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Research Article

Effects of Environmental and Disturbance Factors on Plant Community Distribution in Tropical Moist Afromontane Forests, South-West Ethiopia

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This study was carried out to investigate the effects of environmental and disturbance factors on plant community distribution in the Majang Forest Biosphere Reserve (MFBR) in south-west Ethiopia. A systematic sample design was conducted to collect vegetation and environmental factors in four study sites. In a nested plot design, the vegetation data were collected from 140 main plots, i.e., 400 m^2 (trees), 25 m^2 subplots (shrubs, lianas, seedlings, and saplings), and 1 m^2 (herbs), respectively. The plant community classification was performed using agglomerative hierarchical cluster analysis (Ward's Linkage method) in R software (version 4.0.1). The distribution of plant communities along an environmental gradient was computed using canonical correspondence analysis (CCA). In this study, a total of 15 (9.5%) endemic plant species were recorded in MFBR. Four plant community types were identified, and these were *Celtis zenkeri-Blighia unijugata*, *Pouteria altissima-Lecaniodiscus fraxinifolius*, *Antiaris toxicaria-Celtis toka*, and *Dracaena afromontana-Cyathea manniana*. Environmental and disturbance factors, such as elevations, slopes, harvesting indexes, soil pH, silt, and herbaceous cover, were the most important for determining plant community distribution in the area. Elevation and slope were found to have a significant ($P < 0.05$) negative and positive relationship with species diversity and richness, respectively. Therefore, the finding of this study provides baseline information that could be necessary for making further conservation and management in MFBR.

1. Introduction

Plant ecologists have been successful in defining the variations in species diversity of communities along environmental gradients at various spatial scales [1]. Plant community responses are well related to climatic factors at regional and global scales [2, 3], whereas at local or plot scales, topographic and edaphic factors play an important role in controlling community structure and species distribution [4–8]. As a result, environmental factors are important not only in confirming plant community structure and variability of species distribution at a spatial scale but also for providing insight into the environmental requirements of the tree species required for successful ecological restoration and biodiversity protection [7, 8].

Environmental factors have been a cornerstone in the evolution of ecological theory [9, 10]. A variety of factors influence the spatial and temporal patterns of vegetation change, including the physical environment, land use history, prior disturbance, and initial vegetation composition [11–14]. The most important data required to understand vegetation patterns in forest landscapes are relationships between species diversity and environmental factors [15–21]. As a result, the interaction between physical environmental variables such as elevations, slopes, and anthropogenic factors may influence species diversity and composition [19, 22–29]. Elevations, slopes, and aspects are determinants of the spatial and temporal distribution of elements such as radiation, precipitation, and temperature that determine species composition [30]. Soil heterogeneity, such as soil texture, moisture content, electric conductivity (EC), and pH, creates niches with specific conditions, which in turn affect the distribution pattern of plants [31–33].

Ethiopia has greater geographic diversity with ten ecosystems, 18 major and 49 minor agroecological zones [34]. This diverse physiographic feature is responsible for the existence of a wide range of habitats and is conducive to the survival of various plant and animal species [35]. Accordingly, Ethiopia has a diverse set of plant, animal, microbial, and genetic resources [36]. Ethiopia is recognized as a major centre of diversity and endemism for a number of plant species in the Horn of Africa region [37, 38]. The flora of Ethiopia's is diverse, with an estimated 6000–7000 species of higher plants, including 647 (10.74%) endemic taxa [36].

The study of plant community types and factors (soil, topographic, and disturbance) that influence the distribution patterns of plant communities are essential inputs for forest conservation planning and management. For instance, previous studies have reported an association between plant community distributions and variations in environmental gradients in protected forests [25], fragmented forests [39], and community-managed forests of Ethiopia [40]. However, there are limited studies on the effects of environmental and anthropogenic disturbance factors governing plant community distribution patterns in southwestern forests [41, 42] in general and the Majang Forest Biosphere Reserve (MFBR) in particular. This problem leads to some research questions: (a) What are the main community types in the Majang Forest Biosphere (MFBR)? (b) How do environmental and disturbance factors influence plant community distribution patterns in Majang Forest Biosphere Reserves? Therefore, to answer these questions, we aimed to study to (1) identify the type of plant community in MFBR and (2) determine plant community distribution patterns in response to environmental and disturbance factors (elevation, slope, disturbance, and physical and chemical composition of soil) in MFBR.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in the Majang Forest Biosphere Reserve (MFBR), situated in the Majang zone, *Gambella People National Regional State* of Ethiopia. It has unique biogeography and shares a boundary with Sale Nono woreda of Oromia regional state and Anderacha, Yeki, Sheka, and Guraferda woreda of South-West regional state (Figure 1). It covers a total area of 233,254 ha of forest and agricultural land and rural settlements and towns. MFBR is located between the latitudes of 07°08′00″N and 07°50′00″N and the longitudes of 34°50′00″E and 35°25′00″*E*, with elevations ranging from 562 m to 2444 m.

The climate in the area is generally hot and humid, which is marked on most rainfall maps of Ethiopia as the wettest part of the country. The average annual rainfall is 1774 mm, and the mean monthly minimum and maximum temperatures range between 13.9 and 31.8°C at the Tinishu Meti weather station. In Ermichi, the average annual rainfall is 2053 mm and the mean monthly minimum and maximum temperatures range between 11.8 and 29.7°C. The maximum average monthly temperature is between 29.8°C and 31.8°C in February, while the minimum is between 11.9°C and 13.9°C in July for Ermichi and Tinishu Meti, respectively. The maximum rainfall is between April and October, and the minimum rainfall is from November to March in Tinishu Meti and Ermichi (Figure 2). This temperature and rainfall variation between two stations is due to variations in the elevation gradient (NMSA 2018).

Based on the vegetation classification of Ethiopia, the main vegetation types of the Majang Biosphere is montane evergreen forests. Besides, the vegetation of this area has different categories in terms of life forms such as high natural forests, bush lands, and grasslands [43]. Some environmental factors, such as elevations, slopes, soil pH, total nitrogen, and phosphorus, vary between each study site in MFBR (Table 1).

2.2. Vegetation and Soil Data Collection. A systematic sampling design was established to arrange quadrats and transects as well as to collect vegetation data [44]. The study area was stratified into four sites using a digital elevation model (DEM) in Arc GIS software. The study sites' polygon was digitized using Google Earth by elevation classes. These were site I (<1200 m.a.s.l), site II (1200–1500 m.a.s.l), site III (1500–1800 m.a.s.l), and site IV (>1800 m.a.s.l) (Table 2). A total of 140 quadrats were established for vegetation and forest soil data collection, i.e., site I (1–45), site II (46–85), site III (86–115), and site IV (116–140).

The quadrats' X-Y coordinates were generated in Arc GIS software and loaded to a global positioning system (GPS) receiver for tracking quadrats. Later, a measuring tape was used to lay out $20 \times 20\,m^2$ ($400\,m^2$) quadrats in each site in the biosphere. The sampling intervals between the transect line and the quadrats were 2 km apart [43, 52]. The sizes of the quadrats were determined based on the growth forms of plants [44], i.e., $400\,m^2$ (tree), $25\,m^2$ (shrubs and lianas), and $1\,m^2$ (herbs), respectively, in a nested plot design (Figure 3).

The tree diameters (DBH ≥5 cm) were determined, and their number of stems was counted and recorded in the main plots ($400\,m^2$) (Figure 3). The diameter at breast height and the height of the individual's tree species were measured using a diameter tape, clinometer, and meter tape, respectively. When the branching of multistemmed individuals occurred below DBH, the DBH of each stem was measured separately and developed into a common diameter of all stems by summing up and then taking an average diameter. To determine the diversity and estimate the abundance of shrubs and lianas, subplots (area = $25\,m^2$ each) were established (Figure 3) [44].

