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Plant community analysis along environmental gradients in moist afro-montane 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. Identifying and interpreting the structure of species assemblages is the main goal of plant community ecology. Investigation of forest community composition and structure is very useful in understanding the status of tree population, regeneration, and diversity for conservation purposes.

Method: 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 × 25 m plots. 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. 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. 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. 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 Electrical Conductivity and Potassium.

Conclusions: Description of floristic diversity of species in Gerba Dima forest revealed the presence of high species diversity and richness. The presence of endemic plant species in the study forest shows the potential of the area for biodiversity conservation.

Keywords: Gerba Dima, Indicator species, Moist afro-montane forest, Species diversity
presence/absence or abundance data are commonly employed to evaluate community structure [1]. Legendre [2] distinguished between ‘true gradients’ in species composition, which are induced by environmental gradients, and ‘false gradients,’ which may arise even in the absence of environmental heterogeneity as a result of biotic interactions within the community. Both true and false gradients may form distinct spatial patterns when mapped into geographic space. According to Seabloom et al. [3], different ecological processes create distinct spatial patterns, so that specific processes could be identified from their spatial signature. Hence, spatial analysis of community structure is of direct scientific interest, because spatial structures may be critical for identifying and understanding the underlying ecological processes [4]. Biotic filters determining limiting similarity is the assumed cause for species dissimilarity in traits within communities. Symmetric competitive interactions might indeed lead to the co-existence of ecologically distinct species, which minimize competition for shared resources (“symmetric competition” leading to limiting similarity [5]).

The quest to explain the underlying processes for the assembly of local communities is still a major focus in plant community ecology, as researchers keep examining them through both observational and experimental studies [6]. The multidimensional ecological niche space determines the distribution of a species within a community [7]. Physiographic and edaphic factors can determine which plant species will colonize a site since plant species vary in their tolerance and utilization of resources site [8]. These variations have been regarded as a driving force for the coexistence of species in a similar environment [9] and can explain broad-scale compositional differences among multiple resource gradients [10, 11]. The upper storey tree density as an abiotic factor can also affect community composition as understorey species differ in their ability to tolerate stresses imposed by competitive trees [12, 13]. Moreover, by increasing the abundance of annual and biennial plants, disturbances can affect community composition via favouring stress-tolerant species [13, 14].

Information on species composition and diversity of tree species plays a pivotal role not only to understand the structure of a forest community but also in planning and implementation of conservation strategy of the community.

The recent data on forest resources of Ethiopia reported in FAO [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, species diversity, community types and to relate the distribution of plant community types to some environmental parameters.

**Methods**

**The study area**

This study was carried out in the Gerba Dima forest found in the Illu Aba Bora zone of Oromia regional state of Ethiopia and located between 7° 45’ to 8° 10’ North latitude and 35° 29’ to 35° 50’ East longitude. The study forest is bounded by Baro River to the south and west direction whiles three other rivers, namely Bote, Hoyi and Sor cross part of the forest in the east (Fig. 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 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 1854 mm 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 [20].

The vegetation type at Gerba Dima is part of the moist evergreen afromontane forest with characteristic emergent species that form the upper canopy includes *Pouteria adolfi-friederici* (Fig. 2). *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 [21].
**Sampling method**

In this study, a stratified random sampling design was used to collect vegetation and environmental data [1, 22]. 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 and 1800 m altitudinal ranges whereas strata two and three were found between 1801–2000 m and 2001–2300 m altitudinal ranges respectively (Fig. 1). Sample plots were assigned in each contour in the form of Random points Using Arc GIS version 10.3 (Fig. 3).
Ninety sample plots having a size of 25 × 25 m (625 m²) 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 ≥ 1.5 m were recorded in 25 m × 25 m plots. Within the major plots, five 3 m × 3 m subplots (9 m²) was used to collect shrubs with dbh < 2.5 cm and > 1.5 m height. Within each 9 m² subplots, two 1 m² 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 [23]. 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 [24–32].

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 Woldu [33], 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 [34]. 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 40 cm depth within 1 m × 1 m 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 Addis Ababa University (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 [35]. 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 Bouycous 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.

**Data analysis**

In this study, hierarchical (agglomerative) cluster analysis was performed using the free statistical software R version 3.6.1 [36] 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. The T and A statistic of MRPP output were used to obtain the number 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 [37]. 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 fairly high [37].

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 [38]. 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 [39]. 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 [36]. The Shannon diversity index (H') was calculated from the equation:

\[
H' = - \sum_{i=1}^{s} p_i \ln p_i
\]

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 [1, 39]. The Shannon evenness index (J) was calculated from the ratio of observed diversity to maximum diversity using the equation:

\[
J = \frac{H'}{H_{max}} = \frac{H'}{\ln s}
\]

where \( H_{max} \) 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 [40].

