

Plant Community Analysis along Environmental Gradients in Moist Afromontane Forest of Gerba Dima, South-western Ethiopia

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Abstract

Background

This study was carried out in Gerba Dima Forest, South-Western Ethiopia, to determine the floristic composition, species diversity and community types along environmental gradients. Ninety sample plots having a size of 25 × 25 m (625 m²) were laid by employing stratified random sampling. Nested plots were used to sample plants of different sizes and different environmental variables. All woody plant species with Diameter at breast height (DBH) ≥ 2.5 cm and height ≥ 1.5 m were recorded in 25 m X 25 m plots. Within the major plots, five 3 m x 3 m subplots (9 m²) was used to collect shrubs with dbh < 2.5 cm and > 1.5 m height. Within each 9 m²subplots, two 1 m² subplots were used to collect data on the species and abundance of herbaceous plants. Hierarchical (agglomerative) cluster analysis was performed using the free statistical software R version 3.6.1 using package cluster to classify the vegetation into plant community types. Redundancy Analysis (RDA) ordination was used in describing the pattern of plant communities along an environmental gradient.

Result

One hundred and eighty plant species belonging to 145 genera, 69 families and comprising of 15 endemic species were recorded. Cluster analysis resulted in five different plant communities and this result was supported by the ordination result. RDA result showed altitude was the main environmental variable in determining the plant communities. The ANOVA test indicated that the five community types differ significantly from each other with regard to EC and K.

Conclusions

The studied forest can play a significant role in biodiversity conservation since it harbours high species diversity and richness. Thus, all Stakeholders including Oromia Forest and wildlife enterprise (OFWE) and the regional government should work to designate the forest as a biosphere reserve and being registered under UNESCO.

1. Background

Distinguishing plant communities have been at the heart of vegetation science for centuries, with a traditional focus on the distribution, composition, and classification of plant communities [1]. The plant community structure includes attributes such as the number of species, the relative abundance of species, and the kind of species comprising a community [2, 1]. The overall structure of the plant community could be determined by a combination of several features such as the physical environment, community size, and longevity of species present. The community may be stable or unstable, with high or low primary productivity, and may change seasonally or even daily [3].

Studies focusing on the relationship between plant communities and environmental variables have become increasingly important in understanding the ecology of forest communities [4, 5]. Patterns of plant communities are determined by environmental factors that show variation over space and time, such as climate, topography, and soil, as well as anthropogenic disturbances [6, 7]. The plants form a community when a plant species repeatedly appear in a similar environment. Similarly, it is the classification of the plant community, which temporally and spatially determines the boundaries of a plant community. Each community has its own distribution area with a specific combination of environmental variables [8].

Several scholars [9, 10, 11, 12, 13, 14] have studied the vegetation resources of Ethiopia, including forests, woodlands, and bushlands. [15] have published a detailed vegetation map for Ethiopia, which classified the Ethiopian Vegetation into 12 types. The vegetation type at Gerba Dima is part of the moist evergreen Afromontane forest, which is characterized by one, or more closed strata of evergreen trees that may attain a height of 30 to 40 m.

According to [16], a forest is defined as a minimum land area of 0.5 ha with tree crown cover more than 10-30% and tree height of above 2 m at maturity. The recent data on forest resources of Ethiopia reported in [17] puts Ethiopia among countries with a forest cover of 10-30%. According to this report, Ethiopia's forest cover (FAO definition) is 12.2 million ha (11%). It further indicated that the forest cover shows a decline from 15.11 million ha in 1990 to 12.2 million ha in 2010, during which 2.65% of the forest cover was deforested. This study was conducted in the Gerba Dima forest found in South-Western Ethiopia with the aim of investigating the species composition, community types and to relate the distribution of plant community types to some environmental parameters.

2. Material And Methods

2.1 The study area

This study was carried out in the Gerba Dima forest found in the Illu Aba Bora zone of Oromiya regional state of Ethiopia and located between 7° 45' to 8° 10' North latitude and 35° 29' to 35° 50' East. The study forest is bounded by Baro River to the south and west direction while three other rivers, namely Bote, Hoyi and Sor cross part of the forest in the east (Figure 1). The geology of the study site is characterized by the underlying basement rock consisting of intensively folded and faulted Precambrian rocks, overlain by Mesozoic marine strata and Tertiary basalt types [18]. The main soil types of the study area are red or brownish ferrisols derived from the volcanic parent material. Other soil groups in the area include nitosols, acrisols, vertisols, and cambisols soil types also exist in the study site [19].

The rainfall data collected from the nearest Gore meteorological station to the study forest indicated that the study area receives very high annual rainfall and characterized by unimodal rainfall pattern, which shows low rainfall in December, January and February, gradually increasing to the peak period in August. The mean annual rainfall of 1854mm while the monthly mean maximum and mean minimum temperature of the area is 27.2 °C and 13.3 °C, respectively. The mean annual temperature is 19.2°C and with slight variation from year to year (Figure 2).

The vegetation type at Gerba Dima is part of the moist evergreen afromontane forest with characteristic emergent species that form the upper canopy include *Pouteria adolfi-friederici*, *Albizia gummifera*, *A. schimperiana*, *A. grandibracteata*, *Sapium ellipticum*, *Euphorbia ampliphylla*, *Ekebergia capensis*, *Ficus sur*, *Hallea rubrostipulata*, *Ocotea kenyensis*, *Olea welwitschii*, *Polyscias fulva* and *Schefflera abyssinica* are other characteristic species of this vegetation type [15].

