Regional State, and Western Ethiopia. Meko district is located 534 km West of Addis Ababa and 87 km South West of Bedele town and Dabo Hana district is located 437 km West of Addis Ababa and 20 km South West of Bedele town. For ease of the study, Dabena woodland vegetation was divided into two sites: the Kodi-Gassi site and the Haro-Abba Diko site. The Dabena River borders the two study sites. Kodi-Gassi site is located in Meko district and situated in the western part of Dabena woodland between 08° 39′ 15″–08° 52′ 30″ N latitude and 35° 55′ 30″–36° 7′ 15″ E longitude, with an elevation ranging from 1,450 to 1789 m. a.s.l. Haro-Aba Diko site is situated in the Eastern part of Dabena woodland between 08° 35′ 20″–08° 45′ 55″ N latitude and 36° 15′ 45″–36° 20′ 10″ E longitude, with an elevation ranging from 1,455 to 1,890 m. a. s.l. (Figure 1).

The topography of the area encompasses flat areas, river valley slopes, and water-logged valley bottoms. The study area, with various topographic landforms, is endowed with numerous rivers and streams including Dabena, Gassi, Seba, Disi, and Mieso Rivers which are perennial. The study area possesses different types of soils including red, brown, and black. The rainfall and temperature data for the study area were collected from the nearest meteorological stations at Meko and Kone which are about 16 km and 32 km away from the Dabena woodland, respectively. Metrological data of monthly maximum and minimum temperature and monthly rainfall were taken from both stations for the period from 2008 to 2017. The Mako district's mean annual temperature ranges from 13.3°C to 32.3°C and the mean annual rainfall is 1152 mm (Figure 2(a)). The area experiences widespread and prolonged monsoon rains from May through September reaching a peak in August. The area receives maximum rainfall from June to August and a minimum from January to March. The Dabo Hana district's mean annual temperature ranges from 13.7 to 31.2°C and the mean annual rainfall is 1825 mm (Figure 2(b)). The area receives maximum rainfall from June to September and minimum from January to March.

2.2. Sampling Design. Following a reconnaissance survey, a systematic sampling technique was used for vegetation and environmental data collection following Muller–Dombois and Ellenberg [6] and Kent and Coker [7]. Representative and relatively homogeneous vegetation units of sampling sites were selected on the basis of homogeneity. A total of 19 line transects were laid and the sampling plots were laid at 200 m intervals along each transect. A total of 92 plots (54 plots from the Haro-Abba Diko site and 38 plots from the Kodi-Gassi site of Dabena woodland) was sampled for vegetation and environmental data collection.

2.3. Vegetation Data Collection. A square sample plot of $20\,m * 20\,m$ ($400\,m^2$) was used to collect vegetation and environmental data. All woody species with a diameter of ≥2.5 cm and a height of ≥2 m in each plot were counted and recorded. Shrubs and saplings were sampled from $5\,m * 5\,m$ ($25\,m^2$) plots which were placed at the center of each main plot. To sample herbaceous and seedlings in the vegetation floor, five smaller subplots of $1\,m \times 1\,m = 1\,m^2$ (four at the corner and one at the center of the main plot) were established. Individuals per plant species were counted in each sample plot. Plant specimens occurring outside the plots were also recorded to enrich the diversity of the flora.

