

Research Article

Woody Species Composition, Diversity, and Vegetation Structure of Kolbu Forest, Maji District, South West Ethiopia

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Abstract

The study was conducted in Kolbu Forest in Maji District Southwest Ethiopia. The general objective of this study was investigating woody plant species Composition, Vegetation Structure and plant diversity of Kolbu Forest. Systematic sampling technique was used within 8 Transect lines of fixed distance interval 600m apart to record vegetation data. A Sample quadrat of 20m x 20 metre for Trees and 5m x 5 metre for Shrubs were laid in the main plot. Five (1m*1m) sub plots were laid to collect seedling and sapling to the regeneration status of the forest. A total of 56 quadrants were laid along transects. Each plots was laid at distance of 400 metre and the distance between the transect lines was 600 metre apart from each other. The data of vegetation structure was analyzed using excel spread sheet whereas Plant community determination was performed based on the dendrogram output of cluster analysis and synoptic values of species obtained using R version 3.0.2 statistical software. Shannon –Wiener Diversity Index was used to analyze the species diversity, species richness and evenness of the vegetation. A total of 73 woody species representing 63 genera and 34 families were recorded from the 56 sample plots in the forest. Euphorbiaceae and Rubiaceae were the dominant family followed by Celasteraceae. Three community types were identified by Agglomerative Hierarchical Clustering using Similarity ratio and synoptic values of each species in each plot. The total density of tree species with DBH greater than 2.5cm in the Kolbu forest was 4291 individuals (1915.63ha⁻¹). The most dense species in the study area were *Psydrax parviflora* with density of 874.11 ha⁻¹ followed by *Syzygium guineense* and *Elaeodendron buchananii* with density of 197.32 ha⁻¹ and 172.32 ha⁻¹ respectively. The most frequently observed species in the study area were *Elaeodendron buchananii* and *Syzygium guineense* with a total frequency of 41 out each of the 56 quadrat with frequency of 73.21%. The total basal area of the trees forest was 65.68m²ha⁻¹. DBH and height class profile indicated that the greater number of individuals were in the lower class than higher classes. This shows older trees in forest were continuously removed by anthropogenic activity. Therefore, creating awareness for the community on the conservation and sustainable use of the forest was recommended based on the finding of the study.

Keywords

Kolbu Forests, Plant Diversity, Vegetation Structure, Woody Composition, Plant Species

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1. Introduction

Ethiopia is found in the Horn of Africa with a total area of 1.12 million km² and possesses a wide range of geomorphic landscapes with ecological and socio-cultural variations. The country has great geographical diversity. Altitudes range from the lowest at the Afar Depression to the highest peak at Ras Dashen. The climate ranges from hot desert ecosystem to cool Afro alpine and subafroalpine [28]. The variation of the physical features coupled with other environmental factors has contributed to the different vegetation types in Ethiopia [30, 31, 36]. As a result, the country is considered as one of the most important countries in tropical Africa with respect to endemism of plant and animal species [9, 14, 11, 24]. Ecologically, the forest gives important environmental benefits by providing carbon sink, watersheds protection services and providing habitats for a large amount of animals [36, 37]. People living in or around forests depend on the forests for many forest products. The forest serves as a source of food, household energy, construction and agricultural material, tourism and recreational values and medicines for both people and livestock [3, 34]. However, these biologically rich resources of Ethiopia are vanishing at an alarming rate due to extensive deforestation. Although several factors drive natural forest destruction in Ethiopia, agricultural land expansion triggered by increasing human population is probably the dominant force [8, 9, 21]. The size and quality of remnant forest of Ethiopia particularly south-west Ethiopian forest is deteriorating at an alarming rate due to various threats [29]. Kolbu forest is one of the remnant forests of the south west Ethiopia. The vegetation structure, composition of kolbu forest has been affected by anthropogenic factors including new settlement migrating from northern and central Ethiopia to the current study area. More over, People in the study area extract different products from the forest such as house con-

struction materials, farm implementation tools, fire wood. The forest is over exploiting for those purposes. Therefore this study aimed to document the woody species composition, analyze vegetation structure, study plant diversity, and provide information for the future management of Kolbu forest.

2. Material and Methods

2.1. Description of the Study Area

The study was carried out in Kolbu forest, Maji district West Omo Zone Southwest Ethiopia people region ethiopi. Maji is bordered on the south by the Kibish River which separates it from South Sudan, on the west by Surma, on the northwest by Bero, on the north by Meinit Shasha, and on the east by the Omo River which separates it from the Debub Omo Zone. Towns in Maji include Tum and Maji. The western part of Maji was separated to create Bero woreda and some southern kebeles were added to Nyangatom woreda. The District is found 737 Km far away from Addis Ababa to southwest of Ethiopia. The mean annual temperature of the study area is 20°C and rainfall 1200 mm respectively [4]. From the District to the study site Kolbu forest is 43 km away from Tum the capital city of Maji District. The District is located between 5° 12'0" to 6°25'30"N of latitude and 35°15' 0" to 36°18'0"E longitude and altitude ranging from 900 to 2500 m.a.s.l. Kolbu forest is located about 1700 to 2300 m.a.s.l. Maji district has three distinct traditional agro climatic zones highland (12%), middle altitude (42.8%) and low land (47.2%).

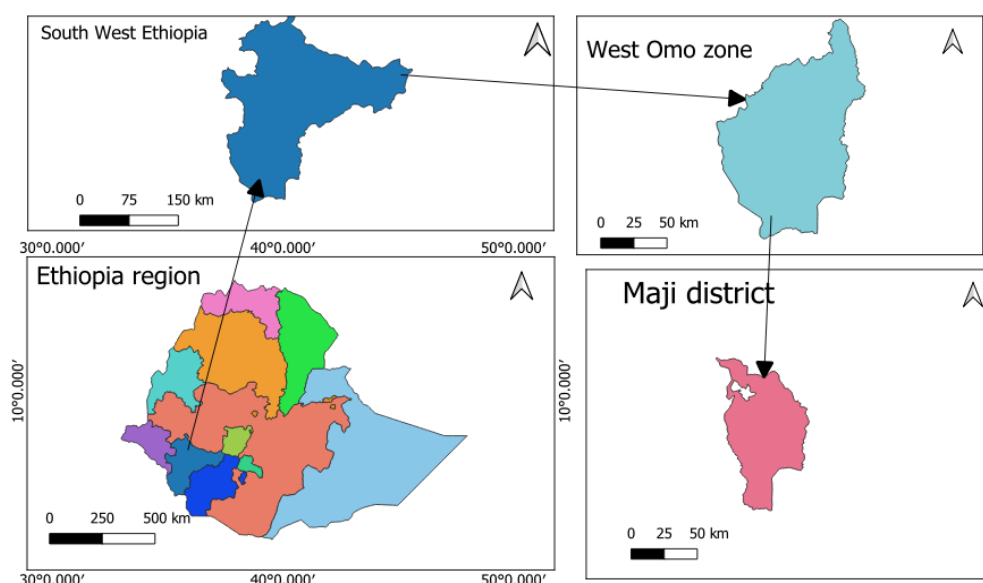


Figure 1. Location Map of the study area drawn by Q GIS 3.40.1.