2.2 Sampling method

In this study, a stratified random sampling design was used to collect vegetation and environmental data [2, 1]. Using Arc GIS version 10.3, the study forest was stratified based on the altitudinal gradient and three types of strata in the form of contour were established. Strata one was distributed between 1500-1800m altitudinal ranges whereas strata two and three were found between 1801-2000m and 2001-2300m altitudinal ranges respectively (Fig. 1). Sample plots were assigned in each contour in the form of Random points Using Arc GIS version 10.3. Ninety sample plots having a size of 25 X 25m (625m²) along each contour were laid. Nested plots were used to sample plants of different sizes and different environmental variables. All woody plant species with Diameter at breast height (DBH) ≥ 2.5 cm and height ≥

1.5m were recorded in 25 m X 25 m plots. Within the major plots, five 3m x 3m subplots (9m²) was used to collect shrubs with dbh < 2.5 cm and > 1.5m height. Within each 9m²subplots, two 1m² subplots were used to collect data on the species and abundance of herbaceous plants. Finally, the percent cover of all plant species found within the sample plot was visually estimated and converted to the Braun-Blanquet scale as modified by [21]. Every plant species encountered in each plot were recorded. Plant specimens were collected, pressed, dried and brought to the National Herbarium (ETH), Addis Ababa University for taxonomic identification. The specimens were determined by comparing with authenticated specimens housed at ETH and by referring to published volumes of Flora of Ethiopia and Eritrea [22, 23, 24, 25, 26, 27, 28, 29, and 30]. Physiographical variables, namely altitude, geographic coordinates, slope and aspect, were recorded for each quadrat using GPS, Clinometer and Compass respectively. The values for aspect were codified based on [31], where N = 0, NE = 1, E = 2, SE = 3, S = 4, SW = 3.25, W = 2.5, NW = 1.25 before analysis. For each sample plot, a disturbance was determined on the basis of a five point scale following [32]. The five scales of disturbance scores were based on visible signs of tree cutting, grazing and presence of beehives. The points of scale were 0 = (No disturbance), 1= (0-20% of the quadrat disturbed), 2= (21-40% of the quadrat disturbed), 3= (41-60% of the quadrat disturbed), 4= (61- 80% of the quadrat disturbed), 5 = (81-100% of the quadrat disturbed). For analysing soil variables, soil samples were collected with a soil core sampler from the top 40cm depth within 1m x 1m subplots at the four corners and middle of the quadrat. Composite soil samples from samples collected from the four corners and the middle of quadrats were brought to the soil laboratories of AAU. The soil samples were air-dried, rolled and passed through a 2 mm sieve for laboratory analyses. These soil samples were analysed for pH, electrical conductivity (EC), sodium, potassium, organic matter, total nitrogen, available phosphorus and texture following standard procedures outlined in [33]. The pH and EC were measured using a pH meter and EC meter in the supernatant suspension of 1:2.5 soil–distilled water mixtures. Available Sodium and Potassium were determined using a flame photometer. Organic matter was determined by the ignition method. The texture was determined on the basis of Bouyous Hydrometer method with the categories sand, silt, and clay (expressed as % weight) while total nitrogen was determined using Kjeldhal method. Available Phosphorus was determined by the Bray-I method and the absorbance of the Bray-I extract is measured at 882 nm in a spectrophotometer.

2.3 Data analysis

In this study, hierarchical (agglomerative) cluster analysis was performed using the free statistical software R version 3.6.1[34] using package cluster to classify the vegetation into plant community types. The similarity ratio with Ward's group linkage method was applied for cluster analysis i.e. to determine plots that can be classified into the same groups based on the species abundance data. The decision on the number of groups (clusters) was based on objective methods of obtaining an optimal number of clusters, the Multi Response Permutation Procedures (MRPP) technique (no-difference hypothesis) and the ecological interpretation of the groups conducted in R program. From the output of the objective method, a sharp bend at the specific cluster in the plot could be a good indication of the number of clusters in the data [35]. The community types identified from the cluster analysis were further refined in a synoptic table where species occurrences were summarized as synoptic cover-abundance values [36]. Dominant species of each community type were identified based on their synoptic values and community types were named after one or more dominant species. The identified groups were tested for the hypothesis of no difference between the groups (clusters) using nonparametric Multi-Response Permutation Procedure (MRPP). Indicator species analysis was performed in R using package labdsv. Indicator values were tested for statistical significance using a randomization (Monte Carlo) technique. Species richness, evenness, Shannon diversity and evenness indices were computed using the free statistical software R version 3.6.1[34]. The Shannon diversity index (H') was calculated from the equation:

[Please see the supplementary files section to view the equation.]

Where p_i is the proportion of individuals found in the i^{th} species. The values of the Shannon diversity index is usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5 [3, 1]. The Shannon evenness index (J) was calculated from the ratio of observed diversity to maximum diversity using the equation:

[Please see the supplementary files section to view the equation.]

Where Hmax is the maximum level of diversity possible within a given population, which equals \ln (number of species). J is normal between 0 and 1, and with 1 representing a situation in which all species are equally abundant [3].

In this study, Redundancy Analysis (RDA) ordination was used in describing the pattern of plant communities along an environmental gradient since the preliminary analysis of the vegetation data using Deterended Correspondence Analysis (DCA) revealed that the longest axis of DCA for the dataset was less than 3 (= 2.22). Before the application of RDA ordination, environmental variables, which were relatively more important in explaining the species data, were selected using the Monte Carlo technique and function Adonis test for their significance. Computation of variance inflation factor (vif) was also conducted to eliminate those environmental variables that are collinear. The community types obtained were subjected to an ANOVA based on environmental variables to find out whether there are significant variations between the groups. Pearson's product-moment correlation coefficient was calculated to evaluate the relationship between the environmental variables.