Seedlings with a height of less than 1.30 m and a DBH of less than 2.5 centimeters, saplings with a height of more than 1.30 m and a DBH of 2.5 to 5 cm, and trees as plants with a DBH of more than 5 cm were selected [53]. Herbaceous

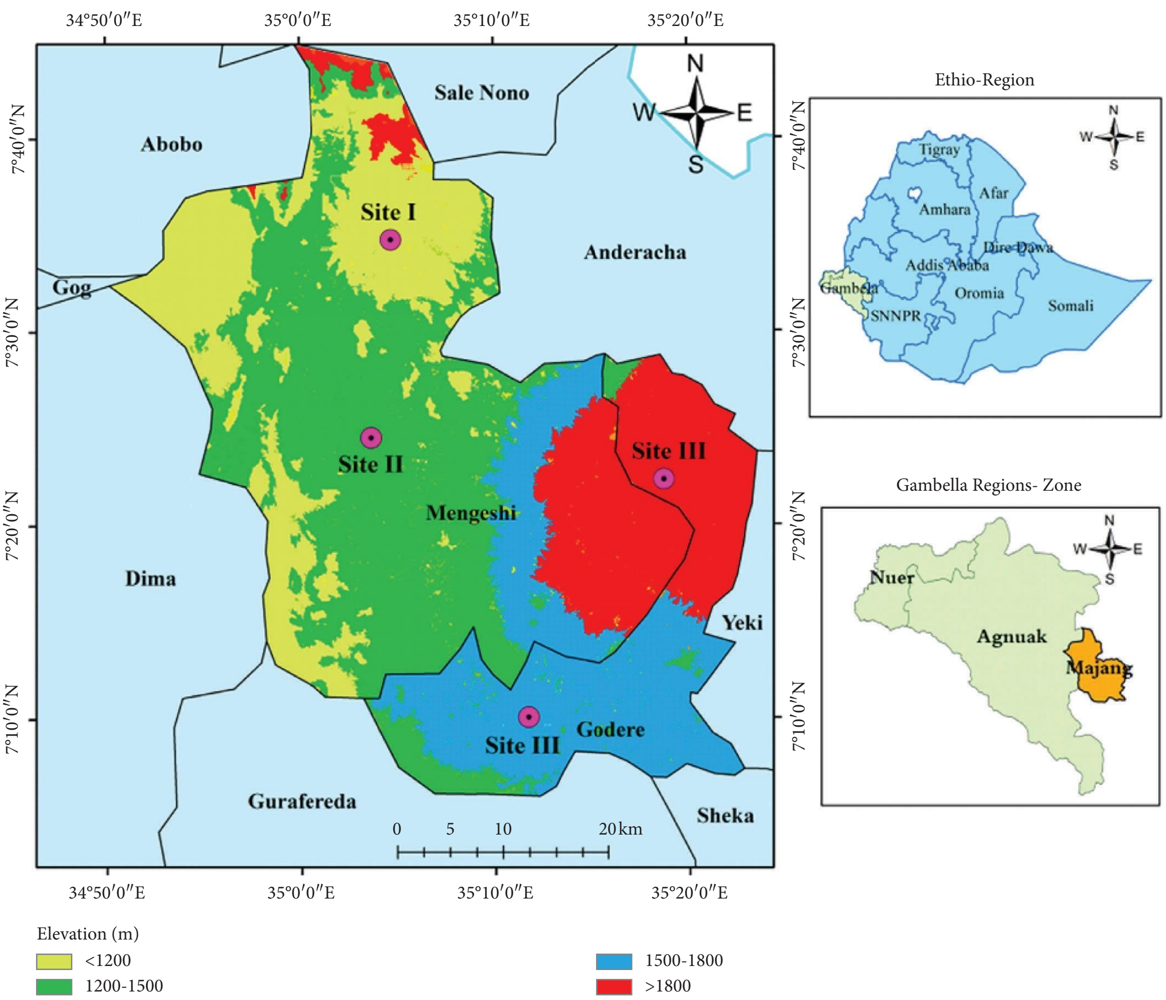

Figure 1: Location of the study sites (sites I–IV). Source: https://earthexplorer.usgs.gov.

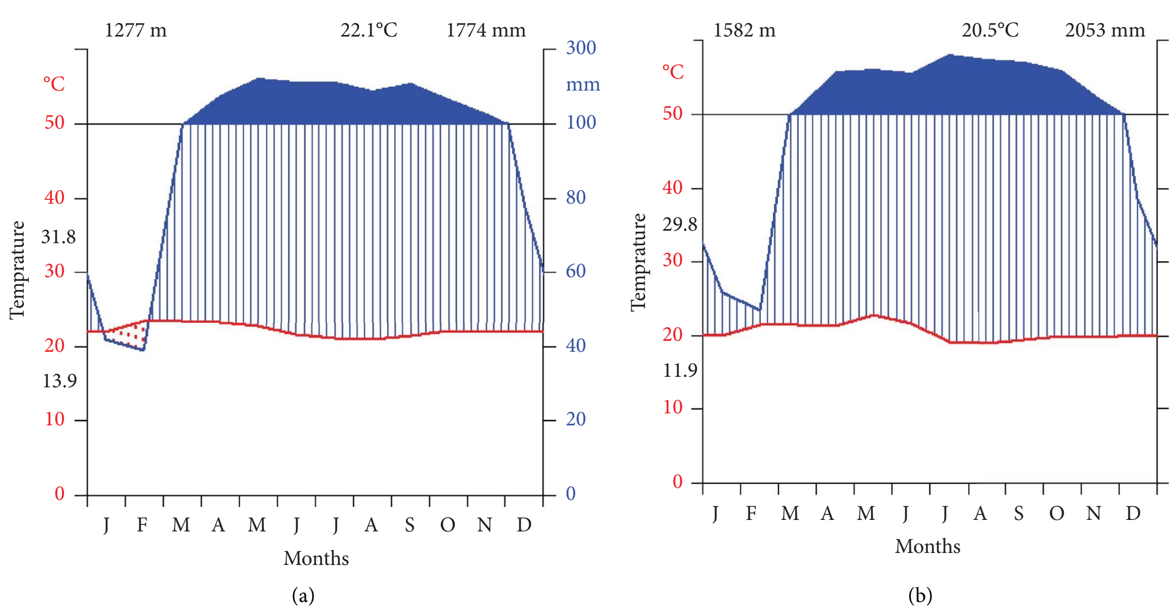

Figure 2: Mean monthly temperature and rainfall recorded. (a) Tinishu Meti (1987–2017) and (b) Ermichi (1987–2017) (NMSA 2018).

Table 1: Topographic and soil characteristics of the study sites.

Study sites	Ele (m)	Slo	Area (ha)	SP
Site I	1042 ± 42	5.3 ± 0.4	22,826.1	40
Site II	1365 ± 24	5.4 ± 0.4	25,220.5	45
Site III	1635 ± 24	7.2 ± 0.5	14,053	30
Site IV	2011 ± 42	11.1 ± 1.2	11,783.5	25

Note. Ele = elevation, Slo = slope, and SP = sample plots.

Table 2: List of equations used for calculation of vegetation parameters.

Vegetation parameters	Equation	Equation no.	Reference
Density	$D = n/N$	1	[45]
Species richness	$D = n/\sqrt{N}$	2	[46]
H	$H' = \sum_{i=1}^{s} (\text{Pi})\ (\text{Inpi})$	3	[44, 47]
Shannon evenness	$J = H'/\text{Hmax} = H'/\text{In s}$	4	[44, 47]
SSI	$S_s = (2a/(2a + b + c))$	5	[44, 48]
Beta (β) diversity	$\beta = (b + c/(2a + b + c))$	6	[49, 50]
Harvesting index	$\text{HI} = \sum_{i=1}^{s} (\text{SD} * \text{EF/LD}$	7	[51]

"a" = number of tree species common to sites A and B; "b" = number of tree species recorded only in the site A; "c" = number of tree species recorded only in site B, "N": total number of individuals of all the species; "n": total number of individuals of the species; Shannon diversity index (H) = where pi is the proportion of individuals found in the i^{th} species; SSI = Sorensen similarity index, H = Shannon diversity index; SD = stump density; EF = expansion factor (3.4 for tropical forest); LD = live tree density.