Maji district has total population of 41546 out of which 19985 are males and 21561 are females (CSA, 2013). It covers a total area of about 691160 hectare of which 299032 hectare is covered with cultivated land 100801 hectare grazing land 136842 hectare forest and shrub lands 104982 hectare which can't be cultivate and 12148 hectare of land covered with others [23]. Kolbu forest is grouped under part of Afromontane rainforest. The study area has varieties of wild life. Some of the bird species in the study area include Yellow billed kite, Brown snake eagle, pied king fisher, cattle egret, Red rumped swallow, Wire tailed Swallow, Crested Francolin, Common Bubul [6].

2.2. Methods of Data Collections

A reconnaissance survey was conducted from 30 september 2023 to 15 october 2023 to obtain first hand information on vegetation and identify sampling sites in the study area. field study was conducted from 1 November 2023 to 30 November 2023. Systematic sampling was used to investigate the vegetation data. The sample sites were arranged in 8 transects lines. A Sample quadrat of 20m x 20 metre for trees and 5m x 5 metre for Shrubs were laid in the main plot. Five (1m*1m) sub plots were laid to collect seedling and saplings. Seedling and sapling data of woody plants were collected to determine the regeneration status of the forest. A total of 56 quadrants were laid along transects. Each plots was laid at distance of 400 metre and the distance between the transect lines was 600 metre apart from each other [1].

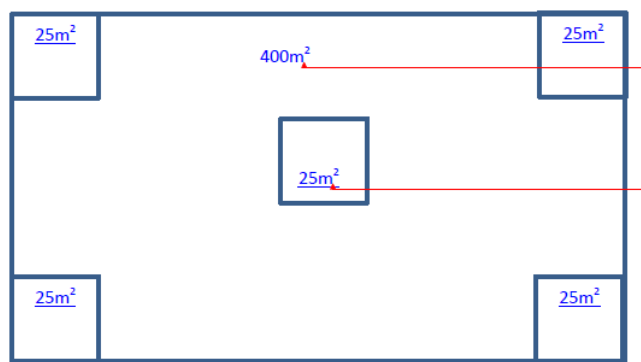


Figure 2. Sampling representation for each plant habits.

In each plot Geographical data (altitude, latitude, and longitude) was recorded using GPS. Each woody species in each plot was recorded using local name (Diizin). Species which were easily identifiable in the field were identified in the field. Species which were difficult to identify in the field were collected, pressed and later identified with the help of published flora of Ethiopia and Eritrea. Height and diameter at breast height (DBH) of each tree species with height ≥ 2 metre and DBH ≥ 2.5 cm were measured using tap meter [1] Shrubs

and liana were recorded for vegetation composition. Cover-abundance values of each woody species were visually estimated later converted to Braun Blanquette scale for community classification.

2.3. Data Analysis

2.3.1. Plant Community Classification

Plant community determination was performed based on the dendrogram output of cluster analysis and synoptic values of species obtained using R version 3.0.2 statistical software. The community types which were identified from the cluster analysis was further refined in a synoptic table and species occurrences were summarized as a synoptic-cover abundance values. Dominant species of each community type was identified based on their synoptic values by which community types were named.

2.3.2. Plant Species Diversity and Similarity Analysis

Shannon –Wiener Diversity Index was used to analyze the species diversity, species richness and evenness of the vegetation as:

$$H' = - \sum_{i=1}^S p_i \ln p_i \quad (1)$$

Where H: Shannon-Wiener Index; Pi: proportion of individual species; S: number of species;

ln: natural logarithm

The equitability or evenness of the species in each quadrat was computed using the formula:

$$\text{Equitability (J) (Evenness)} = \frac{H'}{H_{\max}} = \sum_{i=1}^S p_i \ln p_i \quad (2)$$

Where S: the number of species

Pi: the proportion of individuals of the i^{th} species or the abundance of the i^{th} species expressed as a proportion of total cover ln: log base

The similarity of vegetation types with regard to species composition was assessed using Sorensen's coefficients as described below:

$$Ss = \frac{2a}{2a+b+c} \quad (3)$$

Where: Ss = Sorensen's similarity coefficient

a = Number of species common to both samples/communities/study areas

b = Number of species in sample 1

c = Number of species in sample 2

2.3.3. Structural Analysis

Species structure (frequency, density, abundance, basal

area, and importance value index) of tree species in the forest was computed using Microsoft excel (2007) spread sheet following [17] formula.

$$DBH = \frac{C}{\pi}$$

Where C = circumference and $\pi = 3.14$

Basal Area = $\frac{\pi d^2}{4}$; Where BA = Basal area, $\pi = 3.14$ and d diameter at breast height

$$\text{Relative Basal area} = \frac{\text{Basal area for species}}{\text{Total basal area for all species}} \times 100$$

$$\text{Density (D)} = \frac{\text{Total number of individual of a species in all quadrants}}{\text{Area sampled (ha)}} \quad (4)$$

$$\text{Relative Density (RD)} = \frac{\text{Total number of all individual of a species}}{\text{Total number of individual of all species}} \times 100$$

$$\text{Frequency (F)} = \frac{\text{Number of plots in which a species occurs}}{\text{Total number of plots}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100$$

$$\text{Important Value Index} = \text{RDO} + \text{RF} + \text{RD}$$

$$\text{Relative dominance (RDO)} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all the species}} \times 100$$

3. Result and Discussion

3.1. Woody Species Compositions

A total of 73 woody species belonging to 63 genera and 34 families were recorded from the Kolbu forest (Appendix 1). Out of these 40 were trees, 29 were shrubs, 4 were, liana (Figure 3). Out of the 73 woody species 4 species (*Domboya longibracteolata*, *Milletia ferruginea*, *Senecio gigas*, and *Vernonia leopoldi*) were endemic to Ethiopia [34].

The woody species richness of Kolbu forest is greater than study conducted in Guraferda forest [16], Lammo natural forest [2], Wotagisho forest [33] and more or less similar to Wurg forest which also found in south western Ethiopia [5]. It has smaller woody species composition than Kometu Moist Afromontane forest [14] which is found in western Ethiopia, Boda Dry evergreen forest [10] which is found in eastern Ethiopia. The difference in woody species richness among different study area could be due to Differences in woody species richness across study areas arise from a combination of environmental, ecological, and anthropogenic factors. Climatic conditions, including temperature, precipitation, and seasonality, play a crucial role in determining species distributions, while soil characteristics, such as nutrient availability,

pH, and texture, influence plant growth. Topographic features like elevation, slope, and aspect further shape local biodiversity. Habitat diversity and biogeographic history, including historical events and ecosystem connectivity, contribute to species richness by creating varied niches and enabling species migration. Human activities, such as land use changes, deforestation, and fragmentation, often reduce species richness, whereas conservation efforts can mitigate these effects. Additionally, ecological interactions, such as competition, facilitation, and disturbance regimes, influence community composition. Variations in sampling effort and methodology may also account for differences in reported richness. These factors collectively underscore the complex interplay shaping woody species richness across different regions [13, 14, 35].