3. Results

3.1 Floristic composition

One hundred and eighty (180) plant species belonging to 145 genera and 69 families were recorded and identified in the sample plots in the Gerba Dima forest. Of these, 52 species (28.9%) were trees, 6 species (3.33%) were Trees/shrubs, 31 species (17.22%) were shrubs, 76 species (42.22%) were herbs, and 15 species (8.33%) were Lianas. Angiosperms were represented by 160 species while the rest 20 species were Pteridophytes. Among Angiosperms, *Rubiaceae*, *Acanthaceae* and *Asteraceae* were the richest family each represented by 11 genera and 11 species (6.11%), 9 genera and 11 species (6.11%), 6 genera and 11 species (6.11%), respectively of total floristic composition, followed by *Fabaceae* 8 genera and 9 species (5%), *Euphorbiaceae* 6 genera and 7 species (3.89 %). The remaining families represented less than 3% of species each. Eleven families, 13 genera and 20 species represented pteridophytes. *Aspleniaceae*, *Dryopteridaceae* and *Pteridaceae* were the richest Pteridophytes represented by 6, 3 and 2 species respectively. The genus *Vernonia*, *Ficus*, *Asparagus*, *Dracaena* were represented by 5,4,3,3 species respectively and *Aframomu*, *Albizia*, *Asparagus*, *Cyperus*, *Euphorbia*, *Hippocratea*, *Hypoestes*, *Justicia*, *Maytenus*, *Olea*, *Peperomia*, *Polyscias*, *Pteris*, *Rubus*, *Schefflera*, *Solanaceo*, *Solanum*, *Tacazzea*, and *Zehneria* were represented by 2 species each and the rest genera contained a single species each.

Based on the information available on the published Floras of Ethiopia and in [37] a total of 15 endemic plant species in 11 families were recorded (Table 1), comprising more than 8.33% of the recorded species. *Asteraceae* was the first family having three endemic species, followed by *Acanthaceae* and *Fabaceae* (two species each). The remaining eight families have a single species each in the endemic species list. Among the total endemic species, herb, tree, shrub and liana growth forms were represented by 6,3,4,2 species respectively. Out of the 15 endemic species, *Crotalaria rosenii* and *Polyscias farinosa* have been included in the IUCN red data list of Ethiopia and Eritrea [37] qualifying for near threatened and vulnerable category respectively. In the Gerba Dima forest, at 625m² sample plot, species richness varied from 26 to 59 across the study plots. The Shannon diversity index also varied from 2.92 to 3.83

while evenness ranged from 0.89 to 0.95 in the study plots. The overall mean Shannon diversity index, species richness and evenness of the study area were 3.45, 41 and 0.93 respectively.

Table 1. Endemic species, their habit, IUCN status and geographical distributions

Species	Family	Habit	IUCN category	Altitude (m)	Floristic region*
<i>Acanthopale ethio germanica</i> ^{*a}	Acanthaceae	Shrub	NE	2300_2600	GD SU AR KF SD BA
<i>Aframomum corrorima</i>	Zingiberaceae	Herb	NE	1350_2000	KF IL WG
<i>Arisaema mooneyanum</i> ^{*a}	Araceae	Herb	NE	2000_3450	SD BA
<i>Bothriocline schimperii</i>	Asteraceae	Shrub	LC	1300_2820	GD GJ SU AR WG IL KF GG SD BA
<i>Clematis longicaudata</i>	Ranunculaceae	Liana	LC	1350_3300	GD GJ SU WG KF IL SD
<i>Crotalaria rosenii</i> ^{*a}	Fabaceae	Herb	NT	1350_2800	SU AR BA KF SD
<i>Justicia bizuneshiae</i>	Acanthaceae	Herb	NE	1200_2100	WG IL KF GG SD BA
<i>Millettia ferruginea</i>	Fabaceae	Tree	LC	1000_2500	TU GD GJ SU WG HA IL
<i>Polyscias farinosa</i>	Araliaceae	Tree	VU	1600_2200	TU GD GJ SU KF
<i>Scadoxus nutans</i>	Amaryllidaceae	Herb	NE	1450_2300	IL KF
<i>Solanecio gigas</i>	Asteraceae	Shrub	LC	1750_3350	GD GJ WU SU AR SD IL KF BA HA
<i>Tiliacora troupinii</i>	Menispermaceae	Liana	NE	1500_2100	SU IL KF SD
<i>Urtica simensis</i> ^{*a}	Urticaceae	Herb	LC	1500_3400	TU GD GJ SU AR BA SD
<i>Vepris dainellii</i>	Rutaceae	Ttree	LC	1750_2500	GJ SU WG IL KF SD BA
<i>Vernonia rueppellii</i> ^{*a}	Asteraceae	Shrub	LC	2150_3000	TU GD SU AR SD KF BA HA

* Source: [22, 23, 24, 25, 26, 27, 28, 29, 30, 37]; ^{*a} New records for IL Floristic Region *LC, Least Concern; NE, Not evaluated; NT, Near Threatened; VU, Vulnerable.

3.2 Community types and indicator species

Five community types were derived from the hierarchical cluster analysis in combination with Multi-response Permutation Procedures (MRPP) and objective method of the whole data set (Figure 3). From the output of MRPP, the test statistic T value for the five groups was -38.26 ($P < 0.001$) and the agreement statistic A was 0.13 while the output of objective method revealed a sharp bend at the fifth cluster.

Community 1 (*Croton macrostachyus* - *Bersama abyssinica* community) was found in the altitudinal range of 1677-2020 m. a.s.l and slope from flat to 50%. Fourteen plots were associated with the community and has 2 indicator species with significant indicator values ($P < 0.05$).

Community 2 (*Syzygium guineense* - *Olea capensis* community) was distributed from 1699 to 2240 m a.s.l. and slope ranging from flat to 60%. It comprises of 22 plots and twenty species were associated with this community as indicator species where one of the indicator species exhibit significant indicator values ($P < 0.05$). **Community 3 (*Dracaena afromontana*- *Pouteria adolfi-friederici* community)** was found in the altitudinal range of 1761-2000 m. a.s.l and slope from flat to 25%. Thirteen plots were associated with the community community and seven species were associated with this community as indicator species while two of the indicator species showed significant indicator values ($P < 0.05$).

