Hindawi
International Journal of Forestry Research
Volume 2024, Article ID 7765688, 23 pages
https://doi.org/10.1155/2024/7765688

Research Article

Ecological Study of the Vegetation in the Loka Abaya National Park, Ethiopia

Assegid Assefa,[1] **Tamrat Bekele**,[2] **Sebsebe Demissew**,[2] **and Tesfaye Abebe**[3]

[1]*South Agricultural Research Institute, P.O. Box 06, Hawassa, Ethiopia*
[2]*National Herbarium, Department of Plant Biology & Biodiversity Management, Addis Ababa University, P.O. Box 3434, Addis Ababa, Ethiopia*
[3]*College of Agriculture, Hawassa University, P.O. Box 5, Hawassa, Ethiopia*

Correspondence should be addressed to Assegid Assefa; assegidfa@gmail.com

Received 6 May 2023; Revised 6 December 2023; Accepted 14 December 2023; Published 27 January 2024

Academic Editor: Anna Źróbek-Sokolnik

An ecological study of the vegetation in the Loka Abaya National Park, in the Central Rift Valley of Ethiopia, was conducted. Vegetation data and some environmental variables including physical and chemical properties of the soil, altitude, slope, and ecological disturbance were collected and subjected to the agglomerative hierarchical classification and ordination with the canonical correspondence analysis. For each of the community groups, the mean and standard errors were calculated from the environmental parameters to characterize the community types and quantitative relationships between environmental variables were analyzed by calculating Pearson's product-moment correlation coefficient using the SAS computer software programme. A total of 198 plant species representing 79 families and 139 genera were collected and documented. Seven plant community types, namely, *Vachellia brevispica* Harms–*Rhus natalensis* Krauss, *Ficus sur* Forssk.–*Vachellia albida* (Del.) A. Chev., *Panicum subalbidum* Kunth–*Cyperus latifolius* Poir, *Dodonaea angustifolia* L. f.–*Ximenia americana* L., *Combretum molle* R.Br ex. G.Don–*Combretum collinum* Fresen., *Ilex mitis* (L.) Radlk–*Olea europaea* L. subsp. *cuspidata*, and *Dichrostachys cinerea* (L.) Wight & Arn, were identified. *Ilex mitis*–*Olea europaea* L. subsp. cuspidata community had the highest species richness, whereas the least species richness was recorded for the *Panicum subalbidum*–*Cyperus latifolius* community. The results of vegetation-environment relationships indicated that the measured environmental variables explained 74.99% of the total variation in floristic data. The results of the canonical correspondence analysis (CCA) of community-environment relationships indicated that among measured environmental variables, altitude (r^2 0.0548, $P < 0.01$), slope ($r^2 = 0.0241$, $P < 0.01$), pH ($r^2 = 0.01855$, $P < 0.01$), sodium ($r^2 = 0.01316$, $P < 0.04$), CEC ($r^2 = 0.01424$, $P < 0.03$), magnesium ($r^2 = 0.01282$, $P < 0.04$), potassium ($r^2 = 0.0152$, $P < 0.02$), and soil moisture content (SMC) ($r^2 = 0.01537$, $P < 0.05$) significantly explained the variation in species composition of the communities and their distribution. Therefore, ecosystem-oriented biodiversity conservation and restoration strategies will be implemented by considering these significant environmental variables.

1. Introduction

Ethiopia is a mountainous country with remarkable contrasts; it comprises rugged mountains, flat-topped plateau, deep gorges and river valleys, and rolling plains [1]. This varied topographic setup creates conducive environments for evolution of various life forms, including 6,027 vascular plant species, with about 10% endemism [2, 3]. Endemism is particularly high in the high mountains and in the Ogaden area, south eastern Ethiopia, due to geographical isolation and unique climatic conditions [4, 5]. The responses of flora to altitude, climate, and geology have given rise to different physiognomic vegetation types. These vegetation types are the crucial part of the earth and an integral part of an ecosystem that provide essential services to human society as noted by Kent and Coker [6]. In addition, high floristic endowment and ecological diversity of Ethiopian vegetation are sources for wild and domesticated plant species. Moreover, natural vegetation in the Ethiopian plateau and mountains is the source of a number of great rivers including

Nile, Omo, and Wabi-Shebele which are the only sources of permanent water for the surrounding arid and semiarid lowland environment inside and outside the country [5]. Vegetation also provides food and shelter for wildlife. Despite this, the vegetation cover of Ethiopia has been modified by anthropogenic activities for a longer period of time. This strong and prolonged human interference can totally degrade a range of vegetation types to a badly eroded and denuded landscape with very little differentiation of the vegetation left [7]. According to Asefa et al. [8], the livelihood of the population in the country mainly depends on natural resources and lands. The progressive replacements of natural vegetation to agriculture threaten the biological richness of the country. In addition, Ethiopia also ranks first in Africa with livestock population that exerts heavy grazing pressure and degradation of the natural vegetation. The removal of vegetation through grazing pressure reduces the protection of soil cover and minimizes the regrowth capacity of vegetation as reported by Woldu and Tadese [9]. Furthermore, the ecological crisis the country is facing, such as drought, deforestation, and soil erosion, at different times has locally been catastrophic and detrimental to the biological richness of the country [1].