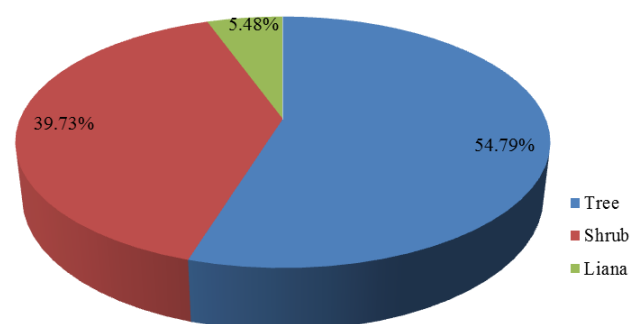


Figure 3. Plant habit representation of Kolbu forest.

The most species rich family in the forest was Euphorbiaceae and Rubiaceae with 7(9.59%) species each followed by Celastraceae with 6(8.22 %). The other species rich family Asteraceae and Fabaceae with 5 (6.85%) and 4(5.48%) species respectively (Table 1). Inline with this study [20] reported similar result however, [5, 22, 37] reported various plant family dominated the respective study area. This difference could arise from the agroecological difference, vegetation difference and altitudinal variation among the study area.

Table 1. Families with their number of Genera and species of Kolbu forest.

No	Family	Number of genera	No species	Percentage (%)
1	Euphorbiaceae	7	7	9.59
2	Rubiaceae	7	7	9.59
3	Celastraceae	3	6	8.22
4	Asteraceae	3	5	6.85
5	Fabaceae	3	4	5.48
6	Araliaceae	2	3	4.11
7	Myrsinaceae	3	3	4.11

No	Family	Number of genera	No species	Percentage (%)
8	Oleaceae	2	3	4.11
9	Sapindaceae	3	3	4.11
10	Apocynaceae	1	2	2.74
11	Boraginaceae	2	2	2.74
12	Capparidiaceae	2	2	2.74
13	Dracenaceae	1	2	2.74
14	Loganiaceae	2	2	2.74
15	Rosaceae	2	2	2.74
16	Rutaceae	2	2	2.74
17	Aquifelaceae	1	1	1.37
18	Dioscoreaceae	1	1	1.37
19	Flacortaceae	1	1	1.37
20	Hypercaceae	1	1	1.37
21	Lauraceae	1	1	1.37
22	Meliaceae	1	1	1.37
23	Melanthaceae	1	1	1.37
24	Moraceae	1	1	1.37
25	Myrtaceae	1	1	1.37
26	Olinaceae	1	1	1.37
27	Pittosporaceae	1	1	1.37
28	Rhamnaceae	1	1	1.37
29	Santilaceae	1	1	1.37
30	Simaroubaceae	1	1	1.37
31	Sterculaceae	1	1	1.37
32	Tiliaceae	1	1	1.37
33	Verbanaceae	1	1	1.37
34	Vitaceae	1	1	1.37
Total		63	73	100

3.2. Plant Community Classification

Three community types were identified from the cluster analysis (Figures 4 and 5). The synoptic value of each species in each plot was used for the analysis (Table 2). The figure also shows similar outputs with that of the dendrogram output of species similarity and sites. Based on the output three plant community types were identified. These plant community types were *Syzygium guineense* – *Elaedendron buehananii*, *Premnaschimperi-Teclea nobilis* community and *Rhamnus staddo-Polyscias fulva* community. Unlike this [7, 15, 20, 22, 26] recorded more number of plant community. The difference in the amount of plant community in the various study

area might be due to the difference in species composition of the study area, agroclimatic difference and vegetation difference due to altitudinal variation among the different study area. Synoptic table of species with synoptic values ≥ 1 is used to determine and name the plant community types. The values are only on the species abundance and frequency comparisons Figure 5.

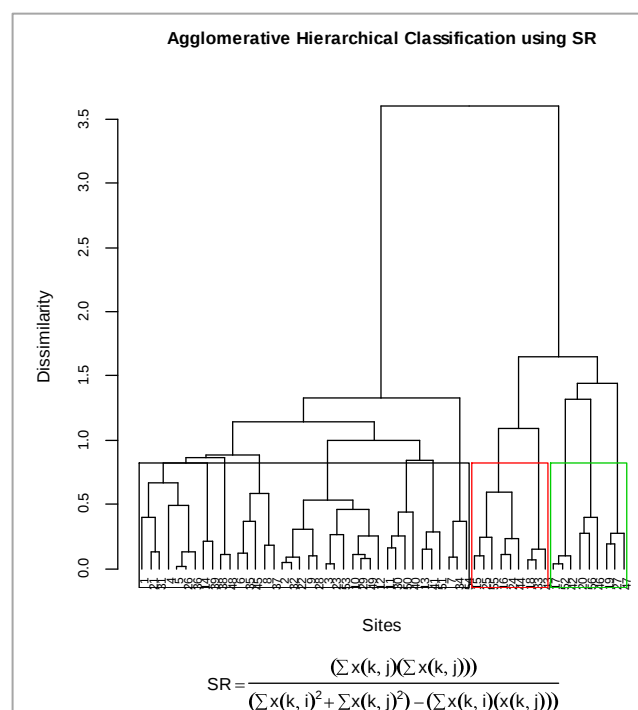


Figure 4. Dendrogram showing the plant community types of Kolbu Forest.

Syzygium guineense – *Elaedendron buehananii*. This community is situated at altitudinal range of 1954-2257 m.a.s.l. It contains 38 plots and 47 species. The indicator species in this community are *Syzygium guineense* and *Elaedendron buehananii*. The other dominant species in the tree layer are *Psydrax parviflora* and *Macaranga capensis*. Species such as *Maytenus arbutifolia*, *Canthium oligocarpum* and *Oxyanthus speciosus* are associated in the shrub layer. *Embelia schimperi* is the dominant species of liana in this community.

Premna schimperi-Teclea nobilis community-This community is situated at an altitudinal range of 1770-1933 m.a.s.l. It contains 9 plots and 34 species. The indicator species in this community were *Premna schimperi* and *Teclea nobilis*. The tree species in the upper canopy of this community were *Otea kenyanensis* and *Sapium ellipticum*. *Capparis micrantha*, *Maytenus undata*, *Dalbergia lactea* *Myrsine Africana* are the dominant species in the shrub layers.

Rhamnus staddo-Polyscias fulva community- This community was found altitudinal range of 1934-1953m.a.s.l. It contains 9 plots and 38 species. The dominant species in this

community were *Rhamnus staddo*, *Polyscias fulva*, *Ekebergia capensis* and *Ficus ovata* were dominant in the species in this community. Species such as; *Buddelja poly-*

stachya, *Dracaena fragrans* and *Pavetta abyssinica* were associated in shrub layer.