Table 2. Synoptic cover value of plant for species reaching $\geq 1\%$ in at least one community.

Cluster number	C1	C 2	C 3	C 4	C 5
Cluster size	14	22	13	14	27
<i>Allophyllus abyssinicus</i>	3.50	1.05	1.15	0.86	1.26
<i>Bersama abyssinica</i>	3.71	1.73	0.08	0.64	1.22
<i>Croton macrostachyus</i>	7.50	1.77	1.54	1.79	2.48
<i>Cordia Africana</i>	2.79	0.55	0.00	0.00	0.63
<i>Olea welwitschii</i>	1.43	1.27	0.15	0.86	0.56
<i>Ehretia cymosa</i>	2.36	2.55	1.92	0.79	1.63
<i>Polyscias fulva</i>	1.64	1.36	1.85	0.93	1.33
<i>Apodytes dimidiata</i>	1.43	2.41	1.54	1.64	0.93
<i>Olea capensis</i>	3.14	5.59	1.54	1.93	1.04
<i>Syzygium guineense</i>	0.64	5.91	1.69	2.43	1.56
<i>Justicia schimperiana</i>	1.29	1.68	0.85	0.36	0.93
<i>Canthium oligocarpum</i>	0.29	1.05	0.62	0.50	0.52
<i>Cassipourea malosana</i>	0.79	1.55	1.08	0.43	0.56
<i>Combretum paniculatum</i>	0.86	1.14	0.54	0.43	1.04
<i>Dracaena steudneri</i>	1.29	3.09	0.92	1.50	1.22
<i>Elaeodendron buchananii</i>	0.64	1.00	0.38	0.00	0.37
<i>Oplismenus hirtellus</i>	2.43	4.50	3.00	2.64	2.85
<i>Rothmannia urcelliformis</i>	1.14	1.95	0.77	0.86	1.15
<i>Sapium ellipticum</i>	0.21	1.64	0.00	1.43	0.93
<i>Tectaria gemmifera</i>	0.93	1.36	1.23	1.29	0.81
<i>Brillantaisia madagascariensis</i>	1.43	2.73	3.00	2.79	2.48
<i>Dracaena afromontana</i>	1.00	3.05	7.69	0.86	0.78
<i>Ficus sur</i>	2.50	1.68	6.77	2.07	1.37
<i>Galiniera saxifrage</i>	1.00	1.05	2.31	1.43	1.56
<i>Hallea rubrostipulata</i>	1.07	0.00	1.31	0.00	0.00
<i>Macaranga capensis</i>	1.21	1.32	2.85	0.71	0.19
<i>Oxyanthus speciosus</i>	1.29	1.73	7.01	2.36	1.56
<i>Pouteria adolfi-friederici</i>	2.21	3.05	7.31	2.07	1.26
<i>Acanthopale ethio-germanica</i>	1.36	0.77	2.08	2.43	1.96
<i>Deinbollia kilimandscharica</i>	0.57	1.45	2.62	4.07	1.59
<i>Ilex mitis</i>	0.43	0.59	1.31	4.71	0.44
<i>Justicia bizuneshiae</i>	0.50	1.23	1.31	1.71	1.37
<i>Landolphia buchananii</i>	1.00	1.32	0.85	1.43	1.19
<i>Piper capense</i>	1.00	0.55	0.46	1.43	1.07
<i>Psychotria orophila</i>	0.93	1.36	0.85	1.36	0.85
<i>Pupalia micrantha</i>	0.64	1.36	0.23	1.86	0.93
<i>Schefflera abyssinica</i>	0.50	1.73	1.38	7.29	1.33
<i>Tiliacora troupinii</i>	1.00	1.23	1.08	1.29	1.07
<i>Vepris dainellii</i>	2.21	3.36	3.00	8.43	3.59
<i>Albizia gummifera</i>	3.07	2.50	2.69	2.07	8.63
<i>Clausena anisate</i>	1.79	1.86	1.31	1.43	2.11
<i>Hippocratea pallens</i>	0.64	1.91	1.23	1.50	1.93
<i>Lepidotrachelia volkensii</i>	0.57	2.59	1.23	2.43	3.30
<i>Maytenus gracilipes</i>	2.00	1.82	1.08	2.00	2.30
<i>Millettia ferruginea</i>	2.00	2.95	2.54	2.79	7.89

Community 4 (*Vepris dainellii* - *Schefflera abyssinica* community) was distributed in the altitude range of 1720–2060m a.s.l. and the slope gradient varies flat to 60%. It comprised of 14 plots, eight species were associated with this community as indicator species, while four of the indicator species exhibited significant indicator values ($P < 0.05$).

Community 5 (*Albizia gummifera* - *Millettia ferruginea* community) was found in the altitudinal range of 1728-2014 m. a.s.l and slope from flat to 50%. Twenty-seven plots were associated to the community. Eight species are associated with this community as indicator species and four of the indicator species exhibited significant indicator values ($P < 0.05$).

Table 3. Indicator species of clusters in Gerba Dima forest with their significant P-value

Name of indicator species	Community type (C)	Indicator value	P-value
<i>Prunus africana</i>	1	0.528	0.018 *
<i>Rubus apetalus</i>	1	0.516	0.017 *
<i>Flacourtia indica</i>	2	0.521	0.02 *
<i>Pilea rivularis</i>	3	0.498	0.016 *
<i>Elastostema monticolum</i>	3	0.467	0.039 *
<i>Ritchiea albersii</i>	4	0.861	0.001 ***
<i>Trema orientalis</i>	4	0.677	0.001 ***
<i>Sapium ellipticum</i>	4	0.636	0.002 **
<i>Vernonia hochstetteri</i>	4	0.538	0.014 *
<i>Zehneria scabra</i>	5	0.581	0.002 **
<i>Zehneria minutiflora</i>	5	0.552	0.005 **
<i>Urera hypselodendron</i>	5	0.478	0.017 *
<i>Vernonia wollastonii</i>	5	0.423	0.045 *

(C1= *Croton macrostachyus* - *Bersama abyssinica*, C2= *Syzygium guineense* - *Olea capensis*, C3 = *Dracaena afromontana*- *Pouteria adolfi-friederici*, C4= *Vepris dainellii*- *Schefflera abyssinica* C5 = *Albizia gummifera* - *Millettia ferruginea* community.