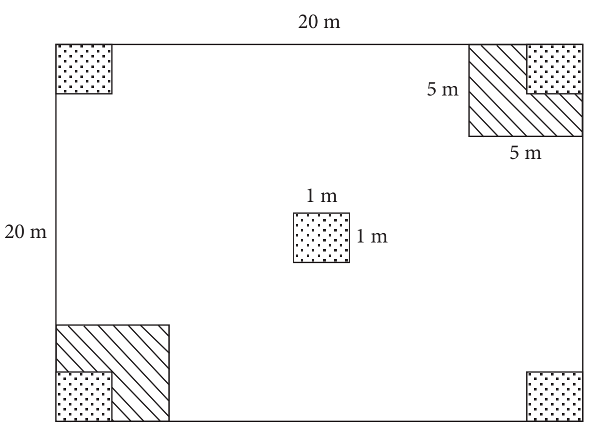

Figure 3: Sampling design used for data collection [44]. Note: subplots (1 × 1 m) are measured for herbs, grasses, and soil samples; subplots (5 × 5 m) are measured for shrubs and lianas, and the main plot (20 × 20 m) is measured for trees, saplings, and seedlings.

cover abundance was assessed in five subquadrats ($1\,m^2$) within the main plot ($400\,m^2$).

The herbaceous cover abundance from each quadrat was changed into 9 cover abundance [54] scale classes: 1 = (<0.5%), 2 = (0.5–1.5%), 3 = (1.5–3%), 4 = (3–5%), 5 = (5–12.5%), 6 = (12.5–25%), 7 = (25–50%), 8 = 50–75%, and 9 ≥ 75% [55]. Canopy openness was measured by using a densiometer located at the centre of each plot. We classified canopy openness by the following classification scheme: very dense canopy >70%, moderately dense canopy 40–70%, open canopy 10–40%, scrub <10%, and nonforest 0% [56].

Plant species were identified in the field, and for those species that were difficult to identify in the field, voucher specimens were collected with the help of local guides, coded, pressed, and dried for subsequent identification and verification at the National Herbarium (ETH), Addis Ababa University. Nomenclature of plants in this article follows those published in the flora of Ethiopia as well as flora of Ethiopia and Eritrea [57–62].

Soil samples were taken with a soil auger from the topsoil at a depth of 0–30 cm, which is recommended as the default sampling depth for soil [63]. The soil samples were taken from five different locations in each plot, four from the quadrat's corners and one from the quadrat's centre. A total of 220 soil samples, 140 from forestland, 40 from farmland, and 40 from grassland, were collected, composited separately, labelled, and transported to the laboratory. To determine soil bulk density, soil was collected on the centre of the quadrats using a stainless core sampler, then placed in plastic bags, and transported to the laboratory for dry weight determination. Fresh wet soil weights were measured in the field with a kitchen balance with 0.1 g precision. A composite sample of 200 g was taken from each quadrat to analyze its chemical composition [64] in the Water Works Design and Supervision Enterprise (WWDSE) laboratory in Addis Ababa.

2.3. Environmental and Disturbance Data Collection. Environmental factors such as elevations, slopes, and aspects were measured and recorded for each of 140 quadrats using clinometers and Garmin GPS, respectively. The elevation was coded into four elevation ranges, namely, 1 ≤1200 m.a.s.l, 2 = 1200–1500 m.a.s.l, 3 = 1500–1800 m.a.s.l, and 4 ≥ 1800 m.a.s.l [65]. Aspect values were collected and arranged ($N = 0$, NE = 1, $E = 2$, SE = 3, $S = 4$, SW = 3.25, $W = 2.5$, and NW = 1.25) in each quadrat [52, 66]. The slope range was classified into three major slope classes [67]. As a result, the classes were as follows: (1) flat <10, (2) intermediate 10–20, and (3) steep >20.

Human disturbance (which includes harvesting/cutting trees for fuel wood, charcoal, timber, and house construction illegally) was computed as the harvesting index. The harvesting index was computed by counting individual stumps that were illegally logged trees within the quadrats. It is calculated from the density of individual tree stumps by following equation (7) in Table 2 [51]. Stumps are a small portion of the trunk that remains after a tree with about 5 cm chopped down [68].

2.4. Data Analysis

2.4.1. Cluster Analysis. The vegetation data, which were originally estimated in the field as a percentage of cover abundance values, were converted into Domin cover scales prior to analysis [54]. The vegetation data were examined using an agglomerative hierarchical cluster (AHC) analysis in package cluster to classify vegetation into plant community types. The similarity ratio (SR) with Ward's group linkage methods (minimum variance clustering) was used for cluster analysis. The similarity ratio is one of the similarity indices that determine how similar or dissimilar vegetation samples, quadrats, or plots are. Ward's group linkage method evaluates cluster distances using the analysis of variance methodology [52]. The goal of this strategy is to eliminate differences in total abundance between sample units (quadrats). In addition, Ward's method minimizes the total within-group mean of squares or residual sum of squares [69].

The maximum number of clusters in a data set is a central issue in partitioning clustering, such as k-means clustering, which requires the user to specify the number of clusters k to be created. In this study, the optimum number of clusters was identified using the gap statistic method and determined by plotting the gap statistic against the number of clusters (k-means). The point, where the maximum gap statistic in the plot is, determines the proper number of clusters. In this study, the maximum gap statistic value in the plot is shown at k-means = 4 (the maximum number of clusters or communities) [70].

Characteristic species were determined using synoptic table analysis. Plant community types were named after two distinctive species with high synoptic cover-abundance ratings [44]. Indicator species analysis was performed using the package labs in R software. The significance of the indicator value was tested using the Monte Carlo test ($P < 0.05$) [71]. The indicator values were calculated from the product of relative abundance (specificity) and relative frequency of species (fidelity) within a community [71]. In this study, the species with the highest significant indicator value is considered an indicator species of a community.

2.4.2. Community Diversity Analysis. Species richness, evenness, Shannon diversity, and beta diversity indices were computed using R software (version 4.0.1). Species richness is usually expressed as the number of species per sample unit and calculated using equation 2 in Table 2 [49]. Shannon's index was computed using abundance and evenness of the species present. The Shannon diversity index (H') and the Shannon evenness index (J) were calculated using equations 3 and 4 in Table 2. The Sorensen similarity index was used to assess the degree of floristic similarity between plant communities. The Sorensen similarity index was calculated using equation 5 in Table 2. Beta diversity was computed by the change in diversity of species from one community to another and calculated using equation 6 in Table 2 [49]. Pearson correlation coefficients were calculated to see the relationship between diversity indices and environmental disturbance factors in MFBR.

2.4.3. Soil Laboratory Analysis. The soil samples were analyzed in the Water Works Design and Supervision Enterprise (WWDSE) laboratory in Addis Ababa, Ethiopia. The Bouyoucos hydrometer method was used to determine soil textures. Soil pH was determined using a pH meter a 1 : 2.5 soil to water suspension potentiometric method [72]. The micro-Kjeldahl [73] and Walkley and Black [74] methods were used to determine total nitrogen (N) and soil organic carbon, respectively. The Bray-I method was used to determine available phosphorus, and the absorbance of the Bray-I extract was measured in a spectrophotometer at 882 nm [75]. Based on C and N concentrations, the carbon-to-nitrogen ratio (C/N) was calculated. The dry weight of each soil sample (MS) was determined using oven-drying set to 105°C for 24 h to achieve a constant weight [76]. The volume of the core sampler (VC) was determined as VC = π r^2h, where r is the radius and h is the height of the core sampler (VC = 3.14 × (2.5 cm) 2 × 5 cm = 98.125 cm^3) to calculate the bulk density for each sample.