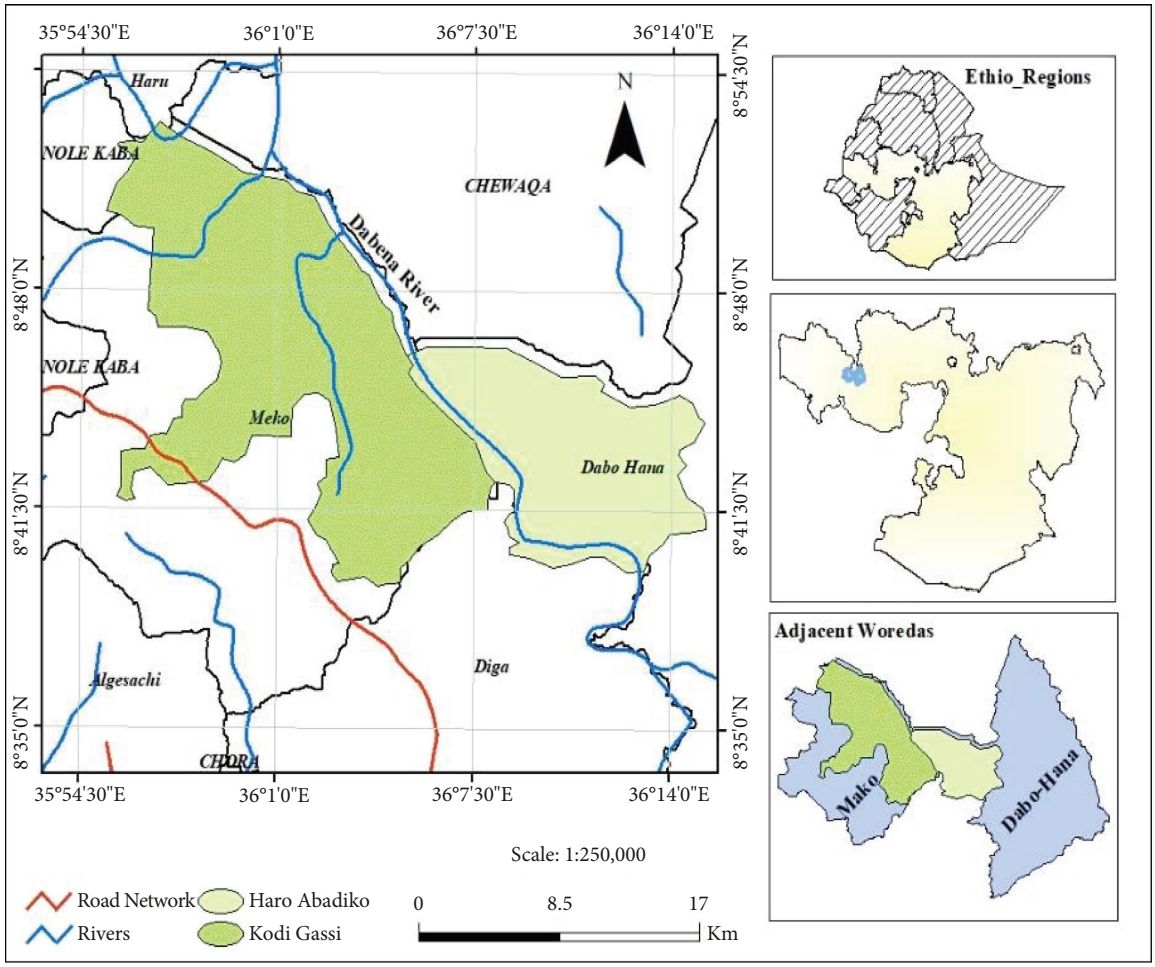


Figure 1: Location map of Dabena woodland (Kodi-Gassi and Haro-Abba Diko site).

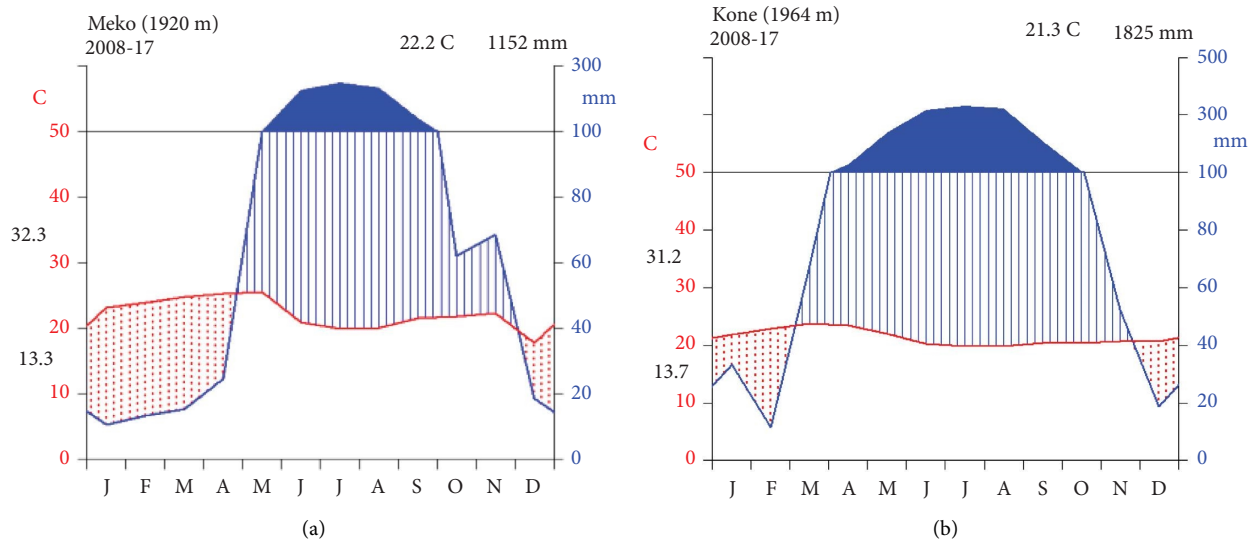


Figure 2: The climadiagram showing the annual mean temperature and rainfall of Meko station (a) and Kone station (b).

The percentage of canopy cover of each plant species within each plot was estimated during data collection in the field. The percentage cover values estimated in each sample plot were converted into cover-abundance values using a 1–9 modified Braun–Blanquet scale [11]. Voucher specimens were collected, pressed, and brought to the National

Herbarium (ETH), Addis Ababa University for identification. The specimens were identified using published books of the Flora of Ethiopia and Eritrea, and other taxonomic works and compared with specimens already deposited in the National Herbarium.

2.4. Environmental Data Collection. Altitude and geographical coordinates were measured using Garmin GPS in the middle of the main plots. An engineering compass was used to measure the direction and aspects of plots. The slope of each plot was measured by a clinometer. The aspect was indicated with the modified scale [12], referring to the total amount of solar energy received as follows: $N = 0$, NE = 1, $E = 2$, SE = 3, $S = 4$, SW = 3.3, $W = 2.5$, and NW = 1.3. The type and state of disturbance were recorded based on grazing intensity, cut stems, and human trails for each plot on an ordinal scale ranging from 0 to 3 (0 = no disturbance, 1 = slightly disturbed, 2 = moderately disturbed, and 3 = highly disturbed). Key informants were also asked to assign the major seven factors perceived as threats to woodland vegetation.

Soil samples were taken from each plot from a depth of 20 cm from the four corners and one at the center of the main plot. The soils taken from these five subplots in the main plot were mixed together and brought to the national soil laboratory in Bedele. Soil samples were air-dried, grounded, and passed through a 2 mm sieve for analysis of total nitrogen, available phosphorus, PH, soil texture classes' analysis of % sand, % silt, and % clay, cation exchange capacity (CEC), moisture content, and organic carbon. The total nitrogen was ascertained by the Kjeldhal procedure after digestion with concentrated H2SO4 [13]. The CEC (meq/100 g) of soils was determined by saturation with 1N sodium acetate followed by replacement of sodium on the exchange complex with 1N ammonium acetate at PH 7 [14]. The PH of the soil samples was determined using a PH meter from a 1 : 1 soil-distilled water mixture (20 g of soil in 20 ml of distilled water). The moisture content of the soil was determined by weighing soil samples in the field and reweighing the samples after they had been oven-dried in the laboratory. Available phosphorus was determined by using a spectrophotometer by Olsen and Dean [15]. Organic carbon was determined by the Walkley–Black method [16].