As part of conservation strategies, the country has established several protected areas which include 21 national parks and 58 national forest priority areas for the conservation of biological diversity and enclosures establishment in different parts of the country for promoting natural regeneration. These areas have been the cornerstone of biodiversity conservation, and their role as sources for renewal and reorganization of ecosystem functioning needs to be recognized as reported by Kim et al. [10]. They also preserved different ecosystems that enhance the ecological integrity inside and outside protected areas [11]. Protected area is also important for effective ethnobotanical practices and a natural solution for climate change though mitigate and facilitate adaptation options [11, 12]. Loka Abaya National Park found in the Loka Abaya district, Sidama Regional State in the central Rift Valley of Ethiopia, was established in 2009, on a total area of 500 km^2. Vegetation of the study park is dominantly woodland, wooded grassland, forestland, and vegetation along the seasonal and permanent riversides, Lake Abaya, and associated wetland vegetation. *Euphorbia tirucalli* L., *Vachellia brevispica, Rhus natalensis, Dodonaea angustifolia*, *Ximenia americana, Combretum molle, Ilex mitis, Olea europaea* L. subsp. *cuspidata*, *Dichrostachys cinerea,* and *Euclea schimperi* (A.DC.) Dandy are the dominant woody species in the vegetation of the study park [13]. The National Park is also partly surrounded by traditional homegarden agroforestry practice. The dominant plant species in the traditional agroforestry practice are *Ensete ventricosum* (Welw.), *Zea mays* L., *Coffea arabica* L, *Catha edulis* (Vahl) Forssk. ex Endl, *Saccharum officinarum* L., *Phaseolus lunatus* L., *Sorghum bicolor* L., and *Cajanus cajan* (L.) Millsp., which are cultivated crops in the system mainly for home consumption. *Croton macrostachyus* Del., *Cordia africana* Lam., *Albizia schimperiana* Oliv., and *Balanites aegyptiaca* (L.) Del. are some of the common woody components in the system. It also harbors a significant variety of different sized mammals in various habitats including the IUCN Red-Listed African Wild Dog [14].

The vegetation of the country is also highly influenced by environmental variables, mainly climate associated with elevation; thus, detailed knowledge of floristic and environmental parameters is also important to design management and conservation plan. Several authors reported that elevation is the most important environmental element that influences the distribution of species and community composition [15–19]. Soil pH and total potassium were soil nutrients that affect the wetland vegetation distribution [20]. In addition to their chemical composition, the physical structure of soil can also influence the distribution of plants species and the nature of vegetation types [21]. Adamu et al. [22] have also reported soil moisture as an important environmental factor in plant community composition in the woodland vegetation of Metema area, Amhara National Regional State, Northwestern Ethiopia. Bowers and Lowe [23] concluded that even within a small region of uniform climate, differences in soil texture can cause larger differences in vegetation. Korvenpää et al. [24] also pointed out that species composition is mainly determined by fine-scale local factors. Thus, understanding these local factors gives key information on effective management of vegetation and associated biodiversity [25–27].

The vegetation resources of the country, including forests, woodlands, and bushlands, have been studied by several scholars [1, 6, 15–17, 19] for the purpose of developing the conservation strategy. Some studies focus on vegetation of the national park [28, 29] in the specific floristic region. Despite these facts, due to recent establishment history, detailed ecological investigation of the vegetation in the Loka Abaya National Park is lacking. Vegetation composition, community structure, and diversity patterns are important ecological attributes significantly correlated with prevailing environmental variables. For effective management and conservation of the vegetation of the National Park, there is a need to develop a sound management plan, and this, in turn, required detailed baseline information on the ecology of the area. In Ethiopia, lack of adequate understanding of vegetation resources and their interaction with the existing environment is the main problem for sustainable utilization and developing a conservation plan [25, 26]. This study was designed to test the hypothesis that there exist no differences among community types in terms of species diversity, while there is a similar response among species to environmental variables in the National Park. Therefore, the objectives of this study were to determine the species composition and richness, identify plant community types, analyze the species richness, evenness, and diversity among community types, and investigate the ecological relationships between some environmental variables and species distribution.

2. Materials and Methods

2.1. The Study Area Description. The National Park (500 km^2) is situated in the Central Rift Valley of Ethiopia between 6° 30′–6° 48′ N latitude and 37° 55′–38° 04′ E longitude. The

altitude ranges from 1178 m.a.s.l (Shala-Odda) to 1650 m.a.s.l. at (Gedano hill) in the park. Additionally, the National Park shares some portion of water body from Lake Abaya (Figure 1).

2.1.1. Human and Livestock Population. The total population of the study area in the year 2018 is 142,523 of which 72,701 (51.01%) are male, while 69,822 (48.98%) are female. The population density of the area is estimated to be 16 people per km^2 which is lower than the national average of 96 people per people per km^2 [30]. In the current study area, 56.9% of the district is covered by the Loka-Abaya National Park.

2.1.2. Climate. According to MOA [31] classification, the current study area lies in the major agroecological zone of hot to warm submoist lakes and rift valleys. The meteorological data were collected by Ethiopian National Meteorological Service Agency, Hawassa branch from Billate Meteorological Station, which is found at an altitude of 1361 m.a.s.l and at a distance of 2 km away from the study. The National Park indicated that the area receives bimodal rainfall; the first peak is from mid-March to the end of April and the second peak is from July to mid-October. The annual rain varies from 374.4 mm to 1194.6 mm (Figure 2(a)). The mean annual rainfall from 2004 to 2017 was 846.67 mm with a mean monthly maximum rainfall of 125.38 mm at April and a mean monthly minimum rainfall of 13.36 mm recorded at December. With regard to temperature, the mean monthly minimum temperature ranges from 16.31°C to 17.86°C with a mean minimum temperature of the area being 16.31°C, while the mean annual maximum temperature ranges from 27.57°C to 33.94°C (Figures 2(b) and 2(c)).

2.1.3. Geology and Soil. Geology of Sidama floristic region is Precambrian rocks aging over 600 million years, which are the oldest rocks in the country and form the basement on which younger formations lie [7]. It is the foundation of all rocks and is exposed in area where the younger cover rocks have been eroded away. The soil type of the study area is dominantly Eutric Fluvisols [32].

2.2. Reconnaissance Survey. The reconnaissance survey was made across the study National Park, in order to obtain an idea on in site conditions of the vegetation, collect information on accessibility, identify sampling sites, calculate sample size, and then transect direction in the 3rd and 4th weeks of February 2017. A systematic sampling design was used to locate the sample quadrats to assess species diversity and composition in the National Park following the Muller–Dombois and Ellenberg [33] and Bazdid et al. [34] methods following altitudinal gradients. Quadrats were laid systematically at intervals of 150–200 m, along transect lines, and 800 m apart between the consecutive transect lines. In order to eliminate any influence of the road effects on the species, all the quadrats were laid at least 50 m away from nearest roads.