2.4.4. Ordination. The canonical correspondence analysis (CCA) ordination method was used to find out plant community distribution along the environmental gradient [77]. The selection of CCA was based on the results of detrended correspondence analysis (DCA), which showed that the longest axis of DCA for a data set was greater than 3 (=4.88) (Table 3). This indicates the presence of higher β-diversity or heterogeneous vegetation data due to the unimodal relationship between species and environmental variables. Permutational multivariate analysis of variance (function adonis test) was used to choose environmental factors that were relatively more relevant in explaining the species data and significance before CCA ordination [78]. Pearson's correlation coefficient was calculated to evaluate the relationship between environmental factors and plant diversity.

3. Result

3.1. Plant Diversity. In this study, a total of 15 (9.5%) endemic plant species were recorded from Ethiopia. Of the total endemic species, 9 are herbaceous, 3 are shrubs, 2 are trees, and 1 is a liana in life form (Table 4). *Rinorea friisii* and *Crotalaria rosenii* were listed as near threatened among the 15 endemic species, while eight others were listed as least concerned (Table 4).

Table 3: Detrended correspondence analysis result of MFBR vegetation.

DCA axes	DCA1	DCA2	DCA3	DCA4
Eigen values	0.8356	0.2267	0.1917	0.1600
Decorana values	0.8599	0.2441	0.1845	0.1449
Axis lengths	4.8857	2.2693	2.4418	2.2889

3.2. Plant Community Types. Four plant community types were identified using agglomerative hierarchical cluster analysis of the entire vegetation data set of MFBR (Figure 4 and Table 5). The identified communities were *Celtis zenkeri-Blighia unijugata* community (C1), *Pouteria altissima-Lecaniodiscus fraxinifolius* community (C2), *Antiaris toxicaria-Celtis toka* community (C3), and *Dracaena afromontana-Cyathea manniana* community (C4).

C1: *Celtis zenkeri-Blighia unijugata* community

This community was found in the elevation range of 830–1896 m.a.s.l and was represented by 77 species. Of these, 67 species are commonly shared with other communities, while 12 are found only in this community type. Among the total species, four species were significant indicator species, with higher indicator values than those of total species (Table 6), namely, *Blighia unijugata, Pouteria alnifolia, Margaritaria discoidea,* and *Garcinia buchananii*. The most dominant shrub species included *Argomuellera macrophylla, Whitfieldia elongata, Dracaena fragrans, Vernonia amygdalina, and Phyllanthus reticulatus. Leptaspis zeylanica, Aspilia mossambicensis, Asplenium bugoiense, Asplenium anisophyllum,* and *Pollia condensata* were the dominant herb layers in the community. The common lianas of this community were *Embelia schimperi, Combretum paniculatum, Dregea schimperi,* and *Goupia glabra*.

C2: *Pouteria altissima-Lecaniodiscus fraxinifolius* community

This community was distributed in the elevation range of 800 to 2310 m.a.s.l. and was represented by 77 species. Of these, 71 species are commonly shared with other communities, while 6 are found only in this community type. Among the total species, four species were significant indicators with higher indicator values (Table 6), namely, *Pouteria altissima, Lecaniodiscus fraxinifolius, Ficus exasperata,* and *Ritchiea albersii*. Moreover, the dominant tree species layers were *Lannea welwitschii, Ritchiea albersii, Grewia molli, Ficus sur, Ficus mucuso, Ficus ovata, Ficus exasperata, Ficus umbellata, Allophylus macrobotrys,* and *Croton sylvaticus. Erythrococca trichogyne, Whitfieldia elongata, Dracaena fragrans, Rinorea friisii, Vernonia amygdalina, Acalypha orbata, Pittosporum viridiflorum, Phyllanthus reticulatus,* and *Oxyanthus speciosus* were prominent shrubs in this community. *Jasminum dichotomum, Combretum paniculatum, Phytolacca dodecandra, Dregea schimperi, Symphytum officinale, Pseuderanthemum tunicatum, Uncaria africana,* and *Saba comorensis* were common lianas. The herb layer was dominated by *Asplenium bugoiense* and *Aspilia mossambicensis*.

Table 4: Endemic plants, their habits, and IUCN status in the Majang Forest Biosphere Reserve.

Plant species	Family name	IUCN category	LF
Acanthopale aethiogermanica Ensermu	Acanthaceae	NA	S
Bothriocline schimperi Oliv. & Hiern ex Benth	Asteraceae	LC	H
Clematis longicauda Steud. ex A. Rich	Ranunculaceae	LC	L
Crotalaria rosenii (Pax) Milne-Redh. ex Polhill	Fabaceae	NT	H
Dorsetnia soerensenii Friis	Moraceae	NA	H
Euphorbia dumalis S. Carter	Euphorbiaceae	LC	H
Impatiens rothii Hook.f	Balsaminaceae	NA	H
Millettia ferruginea (Hochst.) Bak	Fabaceae	LC	T
Pycnostachys abyssinica Fresen	Lamiaceae	NA	H
Rinorea friisii M.G.Gilbert	Violaceae	NT	S
Solanecio gigas (Vatke) C. Jeffrey	Asteraceae	LC	S
Solanum marginatum L.f	Solanaceae	NA	H
Vepris dainellii (Pic. Serm.) Kokwaro	Rutaceae	LC	T
Vernonia filigera Oliv. & Hiern	Asteraceae	LC	H
Vernonia leopoldi (Sch. Bip. ex Walp.) Vake	Asteraceae	LC	H

Note. LF = life form, T = tree, S = shrub, H = herb, and L = liana; IUCN threat categories (LC = least concern, NA = not available, and NT = near threatened).

C3: *Antiaris toxicaria-Celtis toka* community

This community was found in the elevation range of 850–2300 m.a.s.l and was represented by 105 species. Of these, 92 species are commonly shared with other communities, while 13 are found only in this community type. Among the total species, four species are significant indicator species with higher indicator values (Table 6), namely, *Celtis zenkeri, Morus mesozygia, Vernonia hochstetteri,* and *Celtis toka*. Moreover, the dominant species in the tree layer were *Diospyros abyssinica, Morus mesozygia, Combretum molle, Apodytes dimidiata, Olea capensis, Dombeya torrida, Buddleja polystachya,* and *Lepisanthes senegalensis*. The dominant species in the shrub layer were *Vernonia hochstetteri, Acanthopale pubescens, Erythrococca trichogyne, Plectranthus* sp, and *Capparis tomentosa. Marantochloa leucantha, Solanum nigrum, Achyranthes aspera,* and *Asplenium aethopicum* were the dominant species in the herb layer. The dominant lianas in this community were *Peponium vogelii,*

Table 5: Synoptic cover value of plants in MFBR for species ≥1% in at least one community.