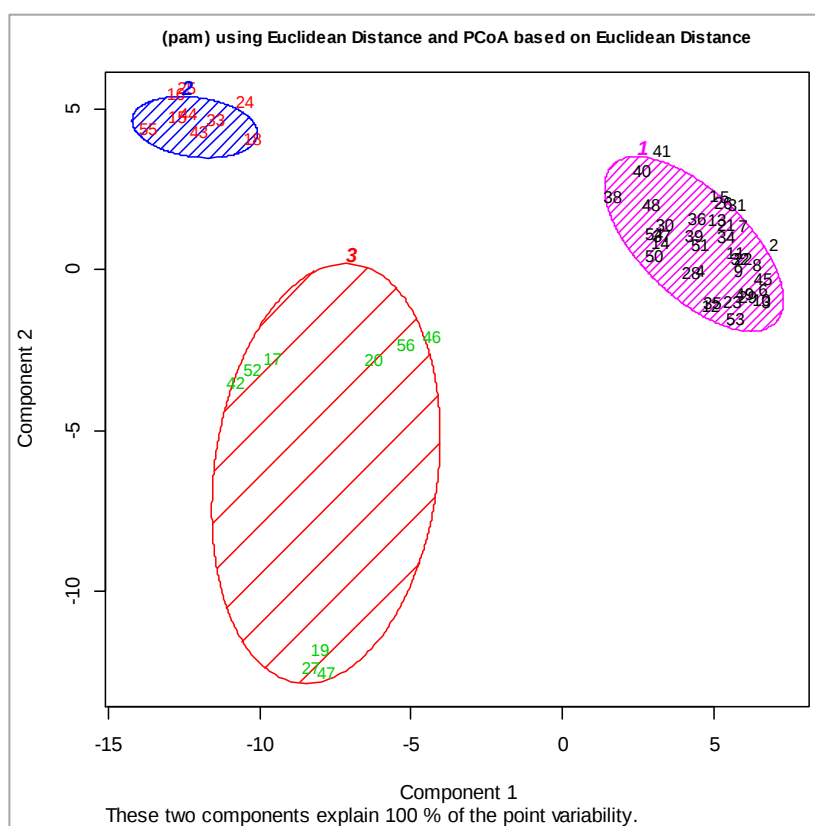


Figure 5. Partitioning around methods using Euclidean distance and PcoA.

Table 2. Synoptic Table of species with synoptic values of ≥ 1 in at least one community type.

Species	Community1	Community2	Community3
<i>Syzygium guineense</i> .	5.76	0	0
<i>Elaeodendron buechananii</i> .	4.82	0	0
<i>Psydrax parviflora</i>	4.18	0	0
<i>Maytenus arbutifolia</i>	3.71	0	0
<i>Macaranga capensis</i>	3.68	0	0
<i>Oxyanthus speciosus</i> .	3.26	0	0
<i>Canthium oligocarpum</i>	2.39	0	0
<i>Embelia schimperi</i>	2.37	0	0
<i>Maytenus senegalensis</i> .	1.66	0	0
<i>Galinierasaxifraga</i>	1.37	0	0
<i>Bersema abyssinica</i>	1.24	0	0
<i>Allophylus abyssinicus</i> .	1.21	0	0
<i>Premna schimperi</i> .	0	3.44	0
<i>Teclea nobilis</i>	0	1.89	0.78

Species	Community1	Community2	Community3
<i>Erecta cymose</i>	0	1.89	0.44
<i>Capparis micrantha</i>	0	1.89	0
<i>Maytenus undata.</i>	0	1.89	0
<i>Prunus africana</i>	0	1.78	0
<i>Oteakenyensis</i>	0.08	1.67	0
<i>Sapium ellipticum.</i>	0	1.67	0
<i>Brucea antidysentrica</i>	0.79	1.33	0.11
<i>Olea.europeasubspss.cuspidate.</i>	0.18	1.22	0
<i>Carissa spinarum</i>	0	1.22	0.44
<i>Hallea.rubrostipulata</i>	0	1.11	0
<i>Schefflera abyssinica.</i>	0	1	0.67
<i>Milletia ferruginea.</i>	0	1	0
<i>Rhamnus staddo</i>	0.42	0	5.78
<i>Polyscias fulva</i>	0.32	0.05	5.44
<i>Maesa lanceolata</i>	0.18	0	5.44
<i>Grewia ferruginea</i>	0	1.67	4.56
<i>Ekebergia capensis.</i>	0	0	3.22
<i>Ficus ovata</i>	0.89	0	3.11
<i>Clausenia anisata</i>	0.97	0	3.11
<i>Albizia schimperiana</i>	1.53	2.33	2.67
<i>Buddelja polystachya</i>	0	2.11	2.33
<i>Dracaena fragrans.</i>	0.79	0.67	2.33
<i>Albizia gumifera</i>	0	1.11	2.11
<i>Olea welwitch.</i>	0.34	0	1.89
<i>Erythrococca trichogyne</i>	0	0	1.67
<i>Coffee Arabica.</i>	0	0	1.33

3.3. Species Diversity Among Plant Community

The Shannon-Wiener diversity index of the study area showed that community 3 has the highest species diversity (3.41) followed by communities 2 and 1 (Table 3). The species richness of the study area varied slightly. Community 1 has highest species richness (47) followed by community 3 (38 species). Species evenness of the study shows fair distribution of species. Based on the data obtained from the study area; community 3 has highest even distribution (0.94) followed by community 2. Comparably community 1 has least species evenness (0.80). this indicates few species dominates few species in the community. [24] pointed out that when there is high evenness value in a forest the location of the

conservation site might not be important as compared to forest with low evenness value. Accordingly the conservation site for community 3 might not be such important as compared to the other communities. The variation in species richness and diversity may be attributed to variation in altitude, disturbance, and other factors [24].

Table 3. Shannon Weiner diversity, Species Richness and Species evenness of the plant Community types.

Clusters	Richness	Diversity (H)	Evenness
1	47	3.09	0.80

Clusters	Richness	Diversity (H)	Evenness
2	34	3.15	0.89
3	38	3.41	0.94

3.4. Vegetation Structure

3.4.1. Density

The vegetation structure of the forest was analyzed for tree species. The total density of tree species with DBH greater than 2.5 cm in the Kolbu forest was 4291 individuals (1915.63

ha⁻¹). The most dense species in the study area were *Psydrax parviflora* with density of 874.11 ha⁻¹ followed by *Syzygium guineense* and *Elaedendron buchananii* with density of 197.32 ha⁻¹ and 172.32 ha⁻¹ respectively. Other dense species are *Albizia schimperiana* and *Macaranga capensis* with density of 67.41 and 64.73 ha⁻¹ respectively. The least dense species was *Deinbollia kilimandscharica* with only single individual recorded in the forest (Table 4). The density of woody species of kolbu forest was compared to other Afromontane forests of Ethiopia. The density of woody species of the current forest is greater than Wurg forest (1745.27ha⁻¹) [5] and Masha forest 1681 ha⁻¹ [1].

Table 4. Density(D), Relative Density(RD), Frequency(F) and relative frequency(RF) distribution of tree species in the Kolbu forest.