2.3. Methods of Data Collection and Analysis

2.3.1. Vegetation Data Collection. All woody vascular plant species encountered in each sample plot were listed and counted, and their cover abundance was recorded by visual estimation of the foliage cover of each species in the sampling plot and recorded as percentage. Then, the percent cover was transformed to ordinal scale and assigned to one of the nine cover classes according to the modified 1–9 Braun–Blanquet scale as follows [1, 35–37]: (1) ≤0.1%, (2) ≤0.1–1%, (3) ≤1-2%, (4)2–5, (5)5–12%, (6)12.5–25%, (7) 25–50%, (8)50–75%, and 9.75–100 cover of the total area. Five 1 m × 1 m subplots at four corners and one at the center were used to estimate the cover of herbaceous plant species and the averages were used for analysis. Finally, plant species in the vicinity but absent in the sample plot were noted for floristic inventory. Those specimens were collected following herbarium procedures, identified based on the published volumes of Flora of Ethiopia and Eritrea [38–44] coded, and finally deposited in the National Herbarium (Ethiopia).

2.3.2. Environmental Data Collection. Composite soil samples from each plot were taken at depth of 0–20 cm from five 1 m × 1 m subplots from four corners and one from the center. The soil samples were air-dried and passed through a 2 mm sieve prior to analysis which was performed at Hawassa University's College of Agriculture Soil Laboratory and Hawassa Agricultural Research Center Soil Laboratory. Soil parameters including soil texture % (sand, silt, and clay), soil pH, soil organic matter (SOM), total nitrogen, available phosphorous, cation exchange capacity (CEC), soil moisture content (SMC), exchangeable potassium (K), exchangeable sodium (Na), exchangeable magnesium (Mg), exchangeable calcium (Ca), and electric conductivity (EC) were analyzed. Topographic variables, including altitude and slope, were recorded, and disturbance assessment through grazing and human was estimated. Soil pH was measured in water suspension (1 : 1 soil/water suspension) using a pH meter following procedures of National Soil Research Center [45]. The soil texture % (sand, silt, and clay) was determined by using the Bouyoucos hydrometer method [46]. Total nitrogen (N) was determined according to the method by Houba et al. [47] using the Kjeldahl procedures. Organic matter content of a soil is estimated from the total nitrogen content of a soil (% OM = % total nitrogen × 20) following [48]. Weigh 5 gm of soil sample and put the soil sample in preweighed and recorded flasks. Put the flasks containing soil samples in an oven at 105°C for 24hours. Remove the flasks from an oven, cool and weight once again, and subtract the weight of the flask. The loss of soil weight is supposed to be hygroscopic water which is physically adsorbed in the pores and on the surface [47], and available phosphorous was determined using the Olsen methods by Olsen and Dean [49]. Exchangeable potassium and sodium were determined by a Gallenkamp flame photometer [50] and exchangeable calcium and magnesium were determined by an atomic adsorption spectrophotometer (AAS) [50]. Cation

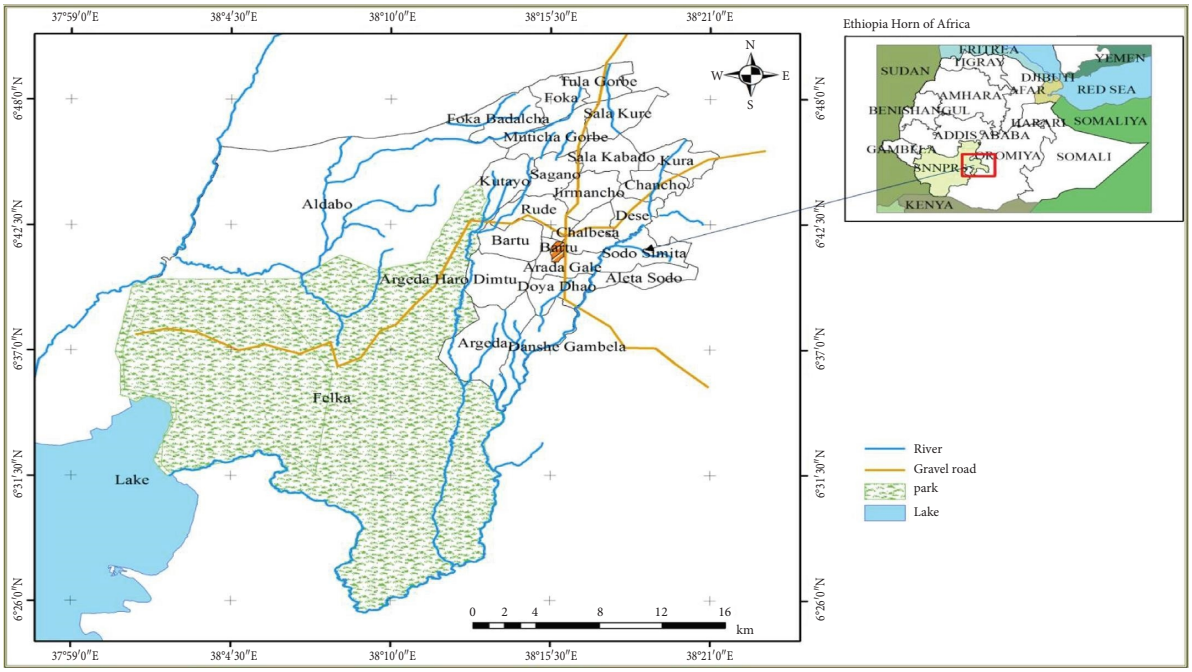


Figure 1: Map of the study area.