Scientific name	C1	C2	C3	C4
Cluster size	36	25	44	35
Celtis zenkeri	3.450	2.120	2.659	0.000
Blighia unijugata	2.806	1.040	1.841	0.000
Apodytes dimidiata	2.444	2.000	1.364	0.000
Pouteria alnifolia	2.222	1.240	1.000	0.000
Trichilia prieuriana	1.694	1.200	0.864	0.000
Margaritaria discoidea	1.694	0.640	0.818	0.000
Argomuellera macrophylla	1.611	1.320	1.000	0.000
Diospyros abyssinica	1.556	0.800	1.955	0.000
Lannea welwitschii	1.500	1.600	1.409	0.000
Combretum molle	1.389	0.600	0.432	0.000
Pouteria altissima	2.472	3.400	2.864	0.000
Lecaniodiscus fraxinifolius	1.472	3.220	1.955	0.000
Erythrococca trichogyne	1.361	2.040	0.750	0.943
Apodytes dimidiata	2.444	2.000	1.364	0.000
Ritchiea albersii	0.944	1.840	1.227	0.000
Ficus exasperata	1.000	1.760	0.364	0.000
Antiaris toxicaria	1.778	1.640	3.532	0.000
Celtis toka	1.417	1.200	2.909	0.000
Morus mesozygia	0.556	0.480	1.477	0.000
Croton macrostachyus	0.472	0.800	1.045	1.171
Deinbollia kilimandschrica	0.250	1.040	1.045	0.000
Grewia mollis	1.222	1.400	1.159	0.000
Ficus sur	0.222	1.520	1.136	0.943
Dracaena afromontana	0.000	0.000	0.000	3.514
Cyathea manniana	0.000	0.000	0.000	3.414
Schefflera abyssinica	0.000	0.000	0.000	2.800
Trilepisium madagascariense	0.000	0.000	0.000	2.686
Galiniera saxifraga	0.000	0.000	0.000	2.600
Schefflera myriantha	0.000	0.000	0.000	1.914
Vernonia bipotini	0.000	0.000	0.000	1.886
Allophylus abyssinicus	0.000	0.000	0.000	1.857
Pouteria adolfi-friedericii	0.000	0.000	0.000	1.829
Clausena anisata	0.000	0.000	0.000	1.829

Note. C1 = community one, C2 = community two, C3 = community three, and C4 = community four.

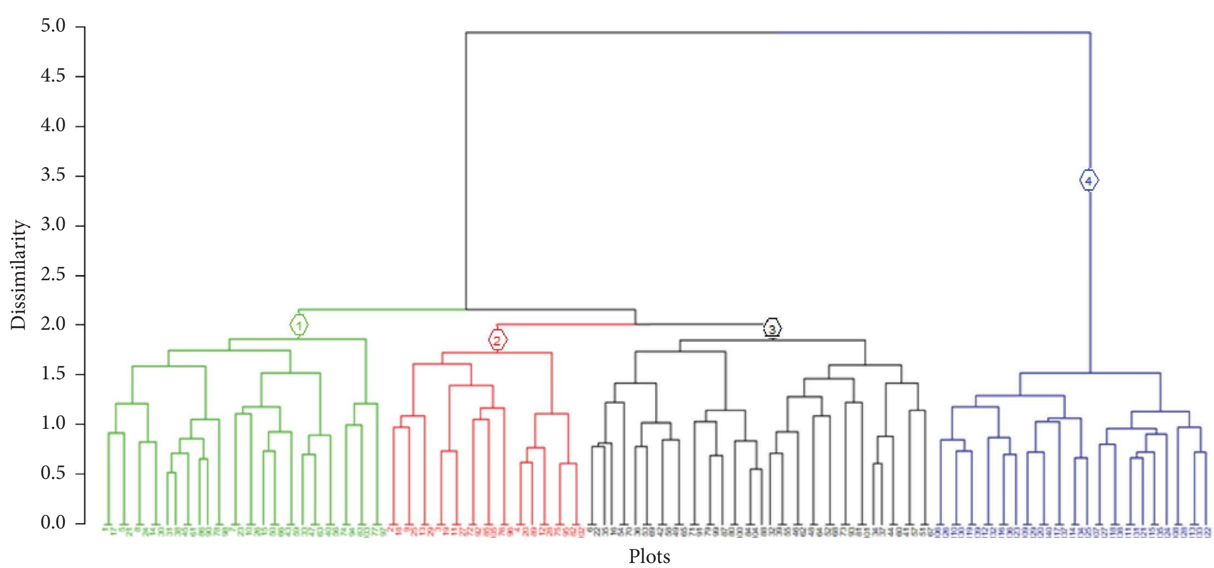

Figure 4: Dendrogram of the cluster analysis results of species abundance found in 140 of MFBR. C1: 1, 17, 5, 21, 8, 24, 14, 30, 31, 38, 45, 61, 86, 90, 78, 98, 7, 23, 10, 26, 15, 50, 66, 43, 59, 33, 47, 63, 40, 56, 74, 94, 83, 103, 77, and 97; C2: 2, 18, 9, 25, 13, 29, 3, 19, 11, 27, 72, 92, 85, 105, 76, 96, 4, 20, 89, 12, 28, 75, 95, 82, and 102; C3: 6, 22, 35, 16, 54, 70, 36, 53, 69, 42, 58, 49, 65, 71, 91, 79, 99, 87, 80, 100, 84, 104, 88, 32, 39, 55, 46, 62, 48, 64, 52, 68, 73, 93, 81, 101, 34, 37, 44, 60, 41, 57, 51, and 67; C4: 106, 126, 110, 130, 119, 139, 112, 132, 116, 136, 123, 109, 129, 120, 140, 117, 137, 114, 134, 125, 107, 127, 118, 138, 111, 131, 121, 115, 135, 124, 108, 128, 113, 133, and 122.

Table 6: Higher indicator values with significance of species in the clusters.

Species	Community	R. Ab	R. Fr	Indval	P value
Blighia unijugata	C1	0.493	0.778	0.384	0.001
Pouteria alnifolia	C1	0.498	0.667	0.332	0.001
Margaritaria discoidea	C1	0.537	0.583	0.314	0.001
Garcinia buchananii	C1	1.000	0.306	0.306	0.001
Pouteria altissima	C2	0.283	0.722	0.389	0.001
Lecaniodiscus fraxinifolius	C2	0.225	0.278	0.343	0.001
Ficus exasperata	C2	0.320	0.361	0.293	0.001
Ritchiea albersii	C2	0.235	0.306	0.275	0.001
Celtis zenkeri	C3	0.841	0.365	0.307	0.005
Morus mesozygia	C3	0.523	0.588	0.307	0.001
Vernonia hochstetteri	C3	0.341	0.799	0.272	0.001
Celtis toka	C3	0.636	0.422	0.268	0.005
Dracaena afromontana	C4	1.000	1.000	1.000	0.001
Cyathea manniana	C4	1.000	1.000	1.000	0.001
Vernonia bipotini	C4	1.000	0.914	0.914	0.001
Schefflera abyssinica	C4	1.000	0.886	0.886	0.001

Note. R.Ab = relative abundance, R.Fr = relative frequency, Indval = indicator values in the class, and indicator species in the respective community types at $P < 0.05$.

Ampelocissus bombycina, Sericostachys scandens, Tacazzea apiculata, Paullinia pinnata, Lagenaria siceraria, and *Cayratia gracilis*.

C4: *Dracaena afromontana-Cyathea manniana* community

The community is distributed in the elevation range of 1820–2359 m.a.s.l and was represented by 70 species in 35 plots. Of these, 35 species are commonly shared with other communities, while 35 are found only in this community type. Among the total species, four species are significant indicator species with higher indicator values (Table 6), namely, *Dracaena afromontana, Cyathea manniana, Vernonia bipotini, Schefflera abyssinica,* and *Pouteria adolfi-friedericii*. The dominant tree species in the community were *Allophylus abyssinicus, Pouteria adolfi-friedericii, Triumfetta tomentosa, Pycnostachys eminii, Dracaena reflexa, Ekebergia capensis, Ilex mitis, Elaeodendron buchananii, Albizia schimperiana, Dracaena afromontana, Cyathea manniana, Schefflera abyssinica, Trilepisium madagascariense, Galiniera saxifrage,* and *Schefflera myriantha*. *Justicia schimperiana, Acanthopale aethiogermanica, Clausena anisata, Vernonia auriculifera, Maesa lanceolata, Maytenus gracilipes, Clematis longicauda,* and *Vernonia bipotini* were the dominant species in the shrub layer. The dominant species in herb layer were *Alchemilla fischeri, Bothriocline schimperi, Justicia* sp, *Asplenium friesiorum, Setaria megaphylla, Asplenium sandersonii,* and *Physalis angulata*. The dominant lianas in this community were *Clematis simensis, Culcasia falcifolia, Hippocratea pallens,* and *Jasminum abyssinicum*.