From computation of vegetation data in the study area Shannon-Weiner diversity and evenness, indices for the five community types showed the output in Table 4.

Table 4. Species richness, evenness and diversity indices of plant community types

Community	Species richness	Shannon diversity index (H')	Shannon Evenness
1	138	4.40	0.89
2	144	4.27	0.86
3	107	3.99	0.85
4	104	4.05	0.87
5	140	4.19	0.85

3.3 Relationship between community types and environmental factors

Heterogeneity or homogeneity of vegetation data test using DCA resulted in short length (gradient) of DCA first axis i.e., < 3 (2.22) which indicate the presence of lower species turnover or homogeneous vegetation data due to the linear relationship between species and environmental variables. The result of Monte test showed that out of 14 environmental variables, seven were found to be significant in explaining patterns of plant community distribution. From the seven significant environmental factors, the vif values of sand and silt were higher than 5. Sand and Silt are highly correlated with at least one of the other variables in the model. One solution in dealing with collinearity is to remove some of the violating variables from the model and thus the one with higher vif value (sand) was eliminated. The result of RDA ordination showed that comparatively, the gradient of altitude and potassium was highly correlated on axis one and gradient of disturbance in axis two. The other factors were correlated with

the five axes with a different value of correlation. The eigenvalue for axis one, two and three were 10.65, 8.06, and 6.32 respectively which shows a decline to the successive higher axis. Cumulative proportion variance explained by the first five RDA axis of the joint biplot was 93.9%. The proportion of variation explained by five RDA axis also shows a decline towards the successive higher axis (Table 5).

Table 5. Biplot score for constraining variables and their correlation with the RDA axis, eigenvalues and proportion of variance explained

Environmental variables	RDA1	RDA2	RDA3	RDA4	RDA5
Disturbance	0.089	-0.68	-0.157	0.522	0.453
Altitude	0.880	0.42	-0.054	-0.018	0.218
SILT	0.084	-0.40	-0.361	-0.323	-0.370
EC	-0.053	0.31	-0.867	0.094	-0.023
OM	-0.094	0.27	-0.208	-0.357	0.844
K	0.703	-0.27	-0.003	-0.381	-0.246
Eigenvalue	10.6445	8.0649	6.3168	5.0057	3.02318
Proportion Explained	0.3024	0.2291	0.1794	0.1422	0.08588
Cumulative Proportion	0.3024	0.5315	0.7109	0.8531	0.93902

RDA ordination of the study plots of Gerba Dima forest formed five groups or community based on the species composition. These five community types were segregated following the arrows of the environmental variables. Community two mostly occur at the higher altitude while species in community one are distributed at the lower altitude and higher EC. Silt, Disturbance and potassium axes were strongly influencing the distribution of community five. Organic matter arrow has strongly influenced the distribution of species in community three and four (Figure 4). The ANOVA test indicated that the five community types differ significantly from each other with regard to EC and K. The result of Tukey's pair-wise comparison test indicates that community 4 and 1 differ significantly with respect to Disturbance and K while community 2 and 3 showed significant differences with respect to EC.

4. Discussion

4.1 Floristic Composition and Diversity of Gerba Dima forest

The existence of diversified flora of Gerba Dima forest was in line with the general pattern of high species diversity in the tropical montane forests. According to [38], tropical forests are among ecosystems that harbour high species diversity of the globe. East African montane forests of Ethiopia, Kenya, Tanzania and Uganda are among the most diverse and richest African regions with regard to flora composition and endemic plant taxa [39, 40, and 41]. Asteraceae, Acanthaceae, Rubiaceae, Fabaceae and Euphorbiaceae are the five dominant families, which contribute more than 27% of the total species in the study forest. These dominant families were also reported as top ten species rich families in many Neotropical forests and Asia [38]. Except for Rubiaceae, these families are also among the top ten species rich families in the flora area [42]. The dominance of the above families together with Rubiaceae was also reported in other moist afro-montane forests of southwestern Ethiopia [43, 44, and 45]. Thus, the dominance of these families in the Gerba Dima forest agreed to their general dominance in the flora area and tropical forests. The dominance of these families in the study area could be attributed to their successful colonization to the land escape owing to their efficient pollination, dispersal and germination mechanisms. For instance, many species of Asteraceae have umbrella shape structures adapted for air dispersal and increase their opportunity for their successful establishment [46].

Among the growth forms, herbs constitute more than 42% of recorded species. The prevalence of herbs could be attributed to the presence of canopy gap because of anthropogenic disturbance. Disturbance of forest in the form of

selective cutting of trees favours the growth of herbaceous species in the forest understory. Under normal circumstances, the forest floor (herbaceous layer) of Afromontane rainforests is usually dark and poor in species composition owing to the closed canopy of the forest that prevents light from reaching the ground [47].