No	Tree species	F	RF	D	RD	BA	RDO
1	<i>Albizia gumifera</i>	0.11	1.29	10.27	0.54	0.08	0.12
2	<i>Albizia schimperiana</i>	0.54	6.44	67.41	3.52	2.7	4.11
3	<i>Allophylus abyssinicus</i>	0.45	5.37	31.25	1.63	0.02	0.03
4	<i>Bersema abyssinica</i>	0.46	5.58	51.34	2.68	0.04	0.06
5	<i>Bridelia micrantha</i>	0.16	1.93	19.64	1.02	0.02	0.03
6	<i>Brucea antidysentrica</i>	0.21	2.58	15.18	0.79	0.06	0.09
7	<i>Chionanthus mildbraedii</i>	0.05	0.64	13.9	0.73	0.06	0.09
8	<i>Cordia Africana</i>	0.14	1.72	21.88	1.14	3.26	4.96
9	<i>Deinbollia kilimandscharica</i>	0.02	0.21	0.45	0.02	0.01	0.02
10	<i>Dracaena steudneri</i>	0.11	1.29	8.93	0.47	0.02	0.03
11	<i>Ekebergia capensis</i>	0.11	1.29	10.27	0.54	0.16	0.24
12	<i>Elaedendron buchananii</i>	0.73	8.8	172.32	8.99	6.2	9.44
13	<i>Erecta cymose</i>	0.13	1.5	5.36	0.28	0.02	0.03
14	<i>Erythrococca trichogyne</i>	0.27	3.22	57.59	3.01	2.46	3.75
15	<i>Ficus ovata</i>	0.3	3.65	19.19	1	4.2	6.39
16	<i>Galiniera saxifraga</i>	0.34	4.08	56.25	2.93	0.41	0.62
17	<i>Hallea rubrostipulata</i>	0.16	1.93	10.27	0.54	0.14	0.21
18	<i>Ilex mitis</i>	0.11	1.29	7.14	0.37	0.05	0.08
19	<i>Macaranga capensis</i>	0.61	7.3	64.73	3.38	12.67	19.29
20	<i>Maytenus gracilipes</i>	0.05	0.64	5.36	0.28	0.1	0.15
21	<i>Maytenus undata</i>	0.05	0.64	3.13	0.16	0.08	0.12
22	<i>Milletia ferruginea</i>	0.16	1.93	24.55	1.28	0.78	1.88
23	<i>Nuxia congesta</i>	0.11	1.29	5.36	0.28	1.25	1.9
24	<i>Olea europeasubspss</i>	0.11	1.29	6.25	0.33	0.08	0.12
25	<i>Olea welwitsch</i>	0.18	2.15	12.95	0.68	0.08	0.12
26	<i>Olinia rochentiana</i>	0.05	0.64	8.91	0.47	0.25	0.38
27	<i>Oncoba spinosa</i>	0.05	0.64	13.9	0.73	0.09	0.14

No	Tree species	F	RF	D	RD	BA	RDO
28	<i>Osyris quatripartita</i>	0.04	0.43	1.79	0.09	0.53	0.81
29	<i>Oteakenyensis</i>	0.11	1.29	10.27	0.54	0.04	0.06
30	<i>Pittosporum viridiflorum</i>	0.11	1.29	8.04	0.42	0.54	0.82
31	<i>Polyscias fulva</i>	0.21	2.58	10.71	0.56	0.01	0.02
32	<i>Pouteria adolfi-friederici</i>	0.05	0.64	7.14	0.37	0.25	0.38
33	<i>Prunus africana</i>	0.3	3.65	37.5	1.96	20.21	30.77
34	<i>Psydrax parviflora</i>	0.59	7.08	874.11	45.65	1.03	1.57
35	<i>Sapium ellipticum</i>	0.09	1.07	9.38	0.49	0.75	1.14
36	<i>Schefflera abyssinica</i>	0.09	1.07	8.04	0.42	0.67	1.04
37	<i>Schefflera volkensi</i>	0.13	1.5	13.81	0.72	0.87	1.32
38	<i>Securinea virosa</i>	0.11	1.29	5.8	0.3	0.01	0.02
39	<i>Syzygium guineense</i>	0.73	8.8	197.32	10.3	5.47	8.33
40	<i>Teclea nobilis</i>	0.09	1.07	8.04	0.42	0.01	0.02
	Total	8.32	100.00	1915.63	100.00	65.68	100.00

3.4.2. Diameter at Breast Height (DBH) Class Distribution

The DBH of class distribution of tree of Kolbu forest was classified in to 9 classes and the density of the individuals of the different DBH classes was given in Figure 6. The overall density

distribution of individuals in the forest decreases from lower DBH classes to higher DBH classes. This distribution showed inverted J-shaped distribution. It indicates the predominance of smaller sized individuals and this also showed forest is in good regeneration and recruitment potential [25, 30, 35].

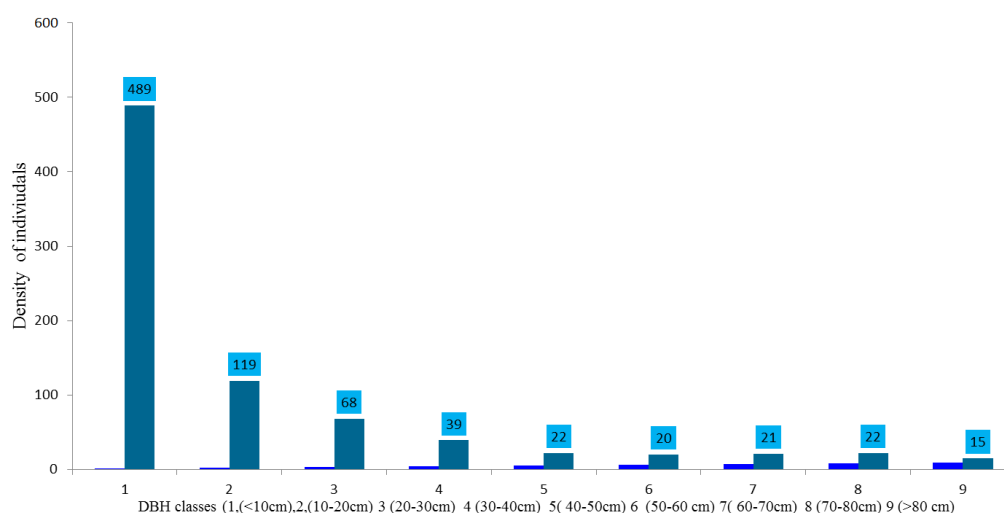


Figure 6. Density distributions of the different DBH classes.

3.4.3. Frequency

The most frequently observed species in the study area were *Elaeodendron buchananii* and *Syzygium guineense* which

occurred 41 times out of 56 quadrats with frequency of 0.73 (73%). The other frequently observed species were *Macarena capensis* and *Psydrax parviflora* which occurred 34 times with frequency of 0.61 (61%) and 33 times with frequency of

0.59% (59%) (Table 4) respectively. The least occurred species was *Deinbollia kilimandscharica* which occurs only in

one plot out of the 56 quadrates.