2.5. Data Analysis. Floristic richness, diversity, evenness indices, and similarity of plant communities were analyzed using R Package 3.2 [17]. Of the various coefficients widely used to compute the diversity of a community, species diversity (α diversity) is the most commonly used [18]. The diversity index is usually used for describing areas of high natural or anthropogenic disturbance and the value usually falls between 1.5 and 3.5, rarely exceeding 4.5 [18–20]. Floristic similarities with regard to species composition among and between study sites or community types were computed by using Sorenson's similarity coefficients [7] by using the following formula:

$$\mathrm{SC} = \frac{2a}{(2a + b + c)}, \quad (1)$$

where SC is the Sorenson's similarity coefficient; a is the number of species common to both categories; b is the number of species present in the first category and absent in the second; and c is the number of species present in the second category and absent in the first.

2.5.1. Plant Community Identification. Hierarchical cluster analysis helps to group a set of observations (vegetation samples) together, based on their features or floristic similarities [7]. For this study, agglomerative hierarchical classification for using similarity ratio as a resemblance index and Ward's method as a clustering technique was performed by using appropriate R programs developed by Woldu [21]. A synoptic table of the results of the hierarchical agglomerative cluster analysis was produced by using the cluster identifications to compute mean values of the cover-abundance of the species in the respective clusters. For this, the R Program was used to produce a table from the simultaneous classification of sites and species [22]. Distinct clusters were identified at appropriate hierarchical levels and the plots of the dataset were then arranged using the sequence of the plots in the dendrogram produced. The plant community type was named after one or two dominant species, using the highest mean cover values of plant species that occur in each group. Based on the cluster analysis output and ecological evaluation in the field, the number of clusters was determined at appropriate similarity levels in the dendrogram.

2.5.2. Ordination. Ordination is most often used in ecology to seek and understand patterns. Its most common use is to describe the strongest patterns in species composition [23]. In this study, CCA was used in R Package 3.2 [17] as recommended by Jongman et al. [24] and ter Braak and Šmilauer [25]. Before the CCA analysis, forward stepwise selection and backward stepwise selection of environmental variables were carried out to identify variables that could significantly explain the relationship between variables and plant community distributions. One-way ANOVA followed by a post hoc Tukey's HSD test was used to assess whether there were significant mean differences among plant communities and environmental variables. The Pearson correlation coefficient between environmental variables and its significance was calculated according to Hammer et al. [26].

3. Results

A total of 239 species with 187 genera and 76 families were recorded from the Dabena Woodland vegetation. Fabaceae, Poaceae, Asteraceae, and Euphorbiaceae were the four most dominant families represented by 21 (8.8%), 18 (7.5%), 18 (7.5%), and 13 (5.4%) species, respectively. Out of the 239 species identified, 13 were endemic, comprising 5.4% of the total species composition of the study area [27].

3.1. Vegetation Classification. Five plant community types were identified using agglomerative hierarchical cluster analysis in R statistical software version 3.4.2 (Figure 3). The species occurrences were summarized by synoptic cover-abundance values and significant indicator values (Table 1).

3.1.1. Clerodendrum myricoides-Vernonia hochstetteri Community Type. This community type is distributed between the altitudinal ranges of 1500–1730 m.a.s.l. *Clerodendrum myricoides* is the characteristics species in the tree layer of this community. *Gardenia ternifolia*, *Syzygium guineense* subsp. *macrocarpa*, and *Combretum collinum* are common tree species. *Vernonia hochstetteri* is a characteristic species in the shrub layer, while other common shrub species associated with the community include *Vangueria apiculata*, *Lippia adoensis*, and *Ocimum lamiifolium*. In this community, *Hyparrhenia rufa* is a dominant herb and other common herbaceous species covering the ground surface include *Habenaria petitiana*, *Tragia brevipes*, and *Bidens biternata*. Various disturbances such as tree cutting, overgrazing, and frequent fire were recorded in most of the sampled plots in this community.

3.1.2. Erythrina brucei-Entada abyssinica Community Type. This community was found at altitudes ranges between 1585 and 1745 m.a.s.l. *Erythrina brucei and Entada abyssinica* were the characteristic species in the tree layer. *Syzygium guineense* subsp. *Macrocarpa*, *Piliostigma thonningii*, *Terminalia schimperiana,* and *Ficus ovata* were common tree species associated with this community, whereas *Abutilon mauritianum* was the dominant woody species at the shrub layer and other common shrubs included *Solanum anguivi*, *Triumfetta rhomboidea,* and *Senna didymobotrya*. *Rubus apetalus* was the climbing species recorded in this community type. The herbaceous layer is dominated by *Hyparrhenia rufa*, *Guizotia schimperi, Girardinia diversifolia*, and *Floscopa glomerata*. It is comprised of 33 species. A lot of disturbances such as tree cutting and overgrazing were observed in this community.

3.1.3. Combretum molle-Gardenia ternifolia Community. The altitudinal location of this community ranges between 1565 and 1770 m.a.s.l, and is relatively represented by a higher number of plots than other community types. It covers most portions of the study area. *Combretum molle* and *Gardenia ternifolia* were the characteristic species in the tree layer, whereas *Lannea schimperi*, *Terminalia brownii*, *Fagaropsis angolensis*, and *Stereospermum kunthianum* were also common tree species associated with this community. *Premna schimperi*, *Ocimum urticifolium*, *Dombeya torrida,* and *Carissa spinarum* were dominant species at the shrub layer. *Jasminum abyssinicum* and *Hippocratea goetzei* are the common climbing species in this community. The common herbaceous species covering the ground layer were *Bidens biternata*, *Pteridium aquilinum*, *Cymbopogon commutatus*, *Cyphostemma pannosum*, *Panicum maximum*, and *Cynodon dactylon*.