Information about endemic species, their habit, IUCN status and geographical distributions was determined by referring to [25–33, 42].

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.

**Results**

**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 (Table 1). 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 Afromomum, Albizia, Asparagus, Cyperus, Euphorbia, Hippocratea, Hypoestes, Justicia, Maytenus, Olea, Peperomia, Polyris, Pteris, Rubus, Schefflera, Solanecio, 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 a total of 15 endemic plant species in 11 families were recorded (Table 2), comprising more than 8.33% of the recorded species. Asteraeaceae 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 3, 4, 3, 2 species respectively. Out of the 15 endemic species, Croton macrostachyus and Polyscias farinosa have been included in the IUCN red data list of Ethiopia and Eritrea qualifying for near threatened and vulnerable category respectively. In the Gerba Dima forest, at 625 m² 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.

**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 (Fig. 4 and Table 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 Α 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) (Table 4).

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) (Table 4).

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 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 4).

Community 4 (Vepris dainelli—Schefflera abyssinica community) was distributed in the altitude range of 1720–2060 m 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) (Table 4).

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 with 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 4).

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 5.

**Relationship between community types and environmental factors**

Heterogeneity or homogeneity of vegetation data test using DCA resulted in short length (gradient) of DCA
| No | Scientific names                        | Family    | Local names\(^a\) | Habit | Voucher No. |
|----|----------------------------------------|-----------|-------------------|-------|-------------|
| 1  | Acanthopale ethio-germanica Ensermu    | Acanthaceae| Dargu            | S     | AD005       |
| 2  | Acanthus eminens C. B. Clark           | Acanthaceae| Qosambe booyee    | S     | AD107       |
| 3  | Acrithispora aspera L                  | Acrithisporaceae| Maxxane       | H     | AD160       |
| 4  | Achyrospermum schimperi (Hochst. ex Briq.) Perkins | Lamiaceae | –                 | H     | AD134       |
| 5  | Adiantum poiretii Wickstr              | Adiantaceae|                  |       | AD120       |
| 6  | Aerangia brachycarpa (A. Rich) Th Dur & Schinz | Orchidaceae | –                 | H     | AD062       |
| 7  | Aframomum coromina (Braun)ansen       | Zingiberaeae| Ogiyo            | H     | AD045       |
| 8  | Aframomum zambesiacaum (Baker) K. Schum| Zingiberaeae| Ogiyo jaldessa    | H     | AD006       |
| 9  | Ageratum conyoides L                  | Asteraceae | –                 |       | AD038       |
| 10 | Ajuga sp. (==Friis et al. 1456)       | Lamiales   | Gondii           | H     | AD118       |
| 11 | Alangium chinense (Lour.) Harms        | Alangaceae | Hudu fardaa/endo  | T     | AD007       |
| 12 | Albizia gummifera (J. F. Gmel.) C. A. Sm. | Fabaceae | Ambabbessa dhalu  | T     | AD078       |
| 13 | Albizia schimperiana Olivi             | Fabaceae   | Ambabbessa kormaa | T     | AD009       |
| 14 | Alchemilla abyssinica Fresen           | Rosaceae   | Korbesso         | H     | AD013       |
| 15 | Allaphyllum abyssinicum (Hochst.) Radlak| Zingiberaeae| –                 | H     | AD179       |
| 16 | Antrophyum mannanium Hook              | Vittariaceae| Gixoo            | H     | AD082       |
| 17 | Apodytes dimidiata E. Mey. ex Arn     | Icacinaceae| Wandabiyo        | T     | AD123       |
| 18 | Aniska maconyeanum Gilbert & Mayo      | Araceae    | Kiicu            |       | AD144       |
| 19 | Asparagus africana L                   | Asparagaceae| Sariti          | H     | AD165       |
| 20 | Asparagus flagellaris (Kunth) Baker    | Asparagaceae| Sariti          | H     | AD180       |
| 21 | Asparagus setaceus (Kunth) Jessop      | Asparagaceae| Sariti          | H     | AD174       |
| 22 | Asplenium aethopicum (Burm.f) Bech    | Aspleniaceae| –                 | H     | AD179       |