The higher value of Shannon diversity index and evenness indicates that the study forest has high species diversity with more even distribution of the species within the study plots. Species diversity increases when the populations have more even abundances and vice versa [3]. High Shannon evenness in the Gerba Dima forest indicates little dominance by any single species but the repeated coexistence of species over all the plots or sites. Therefore, the implication of evenness values is that, when there is a high evenness value in a given forest, the location of conservation sites might not be of much importance compared to when the evenness value of the forest is low

4.2 Plant community types in Gerba Dima forest

The output of Multi-response Permutation Procedures (MRPP) conducted in R software, resulting in T statistics having more negative value with significant P-value ($T = -38.26$, $P < 0.001$) and an agreement statistic A (0.13) confirming the distinctness of clusters. The test statistic T describes the separation between the groups. The more negative T value, the stronger the separation. The P-value associated with T is determined by numerical integration of the Pearson type III distribution. The P-value is useful for evaluating how likely an observed difference is due to chance [48]. The agreement statistic A describes within-group homogeneity, compared to the random expectation, and falls between 0 and 1. When all items within-groups are identical $A = 1$ and 0 if the groups are heterogeneous. In community ecology, A values are commonly below 0.1, and an A value greater 0.3 is high [48]. From the result of this study, the null hypothesis of no difference among groups can be rejected. The five groups occupy different regions of species space, as shown by the strong chance correction within the group (A) and test statistic (T) and thus confirm the existence of 5 distinct plant communities in the Gerba Dima forest. The five plant communities showed a slight variation in their species richness, diversity and evenness. Relatively community types 1, 2 and 5 were the richest with respect to species richness and diversity while community types 3 and 4 the lowest. The differences in species richness among the five communities could mainly be attributed to the dissimilarities of the communities in terms of location, altitude, human impact, rainfall, and other biotic and abiotic factors. According to [49], different altitudes and slopes influence species richness and dispersion behaviour of tree species. Altitude and climatic variables like temperature and rainfall are also other determinant factors that affect species richness [50].

4.3 Plant community – Environmental variables relationship

In the current study, the multivariate analyses (both Ordination and cluster analysis) were consistent in showing the patterns of floristic grouping within the studied forest and hence the two methods are complementary. In the Gerba Dima forest, the variation of plant communities was closely related to environmental factors, including Altitude, disturbance, Silt, Electrical conductivity, Organic matter, and Potassium, among which Altitude was the most important one. From the result of the RDA ordination, it has been found that most of the variation in the pattern of plant distribution was explained by the RDA axis one. The eigenvalue for axis one was 10.65, which was higher than the eigenvalue of the second and successive higher axis. The cumulative proportion variance explained by the first five RDA axis of the joint biplot was 93.9%. From the proportion of variation explained by five RDA axes, more than 53.15% was explained by axis 1 and 2. This indicated that both axes explained most of the variation in patterns of plant species distribution and plant community formation. Axis one explained more than 30.24% of the variation in the patterns of plant species distribution and community formation, followed by axis two (22.91%) and the importance of higher axis in explaining the variation decreased successively.

The variable with the highest score (0.88) associated with axis one was the altitude. Therefore, altitude was the most important variable in weighting axis one and to interpret or explain the axis. Similar studies conducted in other

Afromontane forests of Ethiopia also confirm the importance of altitude as a major determinant of vegetation distribution along altitudinal gradients [51, 52, and 53]. Altitudinal change leads to changes in humidity, temperature, soil type, and other factors that influence the growth and development of plants which in turn determine the patterns of vegetation distribution [54, 55].

Potassium followed by altitude was also the most important constraining variable in weighing axis one in the ordination. In the sandy soil, plant-soil feedback effects were most strongly correlated with potassium. Although most studies investigating abiotic plant-soil interactions have focused on nitrogen and phosphorus dynamics, in sandy soils with little clay content, potassium could be a limiting factor for plant growth [56, 57]. In particular, a growth of forbs can be highly dependent on potassium [56] and hence potassium at least affects the distribution of these species. In the same way, the disturbance was the most important variable in weighting axis two. Disturbance affects the distribution of plant communities by hampering natural regeneration and seedling establishment in tropical forests [58]. Disturbance also favours the growth of herbaceous plant species by improving the availability of light conditions in the ground layer as it widens the canopy gap [59] and thus affects the distribution of communities with these species. An analysis of variance (ANOVA) performed to see any significant variation among the community types of Gerba Dima forest with respect to non-collinear significant environmental variables indicated that the five community types differ significantly from each other with regard to EC and K. Similarly, result of Tukey's pair-wise comparison test indicates that community 4 and 1 differ significantly with respect to Disturbance and K while community 2 and 3 showed significant difference with respect to EC.

5. Conclusions

Description of the floristic diversity of species in the Gerba Dima forest revealed the presence of high species diversity and richness. Of the species recorded in this forest, 15 (8.3%) species were endemic to Ethiopia. However, the percentage of endemic species in the study forest is lower than the proportions generally expected in the Afromontane forest of Ethiopia and this is attributed to the low endemism feature of forests in South-western Ethiopia. In this study, five community types were identified and altitude was the major environmental variable in determining the community types. The existence of high species diversity and a number of endemic plant species in the study forest shows the potential of the area for biodiversity conservation. Thus, all Stakeholders including Oromia Forest and wildlife enterprise (OFWE) and the regional government should work to designate the forest as a biosphere reserve and being registered under UNESCO.

Declarations

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Authors Contribution

All authors have made substantive intellectual contributions to this manuscript. AD is made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data and also been involved in drafting the manuscript or revising it critically for important intellectual content. TS is also made substantial contributions to conception and

design of data, or analysis and interpretation of data but not involved in data collection or acquisition of data. BW has been involved in drafting the manuscript or revising it critically for important intellectual content. All authors read and approved the final manuscript.

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Availability of data and materials

We have also included part of the data used in this research and attached as Additional files 1 and 2.