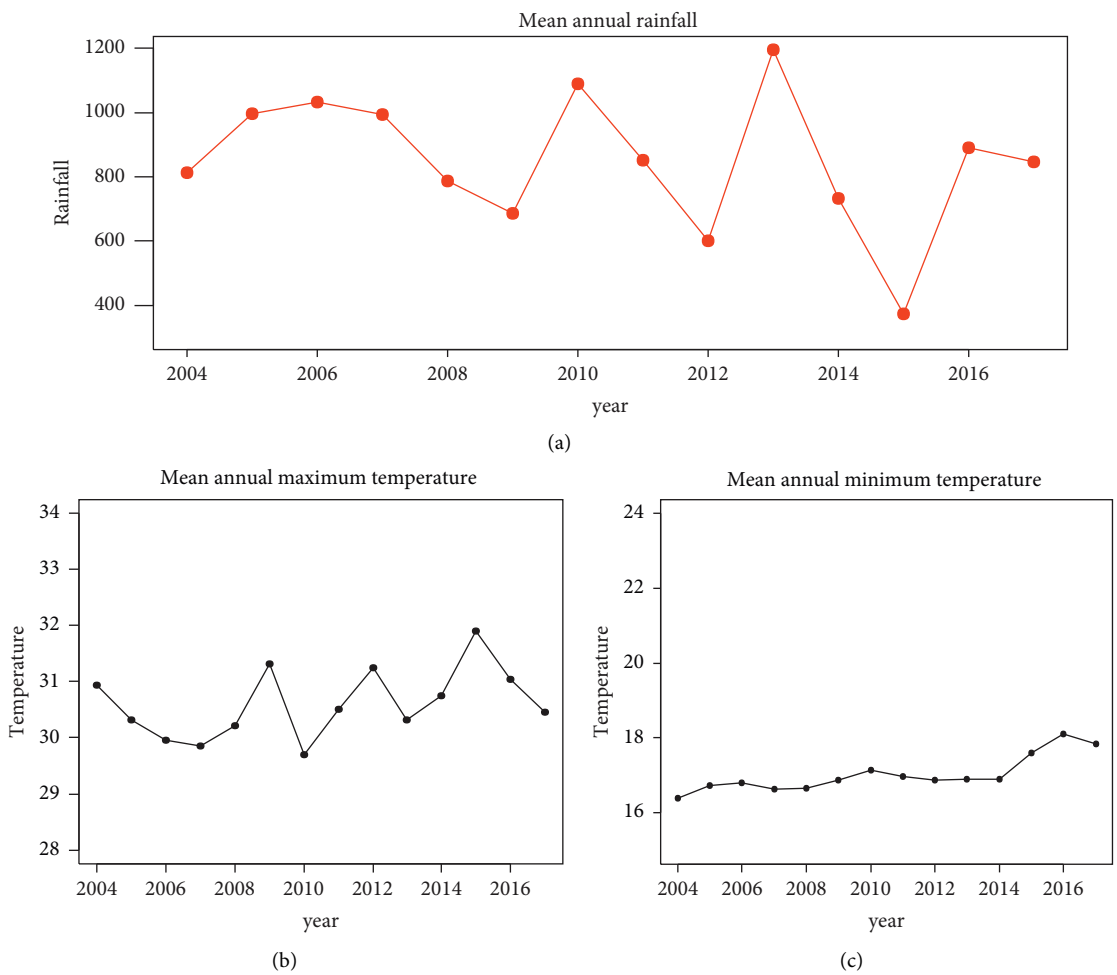


Figure 2: (a) Mean annual rainfall (mm). Mean (b) maximum and (c) minimum temperature (°C).

exchange capacity (extraction with the ammonium acetate method at pH 7) was measured based on the method by Van Reeuwijk [50] and electrical conductivity (1 : 1 soil/water suspension) was based on Cottenie [51] topographic variable. The altitudes for each sample plots were recorded using Garmin GPS 72, and the slope inclination was measured using Sunnto clinometers. The extent of ecological disturbances through grazing was estimated following the method by Woldu and Backeus [15]. 0 = nil (no trampling or no sign of grazing), 1 = slight (few trampling and slight grazing sign), 2 = moderate trampling grazing and sign), and 3 = (heavy trampling and grazing sign). The state of human interference at each sample plot was estimated following (0–3) subjective scale taken into consideration to record the presence or absence of stumps, logs, and signs of fuel wood collection following a method by Woldu and Backeus [15]. Therefore, the magnitudes of the impact were quantified as follows: 0 = nil (no stumps), 1 = low (one stump), 2 = moderate (2 stumps), and 3 = heavy (three and more stumps).

2.4. Methods of Data Analysis

2.4.1. Plant Community Type. Cluster analysis was used to organize sampling quadrats into homogenous subgroups based on their floristic similarities [52]. Similarities vary the most between groups and vary the least within groups. In the current study, hierarchical cluster analysis was performed using R for Windows version 3.5.1 Statistical Package (R Development Core Team, 2017) [52–54] to classify the vegetation into clusters or plant community types based on cover-abundance values for all species found in each quadrat. The optimum number of clusters was determined by plotting within group sum of squares and again number of clusters, and the resulting graphs were used to decide the cut level subjectively following [37, 53]. The sharp break is on 7 indicating that the optimum number of clusters is 7(Figure 3). The data matrix containing % cover values for all species was found in sampling plots ($n = 170$) species on 105 sampling plots.

The distinguished community types were further refined in a synoptic table, where each column represents a community type and species occurrences are summarized as synoptic cover-abundance values. Synoptic table analysis was produced to identify diagnostic species per community types. Two or one diagnostic species with high synoptic cover-abundance values (mean frequency × mean cover-abundance) were used to name the plant community types [52]. In addition, an indicator species analysis was carried out using the indicator value (IndVal) method in R software package. The indicator value index (IndVal) is based only on within-species cover abundance and frequency comparisons. The index is maximum (its value is 0 when there is no indication and 100% when the individuals of a species are observed at all plots belonging to a single community) [54]. The significance of the indicator value of each species was assessed by a Monte Carlo permutation procedure at $P \leq 0.05$.

2.4.2. Species Diversity. The Shannon–Wiener Diversity Index (H′), Equitability/Evenness Index (J), Simpson Diversity Index (D), and Simpson Evenness indices were determined following Kent and Coker [52] and Magurran [55].