| 23 | Asplenium bogoense Hieron             | Aspleniaceae| Gixoo            | H     | AD143       |
| 24 | Asplenium elliptii C. H. Wright,      | Aspleniaceae| Gixoo            | H     | AD122       |
| 25 | Asplenium erectum Bory ex Wild        | Aspleniaceae| –                 | H     | AD101       |
| 26 | Asplenium sandersonii Hook            | Aspleniaceae| Gixoo            | H     | AD083       |
| 27 | Asplenium warnetki Hieron             | Aspleniaceae| Gixoo            | H     | AD042       |
| 28 | Asplenium warnetki Hieron             | Aspleniaceae| Gixoo            | H     | AD042       |
| 29 | Asplenium warnetki Hieron             | Aspleniaceae| Gixoo            | H     | AD042       |
| 30 | Astra stabifera Hook                  | Aspleniaceae| –                 | H     | AD101       |
| 31 | Astra stabifera Hook                  | Aspleniaceae| –                 | H     | AD101       |
| 32 | Astra stabifera Hook                  | Aspleniaceae| –                 | H     | AD101       |
| 33 | Canthium oligocarpum Hiern            | Rubiaceae  | Mixo             | S     | AD029       |
| 34 | Cassiopea malosana (Baker) Alston      | Rhizophoraceae| Loko            | T     | AD046       |
| 35 | Cayratia gracilis (Guill. & Perr.) Suesseng | Vitaceae  | Kalaaza qamale  | H     | AD093       |
| 36 | Celtis africana Burm. f                | Ulmaceae   | Ceyyi            | T     | AD015       |
| 37 | Chionanthus mildbraedii (Gig. & Schellenb.) Stearn | Oleaceae | Kara waayyyu    | T     | AD004       |
| 38 | Cissampelos mucronata A. Rich         | Menispermaceae| –                 | L     | AD008       |
| 39 | Clausena anisata (Wild.) Benth        | Rutaceae   | Ulmaayye         | S     | AD087       |
| 40 | Cleomis paniculatum Vent              | Combreataceae| Bagge          | L     | AD177       |
| 41 | Convolvulus ramosa (Burm.) Varlee     | Convolvulaceae| Qorxabo        | H     | AD161       |
| 42 | Convolvulus ramosa (Burm.) Varlee     | Convolvulaceae| Qorxabo        | H     | AD161       |
| 43 | Cordia africana Lam                   | Boragineae | Waddessa        | T     | AD110       |
| 44 | Crotalaria rosenii (Pax) Milne-Redh. ex Polhill | Fabaceae | Cekkaa          | H     | AD147       |
| 45 | Crotalaria rosenii (Pax) Milne-Redh. ex Polhill | Fabaceae | Cekkaa          | H     | AD147       |
| 46 | Cucurbita erecta Ehreng. ex Spach     | Cucurtitaeeae| Umbaajo       | H     | AD036       |
| No | Scientific names                      | Family          | Local names*         | Habit | Voucher No. |
|----|---------------------------------------|-----------------|----------------------|-------|-------------|
| 50 | Culcasia falcifolia Engl              | Araceae         | Qasso                | H     | AD077       |
| 51 | Cyathea manniana Hook                | Cyatheaceae     | Sesino               | T     | AD074       |
| 52 | Cyperus fischerianus A. Rich         | Cyperaceae      | Qunni                | H     | AD126       |
| 53 | Cyperus longus L                     | Cyperaceae      | –                    | H     | AD011       |
| 54 | Dalbergia lactea Vatke               | Fabaceae        | Sarxe dhittaa        | S     | AD018       |
| 55 | Deinbollia klimandscharica Taub      | Sapindaceae     | Qaso                 | T     | AD017       |
| 56 | Desmodium repandum (Vahli)DC         | Fabaceae        | Maxanne              | H     | AD033       |
| 57 | Didymochlaena truncatula (Sw.)Sm     | Dryopteridaceae | –                    | H     | AD035       |
| 58 | Dombeya torrida (J.F. Gmel.) PBamps  | Sterculiaceae   | Daanisa              | S     | AD034       |
| 59 | Doryopteris concolar (Langsd & Fisch.) Kuhn in von der Deck ef. | Dryopteridaceae | –                    | H     | AD051       |
| 60 | Draecena afromontana Mildbr          | Dracenaceae     | Sarxe                | T/S   | AD072       |
| 61 | Draecena fragrans (L.) Ker Gawl      | Dracenaceae     | Sarxe                | S     | AD090       |
| 62 | Draecena steudneri Engl              | Dracenaceae     | Sarxe                | T     | AD108       |
| 63 | Dryania volkensii Hieron             | Polypodiaceae   | Baleessa             | H     | AD012       |
| 64 | Ehretia cymosa Thonn                 | Boragineaceae   | Ulaagaa              | T     | AD026       |
| 65 | Ekebergia capensis Sparrm            | Meliaceae       | Sombo                | T     | AD061       |
| 66 | Eleoedromon buchanani (Loes.) Loes   | Celastraceae    | Waasso               | T     | AD167       |