Ethics approval and consent to participate

This research is mainly an ecological and study and did not involve experiment on plant species. Thus, Parts related to Ethics approval and consent to participate is not applicable for this work. Related to this part, the collected plant specimens in this research were deposited in the national herbarium of Ethiopia. However, experiment was not conducted on the plant. Permissions were needed and subsequently obtained From Oromia Forest and Wildlife Enterprise in order to use/sample the land as described, and obtain samples

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

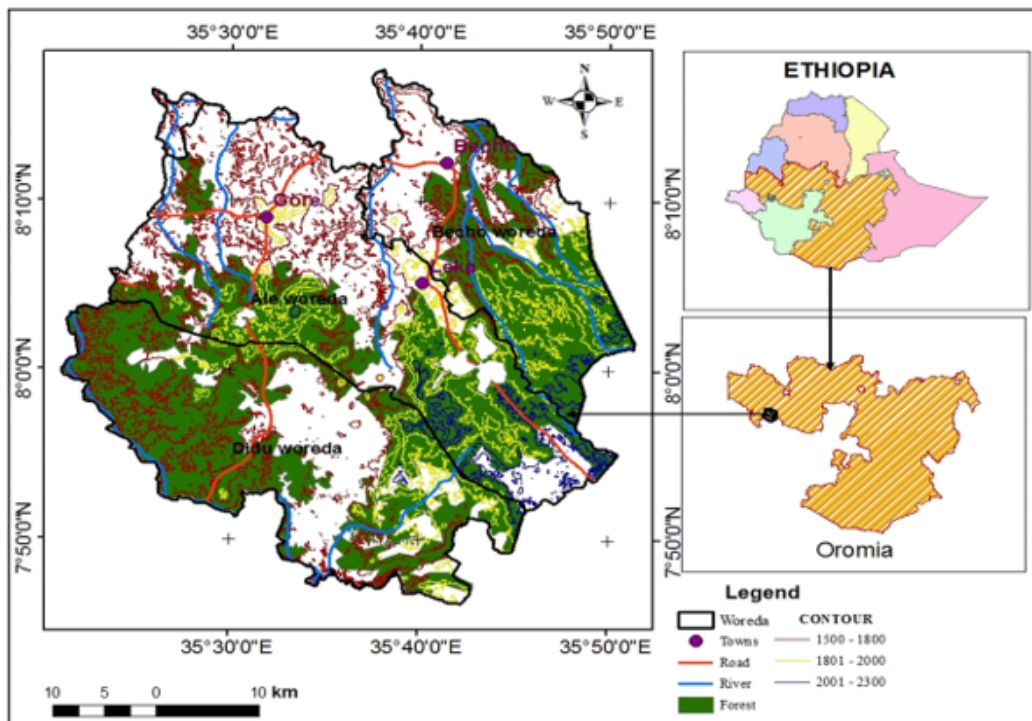


Figure 1

Map of the study area

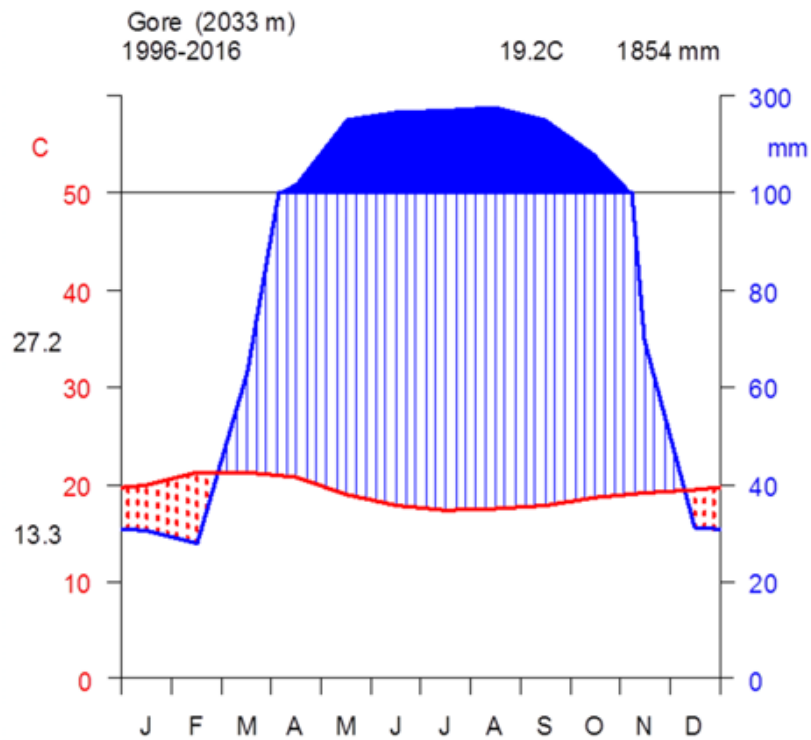


Figure 2

Climate diagram of Gore (Source: [20])