2.4.3. Ordination. In gradient analysis, two models are in use: the linear model and unimodel. The selection depends up on the properties of collected dataset. Performing the preliminary analysis using detrended correspondence analysis (DCA) can help to select the appropriate model [53]. If the value of the longest gradient is greater than 4, the unimodel methods, such as correspondence analysis (CA), detrended correspondence analysis (DCA), or canonical correspondence analysis (CCA), were used, while if the longest gradient is less than 3, the linear model, such as redundancy analysis (RDA) or principal component analysis (PCA), was performed. In this study, the length of the first DCA axis was 10.6287 SD, the second was 7.2077 SD, and the third and fourth were 6.132 SD and 3.5895 SD, respectively. A gradient length exceeding four implies a strong unimodal response between the species and environmental variables, and so, canonical correspondence analysis (CCA) was appropriate [52, 53]. It examines relationships between species distributions and the distribution of associated environmental factors. It incorporates the correlation and regression between floristic data and environmental factors within the ordination analysis itself [55]. It helps to identify the ecological preferences of species [56]. CCA was performed using ordination tools in R package (ver.5.3.1). The statistical significance of the relationship between these species and the measured environmental variables was evaluated using Monte Carlo permutation tests (1000 permutation) under full model to identify the most important environmental variables that explain variation in species composition as noted by ter Braak [53].

2.4.4. An Analysis of Variance (ANOVA) among Community Types. Forward and backward stepwise selection of environmental variables only indicates responsible variables for variation of species distribution and community composition. There is no way to know which of the measured environmental variables are responsible for the significant difference among community types. Tukey honest significant differences (Tukey HSDs) and multiple comparison procedure provide a tool to perform multiple comparisons of the environmental variables to isolate those variables that are responsible for the differences in the plant community at ($P < 0.05$) [52, 54]. Summaries of mean and standard errors were calculated from the measured environmental parameters to characterize the community types.

2.4.5. Relationships between Environmental Variables. Quantitative relationships between environmental variables were analyzed by calculating a matrix Pearson's product-moment correlation coefficient using the SAS computer software programme.

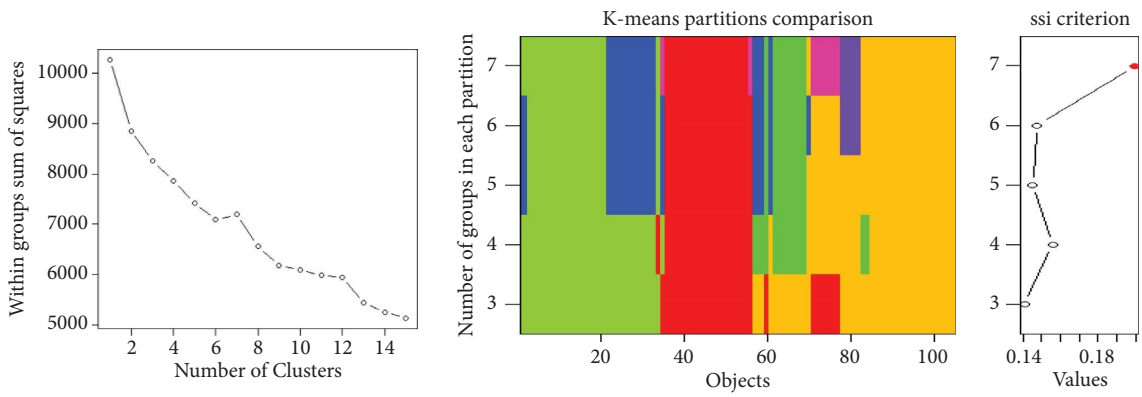


Figure 3: Optimal number of cluster for vegetation data.

2.4.6. Phytogeographic Comparisons. Similarity analysis was carried out to compare the floristic similarity between the study area with other similar study areas using the Sorensen Similarity Index or Sorensen coefficient. It was described using the following formula [52].

$Ss = 2a/(2a + b + c)$. Here, Ss = Sorensen Similarity Coefficient, a = number of species common to both study area, b = number of species in study area 1(LANP), and c = number of species in study area 2. N is the number of species included in the comparison. Species data were received from publication. Furthermore, floristic similarity in their species composition among community types was determined by calculating Sorensen similarity coefficients.

3. Results

3.1. Floristic Composition and Richness. A total of 198 vascular plant species that belong to 72 families in 139 genera were collected, identified, and documented from the studied National Park (Table 1).*Eucalyptus camaldulensis* Dehnh., *Jatropha acerifolia* Pax, and *Melia azedarach* L. were the only three exotic trees species recorded in the natural vegetation of the studied National Park. These species were found in the sample associated with Billate river side vegetation. Among the documented species, *Kirkla burgeri* Stannard, *Barleria grandis* Hochst ex. Nees, and *Kleinia squerosa* Cufod were the red listed plant species recorded in this study. Out of the documented species, *Aloe calidophila* Reynolds, *Aloe pirottae* Berger., *Kalanchoe densiflora* Rolfe., and *Leucas abyssinica* L. were the endemic plant species recorded in the vegetation of the National Park. The vegetation also contained economically important indigenous tree species, including *Celtis africana* Burm.f., *Croton macrostachyus, Cordia africana*, *Ilex mitis,* and *Syzygium* guineese (Willd.) DC. In addition, these are also the sources of commonly reported medicinal plant species, including *Salvadora persica* L., *Withania somnifera* (L.) Dunal., *Asparagus flagellaris* (Kunth), *Ehretia cymosa* Thonn., *Asparagus racemosus* Willd, *Clerodendrum myricoides* (Hochst.) Vatke., and *Stephania abyssinica* Walp. Moreover, it is also a house for popular wild edible plants, including *Balanites aegyptiaca*, *Sclerocarya birrea* (A. Rich.) Hochst., *Ximenia americana, Mimusops kummel* Bruce ex Dc., and *Carissa spinarum* L. The dominant families occurring in the area were Fabaceae representing 18 (25%) species followed by Euphorbiaceae 14 species (19.44%), Poaceae by 13 species (18.05%), and Asteraceae and Cyperaceae by 8 (11.11%) each. Eight families, Asteraceae, Cyperaceae, Euphorbiaceae, Fabaceae, Moraceae, Poaceae, Rutaceae, and Solanaceae, with the highest species richness contribute 79 species (40.10%) of the total species and 34 families were represented by one species. Analysis of the growth diversity indicated that highest growth form was recorded by trees (39.74%) followed by herb (32.1%) and shrubs (21.79%). Climbers were 6 species (3%) and 3 species were epiphytes, including *Tapinanthus globiferus* (A. Rich.) Tieghem, *Phragmanthera regularis* (Oliver) M. Gilbert, and *Commiphora campestris* Vollesen.