3.1.4. Galiniera saxifraga-Flacourtia indica Community. This community type lies between the altitudinal range of 1455–1745 m. a.s.l., and found along the courses of Dabena, Gassi, Haro, and Disii Rivers. *Galiniera saxifraga* is the characteristic species at the tree layer in this community. Common tree species that are associated with this community include *Maesa lanceolata*, *Mimusops kummel*, *Ficus sur*, and *Trema orientalis*. *Flacourtia indica* is the characteristic species at the shrub layer, whereas *Vepris dainellii*, *Crotalaria incana*, *Dodonaea angustifolia*, and *Cadaba farinosa* were dominant shrub species associated with this community. *Phytolacca dodecandra* is a dominant climbing species in this community. The common herbaceous species that cover the ground layer include *Hypoestes aristata*, *Aframomum corrorima*, *Pavetta oliveriana*, *Commelina diffusa,* and *Lunathyrium boryanum*.

3.1.5. Dracaena afromontana-Landolphia Buchananii Community Type. This community type is found at an altitudinal range of 1563–1890 m. a.s.l. This community is located in the moist parts of the Dabena valley along the rivers. *Dracaena afromontana* is the characteristic species in the tree layer. The associated dominant trees of this community were *Syzygium guineense* subsp. *guineense*, *Rothmannia urcelliformis*, *Olea capensis* subsp. *macrocarpa*, *Diospyros abyssinica*, *Bridelia scleroneura*, *Apodytes dimidiata*, and *Allophylus abyssinicus*, whereas *Clausena anisata*, *Bersama abyssinica*, *Millettia ferruginea*, *Calpurnia aurea,* and *Vernonia auriculifera* were the dominant species associated with the shrub layer in this community. Common lianas were *Combretum paniculatum*, *Clematis longicauda*, and *Urera hypselodendron*. Dominant herbaceous species in this community include *Piper capensis*, *Panicum maximum*, *Cynodon nlemfuensis*, *Desmodium repandum*, *Hypoestes aristata*, *Cyperus fischerianus*, and *Oplismenus hirtellus*.

3.2. Species Richness and Diversity of the Five Community. The Shannon–Wiener diversity index was computed for the five plant community types of the woodland vegetation of Dabena (Table 2). *Galiniera saxifraga-Flacourtia indica* community had the highest diversity ($H' = 4.4$), followed by community three (*Combretum molle-Gardenia ternifolia*) diversity index of $H' = 4.3$, while community two (*Erythrina brucei-Entada abyssinica*) showed the smallest diversity index ($H' = 3.2$). Community-type four (*Galiniera saxifraga-Flacourtia indica*) also had the highest species richness ($S = 137$), whereas the least species-rich community was community type two (*Erythrina brucei-Entada abyssinica*) ($S = 33$). However, evenness, which measures the relative abundance of different species present in each community, showed relatively the highest value for community five (*Dracaena afromontana-Landolphia buchananii)* ($J = 0.92$) followed by community types three and two (each $J = 0.90$) and community one (*Clerodendrum myricoides-Vernonia hochstetteri*) had relatively the lowest Shannon evenness ($J = 0.88$).

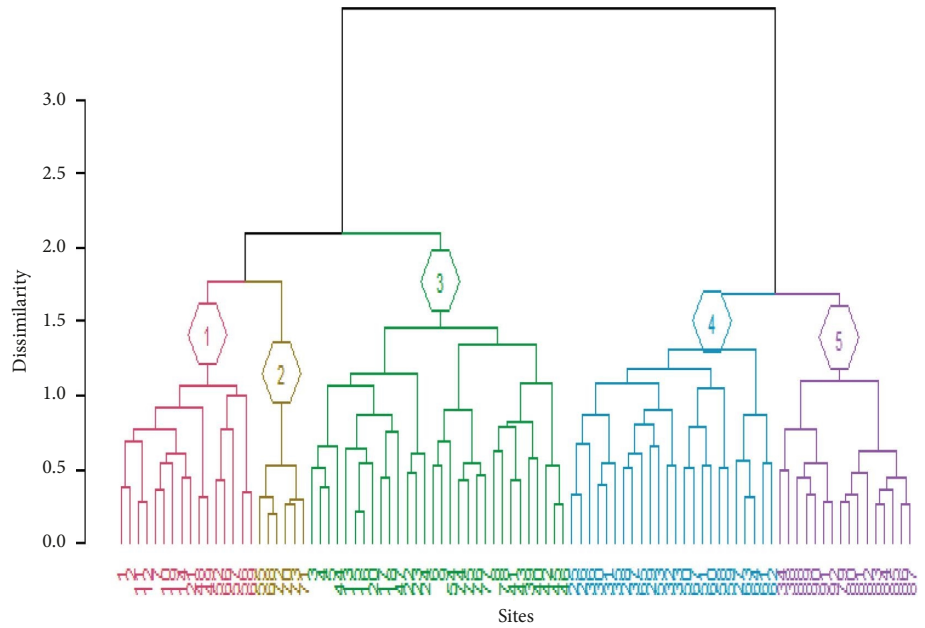


Figure 3: Dendrogram of the vegetation data from cluster analysis using dissimilarity level in Dabena woodland vegetation.

Table 1: Species list with synoptic cover-abundance value reaching ≥1 in at least one community for Dabena woodland vegetation.