| 67 | Elastostema monticolum Hook.f        | Urticaceae      | –                    | H     | AD162       |
| 68 | Ensete ventricosum (Welw.) Cheesman  | Musaceae        | Eeppo                | H     | AD171       |
| 69 | Erythrococca trichogyne (Muell. Arg.) Prain | Euphorbiaceae | Caakkoo              | T/S   | AD032       |
| 70 | Euphorbia ampliphylia Pax            | Euphorbiaceae   | Adaami               | T     | AD040       |
| 71 | Euphorbia schimperiana Schelle        | Euphorbiaceae   | Ananno               | S     | AD064       |
| 72 | Ficus exasperata Vahl                | Moraceae        | Baalaantaayii        | T     | AD068       |
| 73 | Ficus ovata Vahl                     | Moraceae        | Qiblu                | T     | AD065       |
| 74 | Ficus sur Forssk                     | Moraceae        | Harbu                | T     | AD073       |
| 75 | Ficus thonningii Blume               | Moraceae        | Dambii               | T     | AD136       |
| 76 | Flacourtia indica (Burm.f) Merr      | Flacourtiaceae  | Akuku                | T     | AD139       |
| 77 | Galinia saxifraga (Hochst.) Bridson   | Rubiaceae       | Simararu             | T     | AD137       |
| 78 | Glycine wightii (Wight & Am) Verde    | Fabaceae        | Kalaala              | H     | AD170       |
| 79 | Gouania longispicata Engl            | Rhaminaceae     | Hidda reffaa         | L     | AD020       |
| 80 | Hallia rubrostipulata (K. Schum.) J.-F. Leroy | Rubiaceae | Oobo/Bootto          | T     | AD016       |
| 81 | Hibiscus panduniformis Burm.f        | Malviaceae      | Dabbasee             | H     | AD163       |
| 82 | Hippocreadia africana (Willd.) Loes   | Celastraceae    | Xyro                 | L     | AD166       |
| 83 | Hippocreadia pallens Pianch ex Oliver | Celastraceae    | Qavo                 | L     | AD121       |
| 84 | Hypoestes forskali (Vahl) R. Br      | Acanthaceae     | Dargu                | H     | AD124       |
| 85 | Hypoestes triflora (Forsk.) Roem & Schult | Acanthaceae     | Dargu                | H     | AD135       |
| 86 | Ilex mitis (L.) Radik                | Aquifoliaceae   | Qato                 | T     | AD155       |
| 87 | Ipomea indica (Burm. f) Merrill      | Convolvulaceae  | Kalaala              | H     | AD148       |
| 88 | Isoglossa somalensis Lindau          | Acanthaceae     | Ilbu                 | H     | AD001       |
| 89 | Jasminum abyssinicum Hochst. ex DC   | Oleaceae        | Ichime               | L     | AD080       |
| 90 | Justicia bizunsemi Ensermu           | Acanthaceae     | –                    | H     | AD059       |
| 91 | Justicia schimperiana (Hochst. ex Nees) T. Anders | Acanthaceae | Dhumugaa             | S     | AD053       |
| 92 | Kalanche petiriana A. Rich           | Crassulaceae    | Bosoqe muka          | H     | AD044       |
| 93 | Keetia gueinzii (Sond.) Bridson      | Rubiaceae       | Halale               | T/S   | AD111       |
| 94 | Lagera crispata (Vahl) Hepper & Wood | Asteraceae      | –                    | H     | AD117       |
| 95 | Landolphia buchanani (Hall.f) Stapf  | Apocynaceae     | Geebbo               | L     | AD133       |
| 96 | Lepidotrichilia volkensii (Gurke) Leory | Meliaceae      | Haalalee             | T     | AD138       |
| 97 | Lobelia gibba Hemsli                 | Lobeliaceae     | Dingiraro            | S     | AD169       |
| 98 | Loxogramme abyssinica (Baker) MG. Price | Polypodiaceae  | Giixo                 | H     | AD175       |
| No | Scientific names                     | Family              | Local namesa | Habit | Voucher No. |
|---|-------------------------------------|---------------------|--------------|-------|-------------|
| 99 | Macaranga capensis (Baill.) Sim     | Euphorbiaceae       | Ongo         | T     | AD168       |
| 100 | Maesa lanceolata Forsk             | Myrsinaceae         | Abbayyi      | T     | AD027       |
| 101 | Marattia fraxinea Sim             | Marattiaceae        | –            | H     | AD028       |
| 102 | Maytenus gracilipes (Welw ex Oliv.) Exell | Celastraceae | Kombolcha   | S     | AD114       |
| 103 | Maytenus undata (Thunb.) Blakelock | Celastraceae        | Ilikke       | T     | AD132       |
| 104 | Megalastrum lanuginosum (Willd. ex Kaufl) Holtz | Tectaricaceae | –            | H     | AD151       |
| 105 | Microglossa pyrifolia (Lam.) O. Kuntze | Asteraceae | Nobbe        | H     | AD173       |