3.2. Plant Community Classification. The vegetation was classified into seven relatively homogenous plant community types (Figure 4). The plant communities were named after two or one of the dominant species, which occur in each group (Table 2). The identified community types are described as follows.

3.2.1. Vachellia brevispica–Rhus natalensis Community. This community type is distributed between altitudinal ranges of 1185 and 1405 m.a.s.l in the flood plain of the National Park. *Euphorbia tirucalli*, *Vachellia asak* (Forssk.) Willd., *Vachellia tortilis* subsp. *spirocarpa* (Hochst. ex A. Rich.), *Vachellia lahai* Steud. & Hochst. ex Benth., *Lannea schimperi* (Hochst. ex A. Rich.), and *Zanthoxylum chalybeum* Engl. *Olea europaea* L. subsp. *cuspidata* and *Dichrostachys cinerea* dominated the tree layers. *Grewia bicolor* Juss., *Grewia ferruginea* Hochst. ex A. Rich., *Sclerocarya birrea, Ximenia americana,* and *Teclea nobilis* Del. were found at lower layers. The underground flora is dominated by *Aloe calidophila* Reynolds, *Pennisetum sphacelatum* (Nees) Th. Dur. & Schinz., and *Spermacoce sphaerostigma* (A. Rich.).

3.2.2. Ficus sur–Vachellia albida Community. The community was found at an altitudinal range from 1198 to 1390 m.a.s.l. along permanent and seasonal rivers. *Vachellia sieberiana* DC, *Combretum rochetianum* A. Rich. ex A. Juss., *Balanites aegyptiaca, Ozoroa insignis* Del., *Vachellia drepanolobium* Harms ex Sjostedt., and *Vachellia seyal* Delile. were some of the

Table 1: List of species collected identified and documented from the study area.

List of species	Family names	Local name	Growth form	Voucher number
Abutilon anglosomaliae Cufod.	Malvaceae	Futammo	Herb	AA154
Achyranthes aspera L.	Amaranthaceae	Baxaxuresa	Herb	AA191
Acokanthera schimperi (A. DC.) Schweinf.	Apocynaceae	Qararicho	Tree	AA62
Agave sisalana Perro. ex. Eng.	Agavaceae	Qancha	Tree	AA193
Agave tequilana Web.	Agavaceae	Algee	Herb	AA25
Albizia schimperiana Oliv.	Fabaceae	Maticho	Tree	AA150
Aloe calidophila Reynolds	Aloaceae	Argessa	Herb	AA14
Aloe pirottae Berger.	Aloaceae	Lachee	Herb	AA74
Amaranthus graecizans L.	Amaranthaceae	Raffo	Herb	AA195
Argemone mexicana L.	Papaveraceae	Kokole	Herb	AA196
Asparagus aspergillus Jessop.	Asparagaceae	Chee	Shrub	AA23
Asparagus flagellaris (Kunth).	Asparagaceae	Butticho	Herb	AA45
Asparagus racemosus Willd.	Asparagaceae	Butticho	Climber	AA26
Balanites aegyptiaca (L.) Del.	Balanitaceae	Meuu Bedino	Tree	AA52
Balanites rotundifolia (van Tieghem) Blatter.	Balanitaceae	Manu Bedino	Tree	AA06
Barleria eranthemoides R.Br. ex C.B.Clarke.	Acanthaceae	—	Herb	AA198
Barleria grandis Hochst ex. Nees.	Acanthaceae	Bodree	Herb	AA90
Bersama abyssinica Fresen.	Melianthaceae	Xebracko	Tree	AA001
Bidens pilosa L.	Asteraceae	Coggogete	Tree	AA190
Boscia minimifolia Chiov.	Capparidaceae	Qaliqaliha	Tree	AA196
Boscia subtussulcata Chiov.	Capparidaceae	Qaliqalicha	Tree	AA21
Buddleja polystachya Fresen.	Scrophulariaceae	Bulancho	Tree	AA41
Calpurnia aurea (Ait.) Benth.	Fabaceae	Chakata	Tree	AA69
Capparis tomentosa Lam.	Capparidaceae	Gaoo	Climber	AA187
Carissa spinarum L.	Apocynaceae	Otlicho	Shrub	AA94
Cassipourea malosana Baker) Alston.	Rhizophoraceae	Kincho	Tree	AA132
Celtis africana Burm. f.	Ulmaceae	Shisho	Tree	AA181
Chionothrix latifolia Rendle.	Amaranthaceae	Qalqalicha	Tree	AA001
Chlorophytum somaliense Baker.	Anthericaceae	—	Herb	AA002
Chlorophytum tuberosum (Roxb.) Baker.	Anthericaceae	—	Herb	AA189
Cissus rotundifolia (Forssk) Vahl.	Vitaceae	—	Climber	AA197
Clerodendrum myricoides (Hochst.) Vatke.	Lamiaceae	Madhessa	Shrub	AA185
Combretum rochetianum A. Rich. ex A. Juss.	Combretaceae	Lonna	Tree	AA07
Combretum collinum Fresen.	Combretaceae	Xaxalicho	Tree	AA54
Combretum molle R.Br Ex. G. Don .	Combretaceae	Rukessa	Tree	AA08
Commelina benghalensis L.	Commelinaceae	Lalunxxe	Herb	AA61
Commelina subulata Roth.	Commelinaceae	Lallenxxe	Herb	AA191
Commiphora erosa Vollesen.	Burseraceae	Bexreqicho	Tree	AA003
Commiphora campestris Engl.	Burseraceae	Hameessa	Epiphyte	AA189
Commiphora erythraea (Ehrenb.) Engl.	Burseraceae	—	Tree	AA065
Cordia africana Lam.	Boraginaceae	Wadicho	Tree	AA105
Cordia sinensis Lam.	Boraginaceae	Grgeduwde w	Tree	AA178
Crinum abyssinicum Hochst. ex A. Rich.	Amaryllidaceae	—	Herb	AA176
Croton macrostachyus Del.	Euphorbiaceae	Masincho	Tree	AA119
Cucumis africanus L.f.	Cucurbitaceae	Basu-Bakla	Climber	AA118
Clutia lanceolata Forssk.	Euphorbiaceae	Binjle	Herb	AA199
Cyanotis barbata Don.	Commelinaceae	Lalinxe	Herb	AA61
Cyathea manniana Hook.	Cyatheaceae	Cocosso	Herb	AA86
Cynodon dactylon L.	Poaceae	—	Herb	AA20
Cyperus articulatus L.	Cyperaceae	—	Herb	AA21
Cyperus elegantulus Steud.	Cyperaceae	—	Herb	AA22
Cyperus esculentus L.	Poaceae	—	Herb	AA179
Cyperus longibracteatus (Cherm.) Kuk.	Cyperaceae	—	Herb	AA23
Cyperus latifolius Poir.	Cyperaceae	—	Herb	AA101
Cyperus procerus Rottb.	Cyperaceae	—	Herb	AA020
Cyperus pulchellus R.Br.	Cyperaceae	—	Herb	AA021
Cyperus rotundus L.	Cyperaceae	Balfee	Herb	AA022
Cyperus usitatus L.	Cyperaceae	Qunee	Herb	AA023
Dichrostachys cinerea (L.) Wight & Arn.	Fabaceae	Jermancho	Tree	AA09
Digitaria scalarum L.	Poaceae	Sordono	Herb	AA003
Diospyros abyssinica (Hiern) F. White.	Ebenaceae	Lokko	Tree	AA133
Diospyros mespiliformis Hochst. ex A. DC.	Ebenaceae	Babe	Tree	AA28