Community type	1	2	3	4	5	
Total plot number	16	6	30	24	16	*P* value
Vernonia hochstetteri	2.5	0	1.77	0.12	0	0.001
Clerodendrum myricoides	1.31	0	0.38	0	0	0.009
Vangueria apiculata	1.03	0	0.3	0.42	0.19	0.049
Combretum collinum	1.5	0	0.33	0.04	0	0.025
Lippia adoensis	1	0	0.27	0	0	0.009
Ocimum lamiifolium	1	0	0.2	0.04	0	0.021
Erythrina brucei	0.06	2.67	0.57	0.04	0	0.001
Piliostigma thonningii	0.31	2.67	0.17	0	0	0.002
Entada abyssinica	0.31	2.5	0.1	0	0	0.002
Syzygium guineense subsp. *macrocarpa*	0.56	2.17	0.8	0	0	0.001
Terminalia schimperiana	0.38	2	0.4	0	0	0.06
Ficus ovata	0.06	1.17	0.03	0.12	0	0.001
Senna didymobotrya	0	1.17	0.27	0	0	0.002
Combretum molle	2	0.33	2.6	0.17	0	0.001
Gardenia ternifolia	1.44	0.5	2.5	0.54	0.94	0.004
Terminalia brownii	2	0	2.03	0.29	0	0.006
Fagaropsis angolensis	0.88	0	1.17	0	0	0.026
Lannea schimperi	0.19	0	1.17	0	0	0.003
Ocimum urticifolium	0.31	0	1.13	0.38	0	0.016
Stereospermum kunthianum	0.38	0	1.1	0	0	0.004
Galiniera saxifraga	0	0.17	0	2.21	0.81	0.002
Flacourtia indica	0	0	0	1.83	0.81	0.005
Dodonaea angustifolia	0	0	0	1.71	0.75	0.011
Vepris dainellii	0	0	0	1.5	0	0.006
Mimusops kummel	0	0	0.3	1.12	0.75	0.099
Syzygium guineense subsp. *guineense*	1.5	3	0.97	2.67	4.31	0.002
Clausena anisata	1.5	0	1.27	1.96	3.25	0.001
Dracaena afromontana	0	0	0	0.12	3.25	0.001
Rothmannia urcelliformis	0.31	0	0	0.42	3.12	0.003
Millettia ferruginea	0.56	0	0.3	2.38	3.06	0.003
Landolphia buchananii	0	0	0	0.67	3	0.001
Bersama abyssinica	0.12	0	0.2	1.92	2.81	0.001
Apodytes dimidiata	0	0	0.07	0.12	2.5	0.01

Table 1: Continued.

Community type	1	2	3	4	5	P value
Total plot number	16	6	30	24	16	
Diospyros abyssinica	0	0	0.8	0.42	2.44	0.008
Bridelia scleroneura	0	0	0.2	0	2.25	0.001
Allophylus abyssinicus	0.06	0	0.07	1.42	2.19	0.013
Maytenus arbutifolia	0.31	0	0.03	1.54	2.12	0.036
Phoenix reclinata	1.12	0	0.77	1.46	1.94	0.054
Olea capensis subsp. *macrocarpa*	0	0	0	0.08	1.88	0.001

Table 2: Shannon–Wiener richness and diversity of the five communities in Dabena woodland.

Community type	Altitudinal range	Species richness (S)	Shannon diversity index (H′)	Shannon evenness (J)
Clerodendrum myricoides-Vernonia hochstetteri	1500–1730	111	4.16	0.88
Erythrina brucei-Entada abyssinica	1585–1745	33	3.21	0.92
Combretum molle-Gardenia ternifolia	1565–1770	121	4.30	0.90
Galiniera saxifraga-Flacourtia indica	1455–1745	137	4.41	0.90
Dracaena afromontana-Landolphia buchananii	1563–1890	98	4.09	0.89

3.3. Similarity between Plant Community Types. Sorensen's coefficient index was used to compute the degree of similarity among the five plant community types. The highest similarity was observed between communities one (*Clerodendrum myricoides-Vernonia hochstetteri)* and three (*Combretum molle-Gardenia ternifolia),* while the least similarity was observed between communities two (*Erythrina brucei-Entada abyssinica*) and five (*Dracaena afromontana-Landolphia buchananii)* (Table 3).

Table 3: Similarity between the five plant community types.

Community	1	2	3	4	5
1		0.184	0.352	0.226	0.137
2			0.169	0.100	0.053
3				0.246	0.169
4					0.307
5					

Table 4: Result of permutation test of environmental variables.

Variables	Df	F	Pr (>F)
Disturbance	1	2.5277	0.005**
Altitude	1	2.3122	0.005**
CEC	1	2.3078	0.005**
P	1	2.0666	0.005**
OC	1	2.0361	0.005**
Clay	1	1.7454	0.005**
Silt	1	1.6023	0.010**
TN	1	1.5446	0.015*
PH	1	1.3226	0.030*
Aspect	1	1.3223	0.030*
Sand	1	1.2396	0.054“.”
Slope	1	1.1121	0.16
MC	1	0.8126	0.925

Significant codes: 0.001 “**”; 0.01 “*”; 0.05 “.”

3.4. Environmental Variables and Community Relationship

3.4.1. Ordination. CCA consists of two groups of points including sites and environmental variables which show plant communities-environmental variables relationships. The Monte Carlo test using the Adonis function with automatic backward and forward selection of environmental variables showed that 11 environmental variables significantly influenced the floristic composition of the plant communities (Table 4). The remaining environmental variables had no significant effect on the floristic composition and distribution of the plant community types in Dabena woodland vegetation.

Biplot scores for the constraining variables from CCA plots showed the relationship between total vegetation data and environmental variables (Table 5). The eigenvalues for the CCA1 and CCA2 axes were higher than the eigenvalues of the next remaining axes showing that constraining variables were more associated with the first and second axes than any other axis. The cumulative proportion of variance explained by the first six axes of the shared plot in the constraining biplot was 69%. The proportion of variation explained by CCA1 and CCA2 were about 21% and 13%, respectively. The magnitude and direction of the vectors in the species-environment biplots represent the degree of correlation between the species and environmental variables (Figure 4). Community types one, two, and three were more closely related to each other while community types four and five were more distantly related to the other three community types.