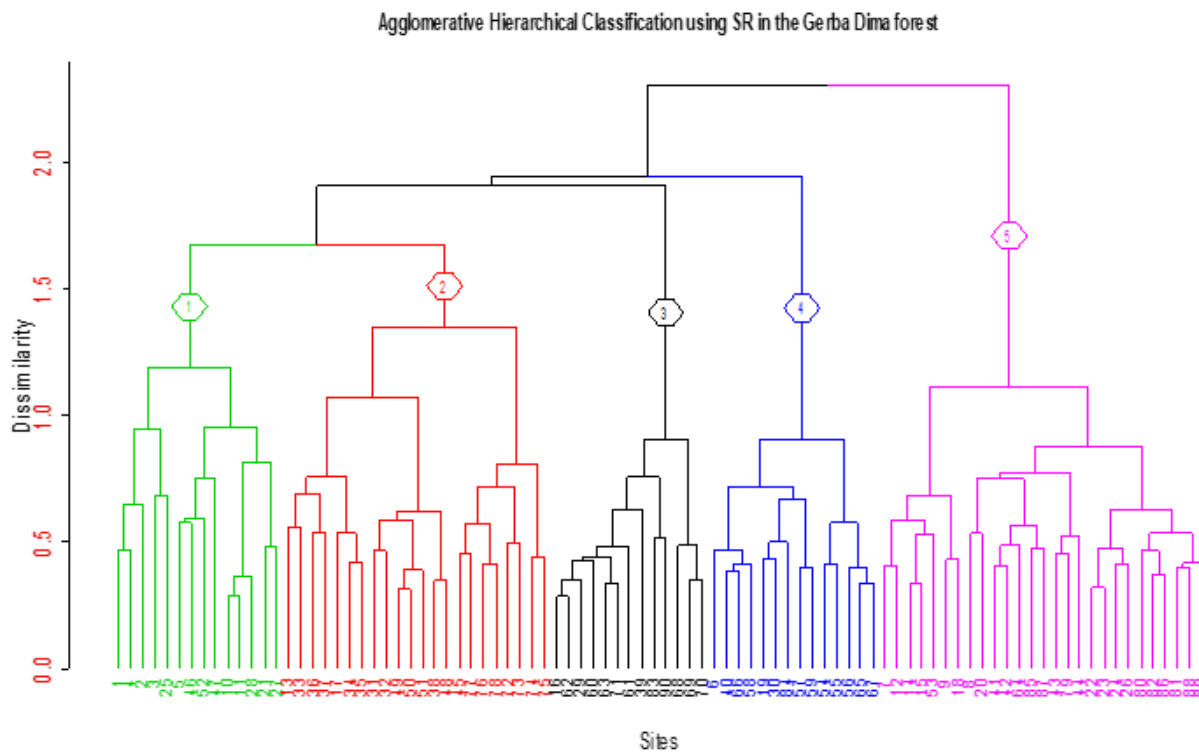


Figure 3

Dendrogram of the cluster analysis results of species abundance found in 90 plots. The plot code and the arrangement of the plots along the dendrogram from left to right are as follows:(1= *Croton macrostachyus* - *Bersama abyssinica*, 2=

Syzygium guineense - Olea capensis, 3 = Dracaena afromontana- Pouteria adolfi-friederici, 4= Vepris dainellii- Schefflera abyssinica 5 = Albizia gummifera - Millettia ferruginea community.

RDA Scaling = 1

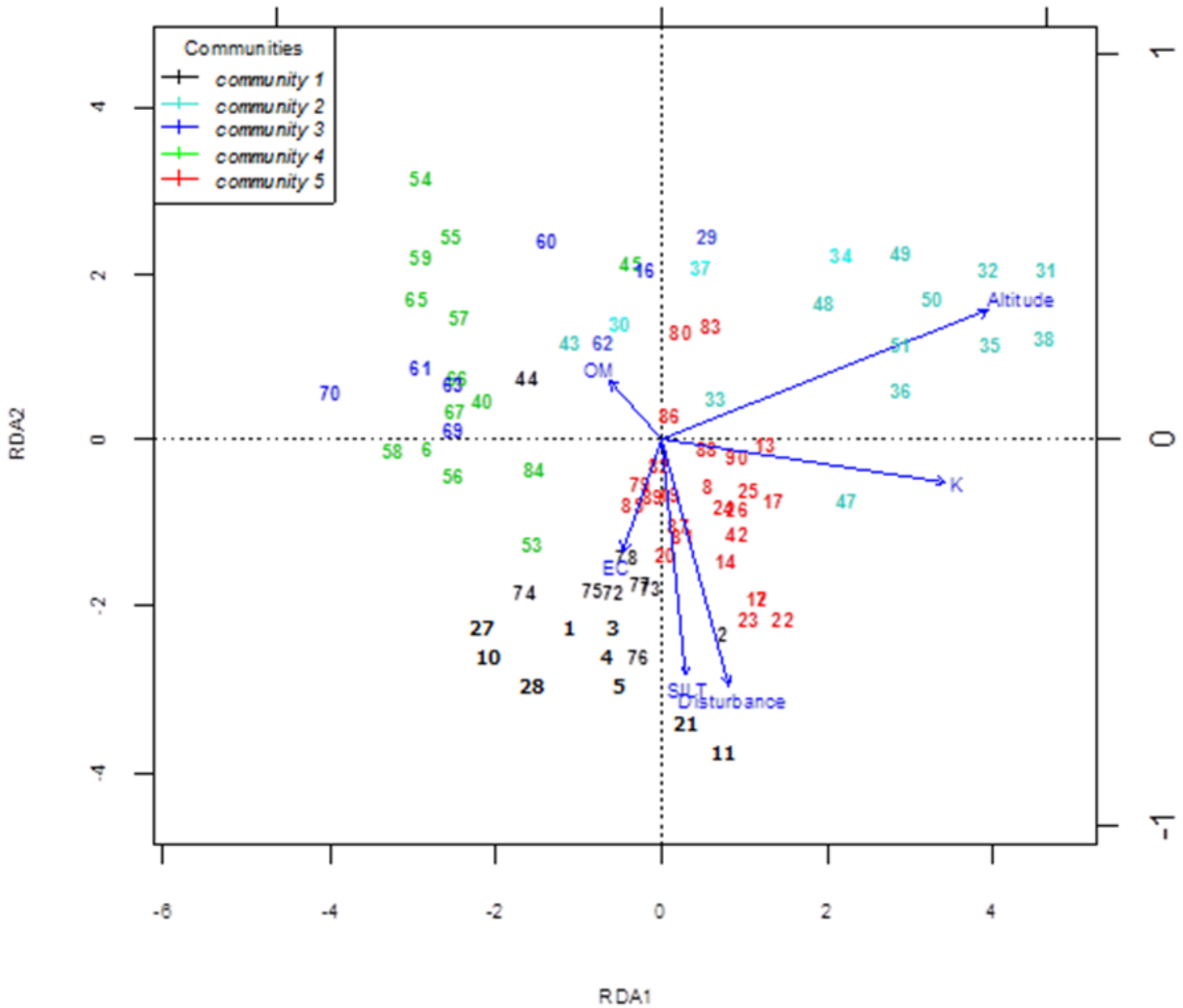


Figure 4

RDA ordination biplot of 90 quadrats and 6 environmental variables of plant communities

Supplementary Files

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