Table 1: Continued.

List of species	Family names	Local name	Growth form	Voucher number
Dodonaea angustifolia L.f.	Sapindaceae	Itancha	Shrub	AA05
Dovyalis abyssinica (A. Rich.).	Flacourtiaceae	Shillo	Shrub	AA181
Duranta erecta L.	Verbenaceae	Komolicho	Shrub	AA011
Ehretia cymosa Thonn.	Boraginaceae	Gidincho	Tree	AA73
Ekebergia capensis Sparrm.	Meliaceae	Oloncho	Tree	AA106
Eleusine indica (L.) Gaertn.	Poaceae	Hysso	Herb	AA0017
Emada abyssinica Steud. Ex A. Rich.	Mimosaceae	Xankqdhicho	Climber	AA96
Eriochloa meyeriana (Nees) Pilg.	Poaceae	Shakota	Herb	AA0115
Eriochloa fatmensis (Eochst & Staud.) W.D.Clayton.	Poaceae	Argata	Herb	AA0016
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Bherzafe	Tree	AA115
Euclea racemosa subsp. *schimperi* (A.DC.).	Ebenaceae	Meessa	Tree	AA0108
Euclea schimperi (A.DC.) Dandy.	Ebenaceae	Meessa	Shrub	AA04
Euphorbia abyssinica Gmel.	Euphorbiaceae	Caricho	Tree	AA34
Euphorbia adjurana Bally & Carter.	Euphorbiaceae	Charicho	Tree	AA020
Euphorbia heterophylla L.	Euphorbiaceae	Binejjle	Herb	AA021
Euphorbia hirta L.	Euphorbiaceae	Qandalia	Herb	AA162
Euphorbia nubica N.E. Br.	Euphorbiaceae	—	Creeping	AA022
Euphorbia septantnolis Bally & Cartor.	Euphorbiaceae	Lako Caricho	Creeping	AA023
Euphorbia spp.	Euphorbiaceae	Caree	Tree	AA024
Euphorbia spp.	Euphorbiaceae	Sringa	Tree	AA025
Euphorbia tirucalli L.	Euphorbiaceae	Annaotte	Creeping	AA48
Faurea rochetiana (A. Rich) Chinov. ex Pichi. Serm.	Proteaceae	Dawaka	Tree	AA82
Faurea speciosa Welw.	Proteaceae	Danshicho	Tree	AA007
Ficus sur Forssk.	Moraceae	Odacko	Tree	AA99
Ficus sycomorus L.	Moraceae	—	Tree	AA153
Ficus thonningii Blume.	Moraceae	Dimbicho	Tree	AA144
Ficus vasta Forssk.	Moraceae	Qilitto	Tree	AA143
Flacourtia indica (Burm. f) Merr.	Flacourtiaceae	Hagalicho	Tree	AA173
Galinsoga parviflora Cav.	Asteraceae	Abadebo	Herb	AA009
Gardenia volkensii K. Schum.	Rubiaceae	Gambella	Tree	AA174
Gnaphalium luteoalbum Jersy	Asteraceae	Umuxagicho	Herb	AA005
Gnidia lamprantha Gilg.	Thymelaeaceae	Mrede	Shrub	AA026
Grewia bicolour Juss.	Tiliaceae	Hororessa	Shrub	AA02
Grewia ferruginea Hochst. ex A. Rich.	Tiliaceae	Somacko	Shrub	AA027
Grewia tenax (Forssk.) Fiori.	Tiliaceae	Shilicho	Shrub	AA78
Grewia villosa Will.	Tiliaceae	Chabicha	Tree	AA028
Hyparrhenia anthistirioides (A. Rich.) Stapf.	Poaceae	Tanjo	Herb	AA072
Hypericum quartinianum A. Rich.	Hypericaceae	Mee-Shana	Herb	AA073
Ilex mitis Radlk.	Aquifoliaceae	Miqqicho	Tree	AA03
Jasminum grandiflorum L. subsp. floribundum. (R.Br. ex Fresen.) P.S. Green	Oleaceae	Toreshicho	Shrub	AA074
Jatropha acerifolia Pax	Euphorbiaceae	Jatrofa	Shrub	AA117
Justicia anagalloides (Nees) T. Anders.	Acanthaceae	—	Herb	AA075
Justicia schimperiana (Hochst. ex Nees)	Acanthaceae	—	Shrub	AA076
Kalanchoe densiflora Rolfe.	Crassulaceae	Siringa	Herb	AA077
Kalanchoe petitiana A. Rich.	Crassulaceae	Hanslule	Herb	AA078
Kirkla burgeri Stannard.	Simaroubaceae	Shomboo	Tree	AA079
Kleinia squerosa Cufod.	Asteraceae	Bokessa	Shrub	AA080
Kniphofia pumila (Aiton) Kunth.	Asphodelaceae	Lachee	Herb	AA79
Lagenaria siceraria (Molina).	Cucurbitaceae	Basu-Baklla	Creeping	AA029
Lannea schimperi (Hochst. ex A. Rich.)	Anacardiaceae	Galicha	Creeping	AA37
Lannea triphylla (A. Rich.) Engl.	Anacardiaceae	Handracko	Tree	AA61
Lantana camara Linn.	Verbenaceae	Lembol-shisha	Shrub	AA64
Leucas abyssinica (Benth.) Briq.	Lamiaceae	Tunxo	Herb	AA072
Leucas martinicensis (Jacq.) Ait.f.	Lamiaceae	Ras-kimere	Herb	AA190
Maerua crassifolia Forssk.	Capparidaceae	Kalkalcha	Shrub	AA030
Maesa lanceolata Forssk.	Myrsinaceae	Gowach	Tree	AA031
Maytenus arbutifolia (A. Rich.) Wilczeck.	Celastraceae	Cucho	Shrub	AA175
Melia azedarach Blanco.	Meliaceae	Meme	Tree	AA116
Mimusops kummel Bruce ex Dc.	Sapotaceae	Olatee	Tree	AA138
Momordica foetida Schumach.	Cucurbitaceae	Srupha	Climber	AA118
Ochna inermis (Forssk.) Schweinf.	Ochnaceae	Bula-Cucho	Shrub	AA032
Ocimum lamiifolium Hochst. Ex. Benth.	Lamiaceae	Chbicha	Shrub	AA125