Altitude, clay, and total nitrogen axes strongly influenced the distribution of species in communities four and five. Disturbance and silt strongly influenced the distribution of species in community types one, two, and three. In order to determine significant differences in environmental variables among the five communities, post hoc comparisons of means were used (Table 6).

Table 5: Biplot scores for the constraining variables, eigenvalues, and proportion of variances explained by the first six axes.

Variables	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6
Aspect	0.030	−0.099	0.429	0.4399	−0.181	−0.3113
Disturbance	0.734	−0.015	0.044	0.1263	0.386	−0.1253
Altitude	−0.079	0.915	0.145	0.0354	−0.169	−0.2552
Sand	−0.189	−0.198	0.295	−0.0355	−0.104	0.1960
Silt	0.443	0.080	−0.038	0.0751	−0.063	−0.2914
Clay	−0.421	0.206	−0.454	−0.2223	0.279	0.1028
OC	−0.634	−0.198	0.035	−0.1354	0.653	−0.1854
CEC	−0.584	−0.124	−0.155	−0.1970	0.157	−0.3479
TN	−0.288	0.115	−0.35	0.58531	0.14	0.1635
P	−0.694	0.054	0.165	−0.0168	0.195	0.0028
PH	0.037	−0.366	−0.379	−0.0002	0.042	−0.4564
Eigenvalue	0.403	0.245	0.191	0.166	0.164	0.153
Proportion explained	0.211	0.128	0.01	0.087	0.086	0.081
Cumulative proportion	0.211	0.339	0.438	0.525	0.611	0.691

OC: organic carbon; TN: total nitrogen; P: phosphorus; CEC: cation exchange capacity.

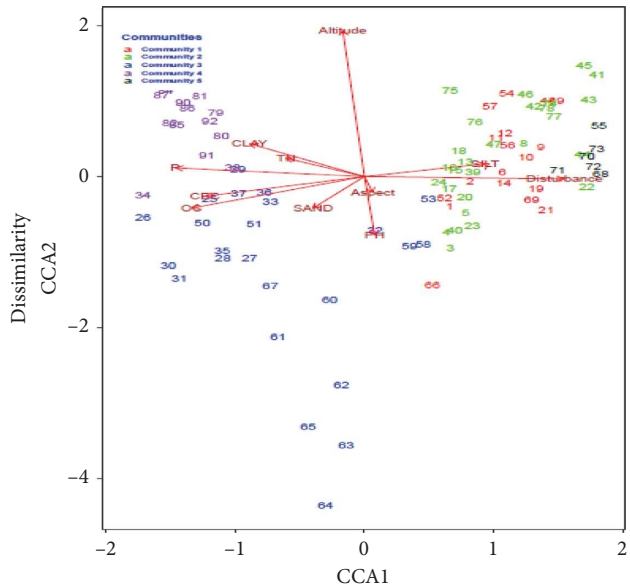


Figure 4: Canonical correspondence analysis (CCA) ordination diagram of 92 plots and 11 environmental variables. Numbers represent plot distribution in the five community types.

Table 6: Post hoc comparison of means between environmental variables and plant communities.

Environmental variable	Community				
	C1	C2	C3	C4	C5
Disturbance	1.33 ± 0.52a	2.5 ± 0.84a	2 ± 0.00a	2 ± 0.00ab	1.17 ± 0.75a
Altitude	1599 ± 27.72e	1653 ± 53.82d	1606 ± 39.52d	1611 ± 30e	1639 ± 48.41c
OC	3.34 ± 0.88a	1.84 ± 0.87a	3.28 ± 1.28ab	5.59 ± 1.22abc	3.62 ± 1.02a
P	0.90 ± 0.40a	0.78 ± 0.31a	3.19 ± 3.05ab	3.1 ± 2.55abc	5.29 ± 3.58a
CEC	11.40 ± 3.62ab	7.74 ± 2.46a	13.99 ± 4.74ab	15.83 ± 4.48abc	13.42 ± 4.56a
Clay	23.00 ± 5.93bc	11.83 ± 0.41ab	18.33 ± 3.56ab	21 ± 5.33bc	19.83 ± 1.60a
Silt	34.67 ± 7.76	38.17 ± 4.83bc	25.33 ± 4.68b	20.83 ± 10.15bc	20.5 ± 1.52a
TN	0.09 ± 0.05a	0.11 ± 0.07a	0.1 ± 0.04a	0.16 ± 0.05a	0.23 ± 0.25a
PH	4.80 ± 0.38a	4.87 ± 0.22a	5.61 ± 0.36ab	5.31 ± 0.22abc	5.16 ± 0.44a
Aspect	2.27 ± 1.04a	3.28 ± 0.48a	2 ± 1.23a	2.77 ± 0.88abc	2.08 ± 1.23a
Sand	42.33 ± 9.61e	50 ± 5.18c	56.33 ± 2.66c	58.17 ± 7.20d	56.33 ± 9.61b

The numbers in the rows of environmental variables show M ± standard deviation. Means that are not significantly different from each other at $p < 0.05$ are indicated with the same letter.

3.4.2. Pearson's Product-Moment Correlation. Clay had a strong positive correlation with OC, CEC, TN, and phosphorus, at $p < 0.001$. Strong positive correlations were also observed between CEC, phosphorus, CEC, and OC (Table 7). Strong negative correlations were observed between sand and silt, silt and PH, and silt and phosphorus $p < 0.001$. Disturbance had a negative correlation with clay and phosphorus at $p < 0.01$.