3.2.1. Species Richness, Evenness, and Diversity among Plant Community Types. The overall Shannon diversity index and evenness in MFBR were 3.64 and 0.94, respectively (Table 7). The highest Shannon diversity was shown in community 1 (3.8), while the least was exhibited in community 4 (3.5). The maximum Shannon evenness was indicated in community type four (0.9), followed by community types three, two, and one (each with 0.7 evenness) (Table 8). The highest species richness was exhibited in community type one (102 species), whereas the lowest plant species richness was revealed in community type four (70) (Table 7).

Similarity coefficients of all communities range from 0.61 to 0.91. The highest Sorensen similarity was exhibited between communities 1 and 2 (0.91) followed by communities 2 and 3 (0.90). The lowest Sorensen similarity was revealed between communities 1 and 4 (0.61) and communities 2 and 4 (0.63) of the total species in MFBR (Table 8).

Sorenson similarity coefficients and beta diversity were inversely related to each other. Therefore, communities with the lowest similarity coefficients had the highest beta diversity (0.45) in communities 1 and 4, whereas communities with the highest similarity coefficients had the lowest beta diversity (0.102) (Table 8).

3.2.2. Species Richness, Evenness, and Diversity along Environmental and Disturbance Factor. Species diversity varied from 2.33 to 3.64; the higher value was recorded at the higher elevation gradient (>1800 m.a.s.l), and the lower value was recorded at the lower elevation gradient (<1200 m.a.s.l). Species richness and Shannon diversity exhibited a significant positive correlation with elevations ($r = 0.302$, $p = 0.0002$) and ($r = 0.493$, $p = 0.00005$), respectively, while evenness showed a significant negative correlation with the elevation gradient ($r = -0.385$, $p = 0.00003$) (Table 9). Similarly, the slope showed a significant positive correlation with species richness ($r = 0.262$, $p = 0.00002$) and species diversity ($r = 0.373$, $p = 0.00001$), while the slope showed a significant negative correlation with species evenness ($r = -0.181$, $p = 0.0005$) (Table 9).

The highest species diversity was shown on the intermediate slope (10–20) gradient, while the lowest diversity recorded the lower slope (<10). The herbaceous cover showed a significant positive correlation with species richness and Shannon diversity ($r = 0.137$, $p = 0.01$) and ($r = 0.171$, $p = 0.004$), respectively. Species richness and Shannon diversity showed a significant negative correlation with the harvesting index ($r = -0.243$, $p = 0.003$) and ($r = -0.376$, $p = 0.00004$), respectively. Similarly, soil pH and silt showed a significant negative relationship with species richness ($r = -0.321$, $p = 0.0001$) and ($r = -0.504$, $p = 0.0004$) and Shannon diversity ($r = -0.302$, $p = 0.0002$) and ($r = -0.458$, $p = 0.00001$), respectively. However, soil pH and silt showed a significant positive relationship with species evenness ($r = 0.365$, $p = 0.0009$) and ($r = 0.353$, $p = 0.00001$), respectively (Table 9).

3.3. Relationship between Community Types with Environmental and Disturbance Factors. The length of the first axis of DCA indicates species heterogeneity in vegetation as

Table 7: Species richness, evenness, and diversity indices of plant community types.

Vegetation parameters	Community type			
	C1	C2	C3	C4
Species richness	102	77	93	70
H′	3.8	3.6	3.7	3.5
Shannon evenness	0.7	0.7	0.7	0.9
Basal area (m^2)/ha^{-1}	58.55	48.82	64.64	76.3
Density (ha^{-1})	1532	1018	1478	1309
Seedling density (ha^{-1})	3349	3087	4431	3804
Sapling density (ha^{-1})	1629	1457	1789	1509

Note. H′ = Shannon diversity index, C1 = community 1, C2 = community 2, C3 = community 3, and C4 = community 4.

Table 8: Pairwise comparison of Sorensen's similarity coefficient and beta diversity among four plant communities.

Communities	C1	C2	C3	C4
C1	1			
C2	0.91 (0.102)	1		
C3	0.87 (0.13)	0.90 (0.104)	1	
C4	0.61 (0.45)	0.63 (0.43)	0.64 (0.38)	1

Note. Values outside the bracket indicate Sorensen's coefficient, while those inside the bracket indicate the beta diversity index. C1 = community 1, C2 = community 2, C3 = community 3, and C4 = community 4.

Table 9: Pearson correlation coefficients between diversity indices and environmental and disturbance factors in MFBR.

Environmental disturbance site factors	Diversity indices		
	SR	H′	J
Hca	0.137^{*}	0.171^{*}	-0.030^{ns}
HI	-0.243^{***}	-0.376^{***}	-0.040^{ns}
Ele	0.302^{***}	0.493^{***}	-0.385^{***}
Slope	0.262^{***}	0.373^{***}	-0.181^{*}
Soil pH	-0.321^{***}	-0.504^{***}	0.365^{***}
Silt	-0.302^{***}	-0.458^{***}	0.353^{***}

Note. Hca = herbaceous cover, HI = harvesting index, Ele = elevation, SR = species richness, H′ = species diversity index, and J = species evenness. Positive signs indicate a positive correlation, and negative signs indicate inverse relations. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, and ns = no significance.

a result of environmental variables (Table 3). The first axis of DCA was> 3 (4.88), which indicates a wider length of the gradient and the presence of higher β- diversity or heterogeneous vegetation data due to the unimodal relationship between species and environmental factors (Table 3). Therefore, CCA was selected to show the effect of environmental and disturbance factors on the patterns of plant community distribution.

Furthermore, significant environmental and disturbance factors ($P < 0.05$) were selected using permutational multivariate analysis of variance (function adonis test). Out of 14 environmental and disturbance factors, six factors were significant in explaining patterns of plant community distribution. More specifically, herbaceous cover ($r = 0.0409$, $p = 0.001$), harvesting index ($r = 0.0445$, $p = 0.001$), elevation ($r = 0.0906$, $p = 0.001$), slope ($r = 0.0143$, $p = 0.014$), pH ($r = 0.0127$, $p = 0.032$), and silt ($r = 0.0114$, $p = 0.0047$) exhibited a significant difference among environmental and disturbance factors (Table 10). Thus, significant environmental and disturbance factors influence the species distribution pattern in all community types.

CCA ordination was performed using data on cover abundance values of plant species in the plots and six statistically significant environmental disturbance factors. In the canonical correspondence analysis (CCA), the eigenvalues obtained in the first and second axes were 54.4 and 4.4, respectively. The correlation results of environmental disturbance factors and the CCA axis showed both a positive and negative correlation from the first to the last axis (Table 11). The elevation and slope showed a positive correlation ($r = 0.868$, $p < 0.05$) and ($r = 0.638$, $p < 0.05$), respectively, in the first axis. Among significant environmental disturbance factors, the elevation was an extremely important constraining factor followed by the slope and harvesting index (HI) on plant species distribution patterns in MFBR. On the other hand, pH and silt showed a strong negative correlation ($r = -0.907$, $p < 0.05$) and ($r = 0.792$, $p < 0.05$), respectively, in the first axis. CCA showed that the cumulative proportion and proportion explained in the first axis accounted 76.3%, respectively, which is explained as species and environmental disturbance factor variations (Table 11).

Ordination of the study plots of MFBR formed four communities based on the species composition. These four community types were separated by following the arrows of the environmental variables. Red, green, blue, and purple represent sample plots of community types 1, 2, 3, and 4, respectively (Figure 5). Community four generally occurs at a higher elevation, while species in communities one, two, and three are distributed at the middle and lower elevations. The distribution of species in communities four was influenced by elevation, slope, harvesting index, and herbaceous cover factors, whereas the distribution of species in communities one, two, and three was strongly influenced by soil pH and silt factors (Figure 5). The length and direction of the vectors in the plots and environment and disturbance biplot represent the degree of correlation between the plots and environmental disturbance factors. Communities' types one, two, and three are more closely related to one another, whereas community type four is different from the other three community types (Figure 5).