| 106 | Millettia ferruginea (Hochst.) Baker | Fabaceae       | Sottallo     | T     | AD131       |
| 107 | Monotheicum glandulosum Hochst     | Acanthaceae         | Dargu        | H     | AD091       |
| 108 | Myrsine africana L                | Myrsinaceae         | –            | S     | AD089       |
| 109 | Ocimum lamifolium Hochst ex Benth | Lamiaceae           | Damakase     | S     | AD097       |
| 110 | Olea capensis L                   | Oleaceae            | Gagarmaa     | T     | AD100       |
| 111 | Olea welwitschii (Knobl.) Gilg & Schellenb | Oleaceae | Ba’aa       | T     | AD050       |
| 112 | Opismenus hirtellus (L.) P. Beav | Poaceae             | Sutto gogorri | H   | AD092       |
| 113 | Oxanthus speciosus DC             | Rubiaceae           | Abraango jaldessa | T/S | AD079       |
| 114 | Pavonia schimperiana Hochst. ex A. Rich | Malvaceae | Gajjo       | H     | AD084       |
| 115 | Pentas schimperiana (A. Rich.) Vatke | Rubiaceae      | –            | H     | AD031       |
| 116 | Peperomia abyssinica Miq           | Piperaceae          | Sarxe mukaa  | H     | AD176       |
| 117 | Peperomia retusa (L.f.) A. Dietr   | Piperaceae          | –            | H     | AD130       |
| 118 | Peponium vogeli (Hook.f) Engl      | Cucurbitaceae       | Tojo         | H     | AD066       |
| 119 | Phaulopsis imbricata (Forsk.) Sweet | Acanthaceae      | Dargu        | H     | AD039       |
| 120 | Phoenix reclinata Jacq            | Araceae             | Mexi         | T     | AD022       |
| 121 | Phyllanthus sepalis Muell. Arg    | Euphorbiaceae       | Qacarmaa     | S     | AD172       |
| 122 | Pilea rivularis Wedd              | Urticaceae          | –            | H     | AD153       |
| 123 | Piper capense Lf                  | Piperaceae          | Tunjo        | H     | AD014       |
| 124 | Pittosporum viridiflorum Sims     | Pittosporaceae      | Soolee       | T     | AD070       |
| 125 | Polyscias farinosa (Del.) Harms   | Araliaceae          | –            | T     | AD095       |
| 126 | Polyscias fulva (Hiern) Harms     | Araliaceae          | Karaso       | T     | AD119       |
| 127 | Polystachya rivae Shwewinf       | Orchidaceae         | Capho        | H     | AD094       |
| 128 | Polystichium wilsonii H. Christ   | Dryopteridaceae     | –            | H     | AD113       |
| 129 | Pouetia adolfi-friederici (Engl) Baehni | Sapotaceae     | Qararo       | T     | AD152       |
| 130 | Premna schimperi Engl             | Verbenaceae         | Urgessa      | S     | AD178       |
| 131 | Prunus africana (Hook. f) Kalkm   | Roseaceae           | Homii        | T     | AD159       |
| 132 | Psychotria orphila Petit          | Rubiaceae           | Xumaane      | S     | AD025       |
| 133 | Pteris dentata Forssk             | Pteridaceae         | Gixoo        | H     | AD157       |
| 134 | Pteris pteridoides (Hook.) ballard | Pteridaceae       | Gixoo        | H     | AD076       |
| 135 | Pterolobium stellatum (Forssk.) Brenan | Fabaceae | Harangamaa | S     | AD154       |
| 136 | Pupalia micrantha Haumam          | Amaranthaceae       | Maxzanne     | H     | AD129       |
| 137 | Ranunculus multiflorus Forssk     | Ranunculaceae       | –            | H     | AD149       |
| 138 | Rhamnus prinoides L’Herit         | Rhamnaceae          | Gesho        | S     | AD067       |
| 139 | Ritchiea albersii Gilg            | Cappandaceae        | Daqoo        | T     | AD140       |
| 140 | Rothmannia urcelliformis (Hiern) Robyns | Rubiaceae | Diibo       | T     | AD069       |
| 141 | Rubus apetalus Poir               | Roseaceae           | Gora         | S     | AD075       |
| 142 | Rubus steudneri Schweinf          | Roseaceae           | Gora         | S     | AD071       |
| 143 | Rytyginia neglecta (Him) Robyns   | Rubiaceae           | Mixo         | S     | AD112       |
| 144 | Sapium ellipticum (Krauss) Pax    | Euphorbiaceae       | Bosoqa       | T     | AD109       |
| 145 | Scadoxus nutans (Friis & J. Bjernstad) Friis & Nordal | Amaryllidaceae | Qulubi jaldessa | H | AD088       |
| 146 | Schefflera abyssinica (Hochst. ex A. Rich.) Harms | Araliaceae | Gatamaa | T | AD104       |
| 147 | Schefflera myriantha (Bak) Drake  | Araliaceae          | Qero         | L     | AD086       |
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 Carlo 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. 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 6).