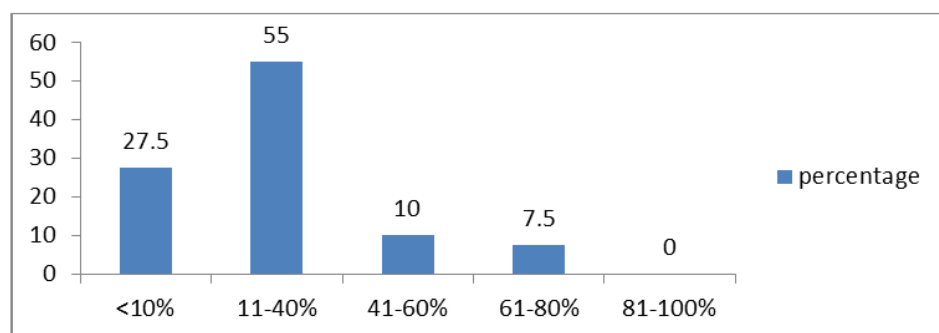


Figure 7. Frequency of woody species for the study area.

The higher number of species in higher frequency classes and low number of species in lower frequency classes shows similar species composition, whereas large number of species in lower frequency classes and small number of species in higher frequency classes indicates higher heterogeneity [37]. The forest shows higher number of species in the lower classes (<20%) than that of the higher classes, these showed heterogeneity of the vegetation [27]. The variation in frequency between species may be attributed to habitat differences, habitat preferences among the species and species characteristics for adaptation.

3.4.4. Basal Area

The total basal area of trees species in Kolbu forest calculated from DBH was 65.68m²/ha. *Prunus africana* has the largest basal area with 20.21 m²/ha (30.77%) followed by

Macaranga capensis with basal area of 12.67m²/ha (19.29%). Other dominant species include *Elaeodendron buechananii*, *Syzygium guineense* and *Ficus ovate* with 6.2 m²/ha (9.44%), 5.47 m²/ha (8.33%) and 4.2m²/ha (6.39%) basal area respectively. Out of the total basal area 74.22% was contributed by the above five species. The rest 36 woody species contributed 25.78% of the total basal area of the forest. Basal area provides a better measure of the relative importance of species than simple stem count. Thus the species with largest basal area can be considered as important species in the study area. *Prunus africana* was important species in the Kolbu forest. Comparison of basal area to the different DBH classes shows there is considerable increase in basal area from lower DBH classes to higher DBH classes (Figure 8). Tree in the highest DBH class contributed 31.31% of the total basal area in the forest.

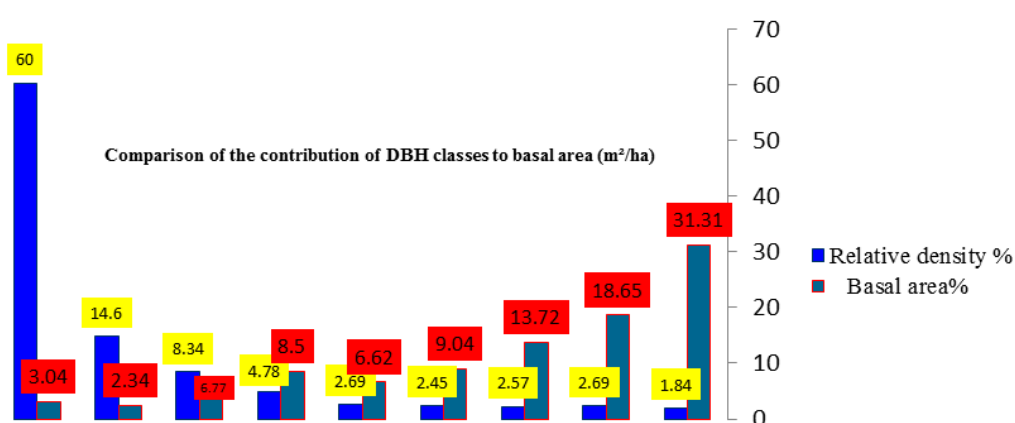


Figure 8. Comparison of Basal area with the different DBH class of the Kolbu forest.

The basal area of Kolbu forest is greater than Guraferda forest (64m²/ha) [16] and lower than Belete forest (103.5m²/ha) [12] Masha forest (142.6m²/ha) [1].

3.4.5. Species Important Value Index

In the current study the highest important value index was contributed by *Psydrax parviflora* with 54.23 important value

index and the least was *Deinbollia kilimandscharica* (0.25) (Table 5). Therefore, *Pyrex parviflora* requires monitoring and management whereas *Deinbollia kilimandscharica* requires high conservation priority. Species important value index admit a comparison of species in a given location and reflects the dominance occurrence of a given species in relation to other associated species in an area. It is also used to compare the ecological significance of species in which high

IVI value indicates that the species sociological structure in the community is high. Therefore, it is a good index for vegetation characteristics and ranking species for management and conservation priority. In general species with smaller important value index need high Conservation efforts, whereas species with larger important value index need monitoring management [18, 19].

Table 5. Important value index of tree species in the Kolbu forest.

No	Tree species	RF	RD	RDO	IVI
1	<i>Albizia gumifera</i>	1.29	0.54	0.12	1.95
2	<i>Albizia schimperiana</i>	6.44	3.52	4.11	14.07
3	<i>Allophylus abyssinicus</i>	5.37	1.63	0.03	7.03
4	<i>Bersema abyssinica</i>	5.58	2.68	0.06	8.32
5	<i>Bridelia micrantha</i>	1.93	1.02	0.03	2.98
6	<i>Brucea antidysentrica</i>	2.58	0.79	0.09	3.46
7	<i>Chionanthus mildbraedii</i>	0.64	0.73	0.09	1.46
8	<i>Cordia Africana</i>	1.72	1.14	4.96	7.82
9	<i>Deinbollia kilimandscharica</i>	0.21	0.02	0.02	0.25
10	<i>Dracaena steudneri</i>	1.29	0.47	0.03	1.79
11	<i>Ekebergia capensis</i>	1.29	0.54	0.24	2.07
12	<i>Elaeodendron buchananii</i>	8.8	8.99	9.44	27.23
13	<i>Erecta cymose</i>	1.5	0.28	0.03	1.81
14	<i>Erythrococca trichogyne</i>	3.22	3.01	3.75	9.98
15	<i>Ficus ovata</i>	3.65	1	6.39	11.04
16	<i>Galiniera saxifraga</i>	4.08	2.93	0.62	7.63
17	<i>Hallea rubrostipulata</i>	1.93	0.54	0.21	2.68
18	<i>Ilex mitis</i>	1.29	0.37	0.08	1.74
19	<i>Macaranga capensis</i>	7.3	3.38	19.29	29.97
20	<i>Maytenus gracilipes</i>	0.64	0.28	0.15	1.07
21	<i>Maytenus undata</i>	0.64	0.16	0.12	0.92
22	<i>Milletia ferruginea</i>	1.93	1.28	1.88	5.09
23	<i>Nuxia congesta</i>	1.29	0.28	1.9	3.47
24	<i>Olea europeasubspss</i>	1.29	0.33	0.12	1.74
25	<i>Olea welwitch</i>	2.15	0.68	0.12	2.95
26	<i>Olinia rochentiana</i>	0.64	0.47	0.38	1.49
27	<i>Oncoba spinosa</i>	0.64	0.73	0.14	1.51
28	<i>Osyris quatripatita</i>	0.43	0.09	0.81	1.33
29	<i>Oteakenyensis</i>	1.29	0.54	0.06	1.89
30	<i>Pittosporum viridiflorum</i>	1.29	0.42	0.82	2.53