3.5. Major Threats to Woodland Vegetation and Conservation Status. Information gathered from the respondents showed that the woodland of Dabena had been subjected to frequent forest fires and other disturbance factors (Figure 5). According to the key informants, the major factors reported for woodland destruction were forest fire, resettlement, charcoal, deforestation, firewood, and construction and building. Among the problems, most informants perceived that forest fire (22.45%) was considered the main threat to woodland destruction followed by agricultural expansion (18.88%) due to resettlement (Table 8). Concerning the conservation of Dabena woodland vegetation, most of the informants reported that there were no successful conservation efforts in the woodland.

4. Discussion

4.1. Vegetation Classification. The vegetation in the study area (>80%) was composed of Combretum-Terminalia and wooded grassland vegetation type. A few parts of the study area consist of riverine vegetation along streams and rivers dominated by *Syzygium guineense* and a few moist Afromontane species such as *Olea welwitschii* at the edge of higher parts [27]. According to this finding, the floristic compositions indicate the presence of high species diversity in the study area (239 vascular plant species which belong to 76 families in 187 genera). The existence of high species diversity in the study area could be due to the heterogeneity existing in different vegetation patches within the vegetation community [28], disturbance [29], and edaphic properties [30] and difference in the range of altitude [31].

Results from the hierarchical cluster analysis showed that five plant community types were identified. The identified plant communities are relatively diverse and rich in species composition. However, each community type has its distinct or indicator species. According to Feyera Senebeta [32], the difference might be directly connected to environmental variables that make the plant communities have their own distinct or characteristic species and also differ in floristic composition. *Galiniera saxifraga-Flacourtia indica* and *Combretum molle-Gardenia ternifolia* community types had the highest number of plant species compared to the remaining three communities. Variations in environmental gradients can limit the ecological distributions of plant species [1]. Variations in floristic composition could also be connected to the effects of environmental factors such as altitude, aspect, soil contents and moisture, human impacts, and grazing intensity [31]. Community-type three also showed the overlap of altitude between community types one and four. The overlap of plant communities indicated the presence of shared species between community types showing similar adaptation, tolerance, and requirements.

Clerodendrum myricoides-Vernonia hochstetteri community type is dominated by grass species such as *Hyparrhenia rufa* and a dominant shrub species known as *Vernonia hochstetteri* with scattered tree species of Combretum and Terminalia. In this community type, disturbance is very high due to the frequent fires and overgrazing. According to Lawton et al. [33] and Fahrig [34], this could be associated with the fact that disturbance in this community could decrease litter production and increase soil erosion and decomposition of organic matter (OM) by oxidation. *Erythrina brucei-Entada abyssinica* community type had the lowest number of plant species. This might be due to the high level of disturbance and it is dominated by a single species such as *Abutilon mauritianum*. Most plots of this community had been obtained from shrubland.

Combretum molle-Gardenia ternifolia community type covers a large portion of the vegetation in the study area. In this community, *Combretum molle*, *Gardenia ternifolia*, and *Ocimum urticifolium* were indicator species, and similar findings were also reported in a woodland vegetation study around Dello Menna by Didita et al. [8]. *Combretum molle* was also reported as an indicator species of communities by Soromessa et al. [35] from the vegetation of the Gamo Gofa zone even at relatively higher altitudes. This indicates that this vegetation type was widespread in its distribution from time to time due to the conversion of natural forests into woodlands because of various anthropogenic factors. Frequent fire, resettlement, and tree cutting for construction and fuel wood are more predominant anthropogenic factors in this community type. Community types four and five were very discrete units and found along streams and rivers in the Dabena valley.

These community types are a buffering zone dominated by *Syzygium guineense* and it is the source of economically important plant species such as *Coffea arabica*, *Piper capense*, and *Aframomum corrorima* and protected by the local communities for honey bee production, wild coffee, and spice production.

4.2. Species Diversity, Richness, and Similarity among Community Types. All community types were high with respect to their diversity, as shown from their Shannon indices (H'), which is greater than 1.5. The optimal value of the Shannon diversity index (H') for vegetation of a given area with higher plant diversity ranges between 1.5 and 3.5, and sometimes to 4.5 [36]. The diversity of plant species in this study is comparable with the diversity in other woodlands of Ethiopia, such as Dello Menna (Motuma Didita et al., 2010), woodland of Metemma area [37], woodland of Sire Beggo [38], and Dirki and Jato woodland [39].

This could be because all of these vegetations belong to the same type of woodland vegetation, which makes them similar to one another [40].

Among the community types identified in this study, community four and community three had a relatively high species diversity and richness. Stream corridors are exceptionally diverse environmentally and normally support high

Table 7: Pearson's product-moment correlation coefficient between environmental variables in Dabena woodland vegetation.

	Aspect	Disturbance	Altitude	Sand	Silt	Clay	OC	CEC	TN	P	PH
Aspect											
Disturbance	0.15ns										
Altitude	0.056ns	0.25*									
Sand	0.04ns	0.16ns	−0.04ns								
Silt	−0.08ns	0.02ns	0.03ns	−0.79***							
Clay	−0.01ns	−0.32**	−0.05ns	−0.16ns	−0.39***						
OC	−0.05ns	−0.21ns	−0.16ns	0.08ns	−0.36***	0.47***					
CEC	−0.04ns	−0.09ns	−0.00ns	0.05ns	−0.35**	0.47***	0.54***				
TN	−0.09ns	0.00ns	0.07ns	0.01ns	−0.29*	0.39***	0.01ns	0.34**			
P	−0.01ns	−0.33**	−0.03ns	0.18ns	−0.45***	0.44***	0.57***	0.58***	0.25*		
PH	0.08ns	0.19ns	−0.17ns	0.36***	−0.39***	0.13ns	0.17ns	0.31*	0.12	0.08	

The magnitude indicates the degree of correlation. Positive signs indicate positive correlation and negative signs indicate negative correlation. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns: no significance.