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 3 and community 4 are found in

| No | Scientific names | Family | Local names | Habit | Voucher No. |
|----|------------------|--------|-------------|-------|-------------|
| 148 | Sericostachys scandens Gilg & Lopor | Amaranthaceae | Suddi | L | AD106 |
| 149 | Setaria megaphylla (Steud) Th. Dur. & Schinz | Poaceae | Gowaa | H | AD058 |
| 150 | Solanaceo manni (Hook.f) C. Jeffrey | Asteraceae | Rejjii caakkaa | S | AD125 |
| 151 | Solanecio gigas (Vatke) C. Jeffrey | Asteraceae | Raafu boyyee | S | AD054 |
| 152 | Solanum adensoe Hochst. ex A. Rich | Solanaceae | Hiddi- xino | S | AD102 |
| 153 | Solanum giganteum Jacq | Solanaceae | Tambo arbaa | S | AD048 |
| 154 | Stellaria mannii Hook f | Caryophyllaceae | Mocoo | H | AD127 |
| 155 | Syzygium guineense (Willd.) DC | Myrtaceae | Baddessaa | T | AD141 |
| 156 | Tacazzea apiculata Oliv | Asclepiadaceae | Gebbo | L | AD116 |
| 157 | Tacazzea conferta N.E. Br | Asclepiadaceae | Gebbo gqalame | L | AD145 |
| 158 | Teclea nobilis Del | Rutaceae | Molalee | T | AD158 |
| 159 | Tectaria gennifera (Fee) Alston | Tectarinaeae | Gixoo | H | AD023 |
| 160 | Thalictrum rhynchnocarpum Dill. & A. Rich | Ranunculaceae | Finge | H | AD105 |
| 161 | Thunbergia alata Baj. ex Sims | Acanthaceae | – | H | AD043 |
| 162 | Tilacora trumpinii Cufod | Menispermaeaceae | Liqixi | L | AD146 |
| 163 | Trena orientalis (L) Bl | Ulmaceae | Huddu farddaa | T | AD164 |
| 164 | Trichilia dregeana Sond | Meliaeae | Luyyaa | T | AD049 |
| 165 | Trifolium rueppellianum Frensen | Fabaceae | Amagixa | H | AD150 |
| 166 | Thielopsis madagascariense DC | Moraceae | Same’eko/ceeyii | T | AD085 |
| 167 | Tristemma montianum J. F. Gmel | Melistantomaceae | – | H | AD052 |
| 168 | Triumfetta brachyceas K. Schum | Tiliaceae | Incirimii | S | AD142 |
| 169 | Turrea holsti Gurke | Meliaeae | Ceekaa | S | AD003 |
| 170 | Ureia hypselodendron (A. Rich.) Wedd | Urticaceae | Capho | L | AD047 |
| 171 | Urtica simensis Steudel | Urticaceae | Doobbii | H | AD115 |
| 172 | Vangueria apiculata K. Schum | Rubiaceae | – | T | AD056 |
| 173 | Vepnis dainelli (Pichi-Serm.) Kokwaro | Rutaceae | Hadhessa | T | AD098 |
| 174 | Vernononia amygdalina Del | Asteraceae | Eebicha | T | AD055 |
| 175 | Vernononia auriculifera Hiern | Asteraceae | Rejjii | T/S | AD156 |
| 176 | Vernononia hochstetteri Sch. Bip. ex Walp | Asteraceae | Soyama masango | S | AD057 |
| 177 | Vernononia rueppelli Sch. Bip. ex Walp | Asteraceae | Tambo Arbaa | S | AD103 |
| 178 | Vernononia wollastonii S. Moore | Asteraceae | – | H | AD060 |
| 179 | Zehneria minitiflora (Cogn) C. Jeffrey | Cucurbitaceae | Kalaalaa bosonu | H | AD063 |
| 180 | Zehneria scabra (Linn. f) Sond | Cucurbitaceae | Kalaalaa bosonu | H | AD081 |

* Local name = Afan Oromo
mid altitude area. Community two mostly occur at the higher altitude while species in community 1 and community 5 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 (Fig. 5). The ANOVA test indicated that the five community types