The correlation results between environmental and disturbance factors exhibited both positive and negative relationships in MFBR (Table 12). The elevation showed a significant positive correlation with slopes ($r = 0.44$), MC ($r = 0.58$), sand ($r = 0.33$), and TN ($r = 0.43$), while it showed a significant negative relationship with pH ($r = -0.76$), silt ($r = -0.90$), and clay ($r = -0.91$). Similarly, the slope showed a significant negative relationship with MC ($r = -0.38$), pH (r = -0.46), silt ($r = -0.42$), TN ($r = -0.47$), and clay ($r = -0.46$), while it showed a significant positive correlation with sand ($r = 0.45$). Soil pH showed a significant positive

Table 10: Result of the function Adonis test of significant environmental and disturbance factors in MFBR.

Variables	Df	Sums of squares	Mean squares	F model	R^2	Pr(>F)
Hca	1	1.8900	1.8898	6.9218	0.0409	0.001***
CaOp	1	0.1770	0.1766	0.6470	0.0038	0.767
HI`	1	2.0610	2.0608	7.5481	0.0445	0.001***
Ele	1	4.1910	4.1912	15.3514	0.0906	0.001***
Slope	1	0.6600	0.6600	2.4173	0.0143	0.014*
Aspect	1	0.4640	0.4640	1.6994	0.0100	0.08
MC	1	0.2000	0.1998	0.7316	0.0043	0.703
pH	1	0.5860	0.5863	2.1473	0.0127	0.032*
Sand	1	0.2280	0.2284	0.8367	0.0049	0.559
Silt	1	0.5290	0.5293	1.9388	0.0114	0.047*
Clay	1	0.3360	0.3365	1.5142	0.0631	0.441
TN	1	0.4140	0.4135	1.5146	0.0089	0.137
OM	1	0.2900	0.2898	1.0614	0.0063	0.369
P	1	0.1750	0.1748	0.6403	0.0038	0.814
Residuals	126	34.4000	0.2730		0.7436	
Total	139	46.2640			1.0000	

Note. Hca = herbaceous cover, CaOp = canopy openness, HI = harvesting index, Ele = elevation, MC = moisture content of the soil, TN = total nitrogen, OM = organic matter, and P = available phosphorus.

Table 11: Scores of constraining variables and correlations between environmental and disturbance factors with CCA axes in MFBR.

Environmental variables	CCA1	CCA2	CCA3	CCA4
Hca	0.429	−0.128	0.160	−0.541
HI	0.522	0.028	0.207	0.335
Ele	0.868	0.066	0.100	−0.014
Slope	0.638	−0.238	0.135	−0.280
pH	−0.907	0.047	−0.029	−0.020
Silt	−0.792	0.060	−0.187	−0.243
Eigenvalue	0.544	0.044	0.040	0.033
Proportion explained	0.763	0.062	0.057	0.046
Cumulative proportion	0.763	0.825	0.882	0.928

Note. Hca = herbaceous cover, HI = harvesting index, Ele = elevation, and MFBR = Majang Forest Biosphere Reserve.

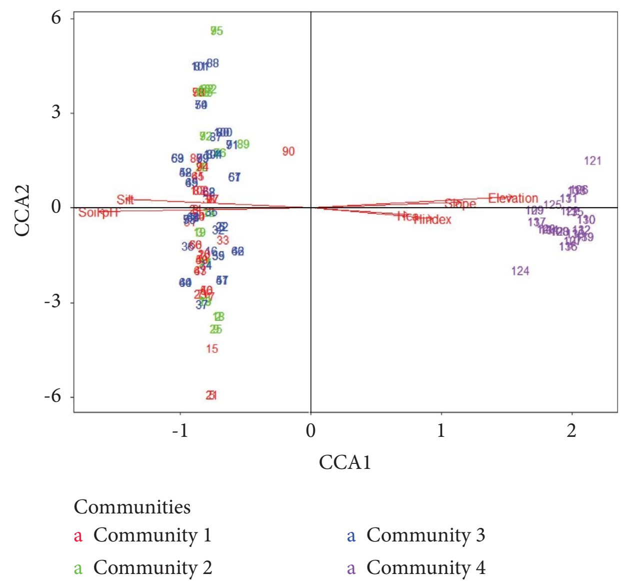

Figure 5: Canonical correspondence analysis (CCA) ordination diagram of 140 plots and 6 significant environmental variables and plot number distribution in four community types.

relationship with silt ($r = 0.91$), TN ($r = 0.93$), and clay ($r = 0.91$), while it showed a significant negative relationship with sand ($r = -0.93$) (Table 12).

4. Discussion

4.1. Endemic Plant Species and Diversity. The Majang Forest Biosphere Reserve had shown high endemism as proposed by the World Conservation and Monitoring Centre (comprises high or 9.5% endemic species) (Table 4) [79]. Thus, endemism is higher than reported in other moist Afromontane forests of southwestern Ethiopia. For instance, Bonga forest recorded 13 endemic species (5.35%) [80] and Yayu forest with only 3 endemic species (1.36%) [81]. On the other hand, the number of endemic species recorded in this study is lower than in some dry Afromontane forests of Ethiopia. For example, Wof Washa forest has 29 species (12%) [82]; Chilimo forest has 18 endemic species (8.45%) [83]. The lower number of endemics in the moist Afromontane forests of the southwestern and dry Afromontane forests of Ethiopia may be due to ecological and geographical separations [84]. Based on the plant species endemic to Ethiopia, *Rinorea friisii* and *Crotalaria rosenii* were listed as near threatened, while other eight were registered as least concerned (Table 4) [85]. This suggests that special attention needs to be given to the forest stand containing species which are threatened and least concerned.

The overall diversity investigation of MFBR showed the higher Shannon diversity index (3.64) and evenness (0.94). The value of species diversity and evenness in MFBR is greater than that of Gesha-Sayilem forest, Kibate forest, Gerba Dima forest, Wurg forest, and Agama forest, while it is lower than that of Belete forest (Table 13). This difference may be due to links with geographical locations, climatic conditions, and elevation factors.

4.2. Plant Community Types. In this study, a total of four plant communities were identified, which are rich in species composition. The major distinguishing features of the identified plant communities were the difference in dominant and indicator plant species. However, communities 1–3 share more species (>70 species) than community 4 (35 species), which could be directly related to environmental and disturbance factors that make the plant communities have their own distinct or characteristic species [42]. Almost all communities identified more than four indicator species with a significant value. Indicator plant species are plants that are easily monitored and predict the condition of the environment where they originated. Indicator species can also be a sign of a distinctive set of environmental qualities or characteristics found in a specific place [91].

Blighia unijugata and Pouteria alnifolia were indicator species in community 1. *Blighia unijugata* is the dominant and indicator species and is among the indicator species of moist Afromontane forests in the middle canopy [92, 93].

Table 12: Pearson's correlation coefficient matrix for environmental and disturbance factors ($N = 14$) in MFBR.