(a)



(b)



(c)



(d)

Figure 5: Continued.



(e) (f)

Figure 5: Major anthropogenic factors in Dabena woodland. Frequent fire (a), resettlement (b–d), and cutting of tree stems for collection of "Damaa bokuu" (e, f) (photo by Kifle Yeshitila, 2019).

Table 8: Direct matrix ranking results of ten key respondents on six factors perceived as threats to Dabena woodland.

Threatening factor	Respondents										Total score	%	Rank
	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}			
Forest fire	4	5	6	6	4	2	3	3	6	5	44	22.45	1st
Resettlement	3	3	6	2	3	3	4	5	5	3	37	18.88	2nd
Deforestation	2	2	4	3	2	1	3	3	3	4	27	13.78	5th
Charcoal	1	2	1	3	3	4	3	2	2	4	25	12.76	6th
Firewood	3	4	2	2	5	4	6	1	1	2	30	15.31	4th
Construction and building material	3	4	4	5	3	2	3	6	2	1	33	16.84	3rd

Values: 1 = least destructive; 6 = most destructive.

species richness [41]. The highest similarity was observed between community types one and three, while the least similarity was observed between community types two and five. The high similarity in floristic composition is due to the geographical proximity and overlaps in elevation and climatic conditions that led to having shared species. The least similarity of floristic composition between communities two and five might be variation in the microhabitat productivity, variation in soil type, and level of anthropogenic disturbance. According to Tamrat [31], differences in floristic composition could also be related to the effects of environmental variables such as altitude, aspect, soil contents and moisture, human impacts, and grazing intensity.

4.3. Plant Community and Environmental Factors Relationship. Plant community formation is highly influenced by environmental gradients, soil physical and chemical heterogeneity, and anthropogenic factors [4, 42–44]. Disturbance, altitude, OC, clay, CEC, phosphorus, and TN content were environmental variables that influenced plant community formation. Disturbance is an important environmental variable that influences the growth and distribution of plants in Dabena woodland. This is also supported by a similar study in Dirki and Jato woodland vegetation by Tadesse et al. [39] in which grazing and human impacts were the main factors. Disturbance governs community patterns by altering the environment and resource distributions, creating enabling conditions for the establishment of new species or minimizing populations of established species [45–47]. Altitude is another environmental factor that influences the distribution patterns of floristic composition and plant community formation. It has been long recognized that altitude is a significant environmental factor that affects radiation, atmospheric pressure, moisture, and temperature, all of which have a strong influence on the recruitment, growth, and development of plants and the distribution of vegetation types [42, 48].

Frequent fire and intensive grazing are the most disturbing activities in *Clerodendrum myricoides-Vernonia hochstetteri* community and *Erythrina brucei-Entada abyssinica community* for expansion of agricultural and grazing land by the local community. This is due to the traditional use of fire aimed at clearing bushes for cultivating crops and/or stimulating the growth of new grass for livestock seems an inevitable activity. In these communities, it could be summarized that disturbance has reduced their natural stability which subsequently might hinder the recovery of woody species and thus dominated mostly by herbs. Disturbance also alters the stability and diversity of ecosystems as it reduces invasion resistance while eliminating the buffering effect of high diversity [49].

In the *Galiniera saxifraga-Flacourtia indica* community, soil organic carbon (OC), CEC, and phosphorus were the most significant environmental factors for the distribution of plants. Soil organic matter (OM) and total nitrogen content were the most significant soil factors for the distribution of plants. This might be related to the high organic matter (OM) content of the area, which could give the soil a buffering capacity by resupplying the soil solution when important nutrients are removed by uptake or leaching [50, 51]. The high temperature that favours the decomposition of vegetation litter might have resulted in the high level of soil organic carbon (OC) in this community. In the *Dracaena afromontana-Landolphia buchananii* community, clay and total nitrogen content of the soil are thought to be a more responsible edaphic factor for the distribution pattern which was mainly represented by moist vegetation due to the presence of rivers and streams in this community.

4.4. Major Threats to Woodland Vegetation. Information gathered from the respondents showed that the woodland of Dabena had been subjected to frequent fire and other factors. According to the key informants, the major factors reported for woodland destruction were forest fire, resettlement, charcoal, deforestation, firewood, and construction and building. Among the problems, most informants perceived that forest fire was considered the main threat to woodland vegetation followed by agricultural expansion due to resettlement. The reason for a forest fire is the main woodland destruction due to the fact that the woodland vegetation type consists of many grass species, which have large attributes for forest fire. In addition to this, the traditional honey production system also contributes to forest fires due to beekeepers using fire during the collection of honey from traditional beehives.

5. Conclusion

The study shows that the Dabena woodland has a large number of plant species of high diversity which are distributed into five community types. *Hyparrhenia rufa-Vernonia hymenolepis*, *Abutilon mauritianum-Erythrina brucei,* and *Combretum molle-Gardenia ternifolia* community types were characterized as *Combretum-Terminalia* and wooded grassland vegetation type, whereas, community types four (*Galiniera saxifraga-Flacourtia indica*) and five (*Dracaena afromontana-Landolphia buchananii*) were very discrete units and found along streams and rivers in the Dabena valley. Among the thirteen environmental variables, disturbance, altitude, CEC, clay, OC, and phosphorus were the most important factors in distinguishing plant community types in Dabena woodland. The major factors reported for woodland destruction were woodland fire, resettlement, fuel wood collection, and construction and building. Frequent fire, grazing, tree cutting for construction, and fuel wood were the predominant anthropogenic factors that affect these communities. We also noticed that by this time, large portions of the vegetation were being converted to agricultural land due to resettlement and grazing by livestock and this situation had influenced several aspects of these communities such as regeneration and recruitment.

Data Availability

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

Disclosure

The funders had no role in the study design, data collection, analysis, decision to publish, or preparation of the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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