Table 2  Endemic species, their habit, IUCN status and geographical distributions

| Species                         | Family         | Habit  | IUCN category | Altitude (m) |
|---------------------------------|----------------|--------|----------------|--------------|
| Acanthopale ethio germanica     | Acanthaceae    | Shrub  | NE             | 2300_2600    |
| Aframomum corrorima             | Zingiberaceae  | Herb   | NE             | 1350_2000    |
| Ansaema mooneyanum              | Araceae        | Herb   | NE             | 2000_3450    |
| Bothriocline schimperi          | Asteraceae     | Shrub  | LC             | 1300_2820    |
| Clematis longicauda             | Ranunculaceae  | Liana  | LC             | 1350_3300    |
| Croton taliari rosenii          | Fabaceae       | Herb   | NT             | 1350_2800    |
| Justicia vizunshiae             | Acanthaceae    | Herb   | NE             | 1200_2100    |
| Milletia ferruginea             | Fabaceae       | Tree   | LC             | 1000_2500    |
| Polycias farinosa               | Araliaceae     | Tree   | VU             | 1600_2200    |
| Scadoxus mutans                 | Amaryllidaceae | Herb   | NE             | 1450_2300    |
| Solanecia gigas                 | Asteraceae     | Shrub  | LC             | 1750_3350    |
| Tiliacora troupini               | Menispermaceae | Liana  | NE             | 1500_2100    |
| Urtica simensis                 | Urticaceae     | Herb   | LC             | 1500_3400    |
| Vepris dainellii                | Rutaceae       | Tree   | LC             | 1750_2500    |
| Vernonia rueppellii             | Asteraceae     | Shrub  | LC             | 2150_3000    |

Source: [24–32, 41] LC, Least Concern = A taxon is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened; NE, Not evaluated = A taxon is Not Evaluated when it is has not yet been evaluated against the criteria; NT, Near Threatened = A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future; VU, Vulnerable = A taxon is Vulnerable when the best available evidence indicates that it meets any of the criteria, and it is therefore considered to be facing a high risk of extinction in the wild

Fig. 4  Dendrogram of the cluster analysis results of species abundance found in 90 plots
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.

Table 3 Synoptic cover value of plant in Gerba Dima Forest for species reaching ≥ 1% in at least one community

| Cluster number | C1 | C2 | C3 | C4 | C5 |
|----------------|----|----|----|----|----|
| Cluster size   | 14 | 22 | 13 | 14 | 27 |
| Allrophyllus abyssinicus | 3.50 | 1.05 | 1.15 | 0.86 | 1.26 |
| Bersama abyssinica | 3.71 | 1.73 | 0.08 | 0.64 | 1.22 |
| Croton macrostachyus | 7.50 | 1.77 | 1.54 | 1.79 | 2.48 |
| Cordia africana | 2.79 | 0.55 | 0.00 | 0.00 | 0.63 |
| Olea welwitschii | 1.43 | 1.27 | 0.15 | 0.86 | 0.56 |
| Ehetria cymosa | 2.36 | 2.55 | 1.92 | 0.79 | 1.63 |
| Polyscias fulva | 1.64 | 1.36 | 1.85 | 0.93 | 1.33 |
| Apodytes dimidiate | 1.43 | 2.41 | 1.54 | 1.64 | 0.93 |
| Olea capensis | 3.14 | 5.59 | 1.54 | 1.93 | 1.04 |
| Syzygium guineense | 0.64 | 5.91 | 1.69 | 2.43 | 1.56 |
| Justicia schimperiana | 1.29 | 1.68 | 0.85 | 0.36 | 0.93 |
| Canthium olligacarpum | 0.29 | 1.05 | 0.62 | 0.50 | 0.52 |
| Cassipourea malosana | 0.79 | 1.55 | 1.08 | 0.43 | 0.56 |
| Combretum paniculatum | 0.86 | 1.14 | 0.54 | 0.43 | 1.04 |
| Dracaena steudneri | 1.29 | 3.09 | 0.92 | 1.50 | 1.22 |
| Elaeodendron buchananii | 0.64 | 1.00 | 0.38 | 0.00 | 0.37 |
| Oplismenus hirtellus | 2.43 | 4.50 | 3.00 | 2.64 | 2.85 |
| Rothmannia urcelliformis | 1.14 | 1.95 | 0.77 | 0.86 | 1.15 |
| Sapium ellipticum | 0.21 | 1.64 | 0.00 | 1.43 | 0.93 |
| Tectaria gennunifera | 0.93 | 1.36 | 1.23 | 1.29 | 0.81 |
| Brillantaisia madagascariensis | 1.43 | 2.73 | 3.00 | 2.79 | 2.48 |
| Dracaena aframptonana | 1.00 | 3.05 | 7.69 | 0.86 | 0.78 |
| Ficus sur | 2.50 | 1.68 | 6.77 | 2.07 | 1.37 |
| Galiniera saxifrage | 1.00 | 1.05 | 2.31 | 1.43 | 1.56 |
| Hallea rubrostipulata | 1.07 | 0.00 | 1.31 | 0.00 | 0.00 |
| Macaranga capensis | 1.21 | 1.32 | 2.85 | 0.71 | 0.19 |
| Oxyanthus speciosus | 1.29 | 1.73 | 7.01 | 2.36 | 1.56 |
| Pouteria adolfi-friederici | 2.21 | 3.05 | 7.31 | 2.07 | 1.26 |
| Acanthopale ethio-germanica | 1.36 | 0.77 | 2.08 | 2.43 | 1.96 |
| Deinbollia kilimandscharica | 0.57 | 1.45 | 2.62 | 4.07 | 1.59 |
| ilex mitis | 0.43 | 0.59 | 1.31 | 4.71 | 0.44 |
| Justicia bazunshae | 0.50 | 1.23 | 1.31 | 1.71 | 1.37 |
| Landolphia buchananii | 1.00 | 1.32 | 0.85 | 4.13 | 1.19 |
| Piper capense | 1.00 | 0.55 | 0.46 | 1.43 | 1.07 |
| Psychotria orophila | 0.93 | 1.36 | 0.85 | 1.36 | 0.85 |
| Pupalia microantha | 0.64 | 1.36 | 0.23 | 1.86 | 0.93 |
| Schefflera abyssinica | 0.50 | 1.73 | 1.38 | 7.29 | 1.33 |
| Tiliaea traupeii | 1.00 | 1.23 | 1.08 | 1.29 | 1.07 |
| Vepris dainellii | 2.21 | 3.36 | 3.00 | 8.43 | 3.59 |
| Albizia gymnifera | 3.07 | 2.50 | 2.69 | 2.07 | 8.63 |
| Clausena anisata | 1.79 | 1.86 | 1.31 | 1.43 | 2.11 |
| Hippocratea pallens | 0.64 | 1.91 | 1.23 | 1.50 | 1.93 |