	Hca	CaOp	HI	Elevation	Slope	Aspect	MC	pH	Sand	Silt	TN	Clay (ns)	OM	P
Hca														
CaOp	0.27^{*}													
HI	0.13^{ns}	0.05^{ns}												
Elevation	0.23^{**}	0.10^{ns}	0.33^{***}											
Slope	0.15^{ns}	-0.07^{ns}	-0.28^{*}	0.44^{***}										
Aspect	-0.08^{ns}	0.08^{ns}	-0.03^{ns}	-0.09^{ns}	-0.11^{ns}									
MC	0.18^{*}	-0.05^{ns}	-0.14^{*}	0.58^{***}	-0.38^{***}	-0.09^{ns}								
pH	-0.28^{**}	-0.08^{ns}	-0.32^{***}	-0.76^{***}	-0.46^{***}	0.09^{ns}	-0.57^{***}							
Sand	-0.27^{**}	0.08^{ns}	0.31^{***}	0.33^{***}	0.45^{***}	-0.06^{ns}	-0.47^{***}	-0.93^{***}						
Silt	0.25^{**}	-0.09^{ns}	-0.29^{**}	-0.90^{***}	-0.42^{***}	0.06^{ns}	0.45^{***}	0.91^{***}	-0.98^{***}					
TN	-0.24^{**}	-0.11^{ns}	-0.27^{**}	0.43^{***}	-0.47^{***}	0.02^{ns}	-0.57^{***}	0.93^{***}	-0.87^{***}	0.85^{***}				
Clay	-0.28^{***}	-0.06^{ns}	-0.32^{***}	-0.91^{***}	-0.46^{***}	0.06^{ns}	0.67^{***}	0.91^{***}	-0.98^{***}	-0.52^{**}	0.85^{***}			
OM	0.03^{ns}	0.01^{ns}	-0.07^{ns}	0.32^{ns}	-0.11^{ns}	-0.03^{ns}	0.21^{*}	-0.12^{ns}	-0.13^{ns}	0.12^{ns}	0.41^{ns}	0.16		
P	0.03^{ns}	0.10^{ns}	-0.03^{ns}	0.09^{ns}	0.01^{ns}	0.03^{ns}	0.08^{ns}	-0.09^{ns}	0.11^{ns}	0.10^{ns}	0.01^{ns}	0.01	0.18^{*}	

Note. The magnitude indicates the degree of correlation, positive signs indicate positive correlations, and negative signs indicate inverse relations. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, and ns = no significance. N = number of variables, MFBR = Majang Forest Biosphere Reserve, Hca = herbaceous cover, CaOp = canopy openness, HI = harvesting index, MC = moisture content of the soil, TN = total nitrogen, OM = organic matter, and P = available phosphorus.

Table 13: Comparisons of the Shannon diversity index and evenness of MFBR with other moist Afromontane forests in southwestern Ethiopia.

Forest area	Elevation (m)	H′	J	Sources
Gesha-Sayilem forest	1734–2803	3.56	0.84	[86]
MFBR	800–2400	3.64	0.94	Present study
Gerba Dima forest	1677–2240	3.45	0.93	[87]
Wurg forest	900–2500	3.38	0.90	[88]
Agama forest	1800–2370	3.25	0.78	[89]
Belete forest	1800–2300	3.79	0.95	[90]

Note. H′ = Shannon diversity index, J = evenness, and MFBR = Majang Forest Biosphere Reserve.

Celtis zenkeri is the dominant species and significant indicator species in this community among five species. This community comprises an important fodder tree for honey production, which contributes to the means of livelihood for local communities in the area [94].

P. altissima was the dominant and significant indicator species in community 2 (Table 6) and is among the indicator species in the upper canopy of the moist Afromontane forest [92, 93], while *L. fraxinifolius* was also the dominant species and significant indicator species in the middle canopy.

A. toxicaria is the dominant species and the distinctive species of moist Afromontane forests in the middle canopy, whereas *Celtis toka* was the other dominant and significant indicator species in community 3 and is among the indicator species of moist Afromontane forests in the middle canopy [92, 93]. The community had the highest number of plant species compared to other communities. This could be due to their location away from human disturbances since they are located in difficult terrain such as sloppy and deep gorges [95, 96].

Dracaena afromontana and Cyathea manniana were the dominant and indicator species with a significant indicator value in this community, and they are among the distinctive species in the middle canopy of the moist Afromontane forest [92, 93]. The *D. afromontana-C. manniana* community type comprises different species as compared to other plant communities, which are found at higher elevations. The species composition difference in the community may be due to an environmental and anthropogenic factor [95, 96].

The Shannon diversity index was extended from 3.5 to 3.8 in four plant community types, which indicates the existence of high diversity in MFBR. The plant communities showed a minor variation in their species richness, diversity, and evenness. Somewhat, community types such as *B. unijugata-P. alnifolia* and *P. altissima-L. fraxinifolius* were higher in species richness, while community types *A. toxicaria-C. toka* and *D. afromontana-C. manniana* had the lowest species richness. This variation in species richness among communities could be due to the variations of topography, anthropogenic impact, climate, and edaphic factors [97, 98]. Each community has its own distribution area with a specific combination of environmental variables [27, 99–101].

The communities with the highest similarity coefficients had the least beta diversity, while communities with the least similarity coefficients had the highest beta diversity. The higher Sorensen similarity between communities 1 and 2 might be due to the narrow topographical distance between the two communities where most of the plots forming these communities may have relatively similar environmental factors [52, 102–105].

4.3. Species Richness, Evenness, and Diversity Indices along Environmental Gradients. We found high species richness and diversity at higher elevations than at lower elevations (Table 9). Higher species richness and diversity at higher elevations may be due to variations in climatic and edaphic factors [106]. The maximum species diversity and richness were found on intermediate sloping terrain, followed by on lower sloping terrain (Table 9). The slope has been identified as one of the topographic factors that influence species diversity and richness [95, 96, 107]. This result agrees with the findings of Wondie et al. [108], who stated that forests grow favourably on intermediate sloping terrain. The increase in species richness and diversity at intermediate sloping terrain may be due to soil moisture availability and edaphic factors (soil nutrients and low soil erosion) [109, 110].

4.4. Relationship between Community Types with Environmental and Disturbance Factors. Studies focusing on the relationship between plant communities with environmental and disturbance factors have become increasingly important in understanding the ecology of forest communities [111–115]. Plant species distribution patterns and plant community formation are highly influenced by microclimate, edaphic, and anthropogenic factors [41, 93, 116–119]. Plants form a community when a plant species repeatedly appears in a similar environment. Similarly, it is the classification of plant communities, which temporally and spatially determines the boundaries of a plant community [120–122]. Each community has its own distribution area with a specific combination or preference of environmental variables.

Relatively, the elevation was the most significant environmental factor influencing and describing the community type distribution [42, 81, 123–129]. Accordingly, the variation of plant communities was also closely related to other environmental, disturbance, and site factors, including herbaceous cover, harvesting index, slope, pH, and silt (Table 10).

Disturbance (illegal logging) affects the distribution of plant communities by hindering seedling establishment and regeneration in tropical forests [130–133]. It can also assist in the ground layer plant species growth by facilitating the availability of light [134, 135].

The correlation among environmental, disturbance, and site factors governs the pattern of species distribution in the plant communities of MFBR (Table 12). There was a positive correlation between the elevation and organic matter. The high amount of organic matter at higher elevations can be attributed to a low rate of decomposition due to relatively low temperatures [113]. High organic matter content in soils of higher elevations was also reported in other Afromontane forests of Ethiopia [136].

5. Conclusion

This study was aimed to identify the type of plant community in MFBR and determine plant community distribution patterns in response to environmental disturbance factors (elevation, slope, disturbance, and physical and chemical composition of soil) in MFBR. MFBR is rich in endemic plant species. Our study identified four plant community types and indicated the elevation as a major environmental factor for determining the community type distribution. *Celtis zenkeri-Blighia unijugata*, *Pouteria altissima-Lecaniodiscus fraxinifolius*, *Antiaris toxicaria-Celtis toka*, and *Dracaena afromontana-Cyathea manniana* were the dominant species in the community. The highest species diversity and richness were found in community type one among the identified community types. The elevation and slope were the most significant environmental factors influencing species richness and Shannon diversity. Moreover, the slope and harvesting index were significantly positively correlated with species richness and Shannon diversity in all community types. Therefore, the findings of this study provide baseline information that should be necessary for further conservation and management practices in MFBR.

Data Availability

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

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Supplementary Materials

Appendix 1: list of plant species and community types in four sites (key: C1, C2, C3, and C4 = community 1, 2, 3, and 4; Indval cls = indicator values in the class). Appendix 2: environmental factor data in MFBR. (*Supplementary Materials*)

References

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