No	Tree species	RF	RD	RDO	IVI
31	<i>Polyscias fulva</i>	2.58	0.56	0.02	3.16
32	<i>Pouteria adolfi-friederici</i>	0.64	0.37	0.38	1.39
33	<i>Prunus africana</i>	3.65	1.96	30.77	36.38
34	<i>Psydrax parviflora</i>	7.08	45.65	1.57	54.3
35	<i>Sapium ellipticum</i>	1.07	0.49	1.14	2.7
36	<i>Schefflera abyssinica</i>	1.07	0.42	1.04	2.53
37	<i>Schefflera volkensi</i>	1.5	0.72	1.32	3.54
38	<i>Securinega virosa</i>	1.29	0.3	0.02	1.61
39	<i>Syzygium guineense</i>	8.8	10.3	8.33	27.43
40	<i>Teclea nobilis</i>	1.07	0.42	0.02	1.51
	Total	100	100	100.7	300.7

3.4.6. Vertical Structure

According to IUFRO classification scheme; three vertical structures are distinguished in the tropical forests. These are; upper story (tree height >2/3 of top height), middle story (tree

height between 1/3 and 2/3 of top height) and lower story (<1/3 of top height). Accordingly the top height in Kolbu forest was *Syzygium guineense* with 33 m height.

Table 6. Density distribution of Tree species in the Kolbu forest by the story.

Story	No of individuals	Density (A)	Percentage	Number of species (B)	Percentage	Ratio (A/B)
Lower story (<11m)	3085	1377.23	71.89	25	62.5	55.08:1
Middle story (11-22m)	959	428.13	22.35	10	25	42.81:1
Upper story (>22m)	247	110.27	5.76	5	12.5	22.05:1

The highest density of stems (71.89%) was found in the lower story and the lowest density (5.76%) was found in the upper story, the remaining 22.35% was in middle story (Table 6). Similarly, more species were found in the lower story (62.5%) followed by the middle story (25%) and upper story (12.5%). The upper story was occupied by only five species *Syzygium guineense*, *Elaeodendron buchananii*, *Albizia gumifera*, *Prunus africana*, *Pouteria adolfi-friederici*.

3.4.7. Regeneration Status of the Kolbu Forest

The regeneration status of Kolbu forest was determined by the composition and density of seedling sapling and adult trees [32]. The total density of seedling, sapling and adult plant species were 626.54 individuals ha⁻¹ (32.71%), 788.23 individuals ha⁻¹ (41.15%) and 500.86 individuals ha⁻¹ (26.15%) respectively (Figure 9). The general pattern of seedling, sapling and matured trees/shrubs indicates the forest is in a fair

regeneration potential (Seedling<sapling> adult).

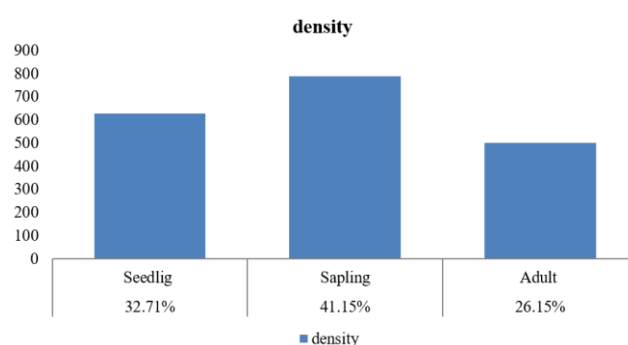


Figure 9. Percentage distributions of seedling, sapling, and matured trees in Kolbu forest.

4. Conclusion and Recommendations

4.1. Conclusion

The Kolbu forest relatively contains high species diversity. It comprises a total of 73 species belonging to 63 genera and 34 families. out of the species recorded in the forest four species (*Domboya longebracteolata*, *Milletia ferruginea*, *Senecio gigas*, and *Vernonia leopoldi*) are endemic to Ethiopia. Euphorbiaceae and Rubiaceae were the dominant family followed by Celasteraceae. Three community types were identified by cluster analysis using the cover abundance value of each species in each plot. The DBH class distribution shows the density of individuals decrease with increasing DBH class. There is predominance small sized individuals in the forest indicating that the forest is in good regeneration and recruitment and reproduction potential. DBH profile and Regeneration status analysis shows that the forest is highly threatened with human activities such as firewood, house building material, and farm implementation tools. However, The general pattern of seedling, sapling and matured trees/shrubs indicated that the forest is in a fair regeneration potential (Seedling<sapling> adult).

4.2. Recommendations

Based on the above conclusion the following recommendations were forwarded.

- 1) Raising community awareness through extension program on the use of forest resource is required.
- 2) Promoting private and community plantation is required to ensure self-reliance with respect demand of wood to decrease pressure on the natural forest.
- 3) Ethno botanical study is required to explore the wealth of indigenous knowledge on the diversity of plants and their implication in conservation.
- 4) A detailed ecological study of the forest is required.

Abbreviations

DBH	Diametre at Breast Height
IUFRO	International Union of Forest Research Organizations
RD	Relative Density
RDo	Relative Dominance
RF	Relative Frequency
Ss	Sorensen's Similaritycoefficient

Appendix

List of Species Collected and Identified in the Kolbu Forest

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Author Contributions

Muluye Asnakew: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Abadir Abdu: Conceptualization, Data curation, Formal Analysis, Methodology, Software, Validation

Zewdie Kassa: Data curation, Formal Analysis, Methodology, Project administration, Software, Supervision, Validation, Visualization

Ethics Approval and Consent to Participate

Before collecting data, permission was obtained from the maji District Administration Offices.

Informed Consent Statement

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Consent to Publish

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Data Availability Statement

All data used for this manuscript is included in the body of manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Table 7. List of species collected and identified in the Kolbu forest.