| 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            |

**Discussion**

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 Gentry
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 [43–45]. 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 [42]. Except for Rubiaceae, these families are also among the top ten species rich families in the flora area [46]. The dominance of the above families together with Rubiaceae was also reported in other moist afromontane forests of southwestern Ethiopia [47–49]. 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 landscape owing to their efficient pollination, dispersal and germination mechanisms [50]. For instance, many species of Asteraceae have umbrella shape structures adapted for air dispersal and increase their opportunity for their successful establishment [50].

Table 6 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|

Fig. 5 RDA ordination biplot of 90 quadrats and 6 environmental variables of plant communities
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 [51].

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 [40]. 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.

To give a general impression of the species richness of Gerba Dima Forest, the results of the present study were compared with results from other Moist Afromontane forests in Ethiopia. The species richness of Gerba Dima forest is higher than some moist afromontane forest of Ethiopia such as Masha forest (130 species) [48], Belete forest (157 species) [52], Gelesha forest (157 species) [53], Agama forest (162 species) [49] and more or less similar in species richness with some other moist afromontane forest of Ethiopia such as Komto forest (180 species) [54] and Jibat forest (183 species) [55]. However, the species richness of Gerba Dima forest was much lower than the values reported for few other moist afromontane forest of Ethiopia which include Bonga forest (243 species) [47], Yayu forest (220 species) [56] Mana Angetu forest (212 species) [57] (Magada forest (197 species) [58] and Gesh and Sayilem forest (300 species [59].

The difference in species richness among the compared forests could be attributed to the variations of forest sites with regard to geographical location, altitude, anthropogenic impact, rainfall and other climatic, physiographic and edaphic factors [60, 61]. Climatic and physiographic factors have a wide range of effect on the diversity of plant species across the land escape whereas suitable environmental conditions and biotic factors influence diversity at the site level [62, 63]. Species composition of forests is also influenced by regeneration success and competition among species [64].

**Plant community types in Gerba Dima forest**

The output of Multi-response Permutation Procedures (MRPP) results 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. 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 [37]. 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 Eilu and Obua to [65], 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 [66].

**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. 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 [57, 67, 68]. 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 [69, 70].

Potassium followed by altitude was also the most important constraining variable in weighting 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 [71, 72]. In particular, a growth of forbs can be highly dependent
on potassium [71] 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 [73]. 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 [74] 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 pairwise 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.

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 endemity 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.

Abbreviations
DCA: Detrended Correspondence Analysis; RDA: Redundancy Analysis; Vif: Variance inflation factor; MRPP: Multi-response Permutation Procedures.

Supplementary Information
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Authors’ contributions
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. 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.

Declarations
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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Additional file 1: Dominant families with their respective species number of Gerba Dima Forest.
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