Scientific name	local name	Family	Habit
<i>Albizia gumifera</i> (J. F. Gmel.) C.A.Sm.	Ziagi	Fabaceae	Tree
<i>Albizia schimperiana</i> Olive., C.Sm.	Ziinu	Fabaceae	Tree
<i>Allophylus abyssinicus</i> (Hochst.) Radlkofer	Xhiyashi	Sapindaceae	Tree
<i>Bersema abyssinica</i> Fresen	Zokuknaabuchu	Melanthaceae	Tree
<i>Bridelia micrantha</i> (Hotchst.) Robyns	Echim	Euphorbiaceae	Tree
<i>Brucea antidysentrica</i> J.F.Mill.	Diyagn	Simaroubaceae	Tree
<i>Buddelja polystachya</i> Fresen	Dekn	Loganiaceae	Shrub
<i>Canthium oligocarpum</i> Hiern	Xhalbizh	Rubiaceae	Shrub
<i>Capparis micrantha</i> A.Rich	Zelm	Capparidiaceae	Shrub
<i>Carissa edulis</i> Vahl.	Niyadin buolu	Apocynaceae	shrub
<i>Carissa spinarum</i> L.	Niyadin	Apocynaceae	shrub
<i>Chionanthus mildbraedii</i> (Gilg & Schellenb.) Stearn	GalgakAkre	Oleaceae	Tree
<i>Clausenia anisata</i> (Wild.) Hook.F.ex.Benth	Uwilaushim	Rutaceae	Shrub
<i>Clusia abyssinica</i> Jaub.& Spach	Tiartiar	Euphorbiaceae	Shrub
<i>Coffea Arabica</i> L.	Giyanu	Rubiaceae	Shrub
<i>Cordia Africana</i> Lam	Abshi	Boraginaceae	Tree
<i>Cyphostemma adenocaulis</i> (Steud. Ex A. Rich.) Descoings	Baar tsuku	Vitaceae	Liana
<i>Dalbergia lactea</i> Vathek	Gaari boo	Fabaceae	Shrub
<i>Deinbollia kilimandscharica</i> Taub.	Daadu buolu	Sapindaceae	Tree
<i>Dioscorea Shimperiana</i> Hochst.ex Kunth	Yagd	Dioscoreaceae	Liana
<i>Dombeya longibracteolata</i> Seyni	Shubshu	Sterculaceae	shrub
<i>Dracaena fragrans</i> (L.) Ker-Gawl	Guoru	Dracenaceae	Shrub
<i>Dracaena steudneri</i> Engler	Uezi	Dracenaceae	Tree
<i>Ekebergia capensis</i> Sparm	Xsuwi	Meliaceae	Tree
<i>Elaeodendron buechananii</i> (Loes) Loes.	Gorshin	Celastraceae	Tree
<i>Embelia schimperiana</i> Vathek	Meding	Myrsinaceae	Liana
<i>Erecta cymosa</i> Thonn	Kuumu	Boraginaceae	Tree
<i>Erythrococca trichogyne</i> (Muell. Arg) Prain.	Uufu	Euphorbiaceae	Tree
<i>Ficus ovata</i> (Vahl)	Guytkichiyamu	Moraceae	Tree
<i>Galiniera saxifrage</i> (Hochst.) Bridson	Burntsubuz	Rubiaceae	Tree
<i>Grewia ferruginea</i> Hochst.ex.A.Rich	Xhabxhab	Tiliaceae	Shrub
<i>Hallea rubrostipulata</i> (K. Schum.) J. F. Leroy	Chikibuolu	Rubiaceae	Tree
<i>Hippocratea africana</i> (Willd.) Loes	Yarmbaytsuku	Celastraceae	Liana
<i>Hypericum revolutum</i> Vahl	yarmqushin	Hypericaceae	Shrub
<i>Ilex mitis</i> (L.) Radlk.	Kuri	Aquifoliaceae	Tree
<i>Macaranga capensis</i> (Ball) Sim	Chanm	Euphorbiaceae	Tree
<i>Maesa lanceolata</i> Forssk	Tulu	Myrsinaceae	Shrub

Scientific name	local name	Family	Habit
<i>Maytenus arbutifolia</i>	Shishir	Celastraceae	Shrub
<i>Maytenus gracilipes</i>	Gundu tsuonu	Celastraceae	Tree
<i>Maytenus senegalensis</i>	Tsutsu	Celastraceae	Shrub
<i>Maytenus undata</i>	Xhyiadin	Celastraceae	Tree
<i>Milletia ferruginea</i>	Birbir	Fabaceae	Tree
<i>Myrsine africana</i>	Shugiti	Myrsinaceae	Shrub
<i>Nuxia congesta</i>	Ebsu	Loganiaceae	Tree
<i>Olea europeasubspss cuspidate</i>	Orsu	Oleaceae	Tree
<i>Olea welwitch</i> (Knobl.) Gilg&Schellenb	Qiyagu	Oleaceae	Tree
<i>Olinia rochentiana</i> A.Juss	Gundu	Oliniaceae	Tree
<i>Oncoba spinosa</i> Forssk	Xustinkay kubt	Flacortaceae	Tree
<i>Osyris quatripatita</i> Dec	Goym	Santaleaceae	Tree
<i>Oteakenyensis</i> (chiov.) Robyns&Wilcz	Diemu	Lauraceae	Tree
<i>Oxyanthus speciosus</i> DC	Tsirbu	Rubiaceae	Shrub
<i>Pavetta abyssinica</i> Fresen.	Nebdi	Rubiaceae	Shrub
<i>Phyllanthus ovalifolius</i> Forssk.	Xustinkaykart	Euphorbiaceae	Shrub
<i>Pittosporum viridiflorum</i> Sims	Botkuxhiali	Pittosporaceae	Tree
<i>Polyscias fulva</i> (Hiern) Harms	Kajul	Araliaceae	Tree
<i>Pouteria adolfi-friedericii</i> (Engl.) Baehni	Qumbus	Sapindaceae	Tree
<i>Premna schimperi</i> Engl.	Xiads	Verbanaceae	Shrub
<i>Prunus africana</i> (Hook.f.) Kalkm.	Okum	Rosaceae	Tree
<i>Psydrax parviflora</i> (Afz.) Bridson	Giyan uinchi	Rubiaceae	Tree
<i>Rhamnus staddo</i> A.Rich	Temdi	Rhamnaceae	Shrub
<i>Ritchiea albersii</i> Gilg.	Kaabu	Capparidaceae	Shrub
<i>Rubus steudneri</i> Schweinf.	Gorknaguochi	Rosaceae	shrub
<i>Sapium elipticum</i> (Krauss) Pax	Balu	Euphorbiaceae	Tree
<i>Schefflera abyssinica</i> (Hochst.ex.A.Ric) Harms	Kuoru	Araliaceae	Tree
<i>Schefflera volkensi</i> (Harms) Harms	Chomuz	Araliaceae	Tree
<i>Securinega virosa</i> Roxb.ex Willd) Pax.&Hoffm	Derm	Euphorbiaceae	Tree
<i>Senecio gigas</i> Vatke	Erkisi	Asteraceae	Shrub
<i>Solanecio manni</i> (Hook. f.) C. Jeffrey	Tiasi	Asteraceae	shrub
<i>Syzygium guineense</i> (Wild.) DC.	Chuoru	Myrtaceae	Tree
<i>Teclea nobilis</i> Del.	Galgai	Rutaceae	Tree
<i>Vernonia bipotinii</i> Vakte	Tsodgu	Asteraceae	Shrub
<i>Vernonia hochstetteri</i> Sch. Bip. ex Walp.	Tiasi	Asteraceae	Shrub
<i>Vernonia myritha</i>	Dougu	Asteraceae	Shrub

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