Table 1: Continued.

List of species	Family names	Local name	Growth form	Voucher number
Ocimum urticifolium Roth.	Lamiaceae	—	Herb	AA100
Olea europaea L. subsp *cuspidata* (Wall. Ex G.Don) Cif.	Oleaceae	Egerssa	Tree	AA39
Olyra latifolia L.	Poaceae	—	Herb	AA033
Opuntia ficus-indica (L.) Miller.	Cactaceae	—	Shrub	AA191
Osyris quadripartita Decn.	Santalaceae	Karcho	Shrub	AA31
Ozoroa insignis Del.	Anacardiaceae	Garee	Tree	AA18
Panicum abyssinicum A Rich.	Poaceae	—	Herb	AA034
Panicum maximum Jacq.	Poaceae	—	Herb	AA035
Panicum subalbidum Kunth.	Poaceae	—	Herb	AA036
Pennisetum sphacelatum (Nees) Th. Dur. & Schinz.	Poaceae	Buyoo	Herb	AA037
Phragmanthera regularis (Sprague) M. Gilbert).	Loranthaceae	Hamessa	Epiphytes	AA49
Phyllanthus amarus Schum. & Thonn.	Euphorbiaceae	Sooke	Shrub	AA176
Physalis peruviana L.	Solanaceae	Mmarera	Herb	AA177
Phytolacca dodecandra L'Her.	Phytolaccaceae	Mee sahna	Shrub	AA038
Piliostigma thonningii (Schum.) Milne-Redh.	Fabaceae	Korra	Tree	AA191
Pittosporum viridiflorum Sims.	Pittosporaceae	Boncho	Tree	AA77
Plantago lanceolata L.	Plantaginaceae	Machamo	Herb	AA040
Plectranthus lanuginosus (Hochst. ex Benth.)	Lamiaceae	Hele	Herb	AA011
Premna schimperi Engl.	Lamiaceae	Uddo	Shrub	AA013
Pterolobium stellatum (Forssk.) Brenan.	Fabaceae	Harangama	Climber	AA178
Pygrophila auriculata (Schum) Heine.	Acanthaceae	—	Climber	AA179
Rapanea simensis (Hochst. ex DC.) Mez.	Myrsinaceae	Morocho	Herb	AA134
Rhoicissus tridentata (L. f.) Wild & Drummond	Vitaceae	Chee 2	Tree	AA041
Rhus natalensis Krauss.	Anacardiaceae	Dawowessa	Shrub	AA 137
Rhus vulgaris Meikle.	Anacardiaceae	Shisha	Shrub	AA074
Ricims communis L.	Euphorbiaceae	Qombo	Shrub	AA120
Rubus niveus Thunb.	Rutaceae	Gora	Climber	AA042
Rumex abyssinicus Jacq.	Polygonaceae	Shishonee	Herb	AA108
Salvadora persica L.	Salvadoraceae	Ukka	Shrub	AA110
Sambucus canadensis (Eng)	Caprifoliaceae	Burchana	Shrub	AA043
Sarcocephalus latifolius (Smith) Bruce.	Rubiaceae	Malcho	Tree	AA055
Schoenoplectus corymbosus (Roem. & Schult.)	Cyperaceae	Skakotta	Herb	AA044
Schrebera alata (Hochst.) Welw.	Oleaceae	Tsemayee	Tree	AA89
Sclerocarya birrea (A. Rich.) Hochst.	Anacardiaceae	Woshalicha	Tree	AA186
Senna didymobotrya (Fresen.) Irwin & Barneby.	Fabaceae	Xoxamo	Shrub	AA87
Senna italica (Mill.)	Fabaceae	—	Shrub	AA095
Senna occidentalis (L.)	Fabaceae	Hamshe hqa	Herb	AA045
Senna septemtrionalis (Viv.) Irwin & Barneby	Fabaceae	Woshicho	Shrub	AA122
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	—	Herb	AA39
Setaria verticillata (L.) P. Beauv.	Poaceae	Woshmichicha	Herb	AA141
Sida rhombifolia L.	Malvaceae	Qrqixecho	Herb	AA189
Smilax aspera L.	Smilacaceae	Chee	Climber	AA43
Solanum nigrum L.	Solanaceae	Tunayee	Herb	AA186
Solanum villosum Mill.	Solanaceae	Tunayee	Herb	AA172
Solanum incanum L.	Solanaceae	Borbodhicho	Shrub	AA85
Solanum somalense Franchet.	Solanaceae	Borbodhicho	Shrub	AA046
Spermacoce sphaerostigma (A. Rich.)	Rutaceae	Cikicha	Herb	AA188
Sporobolus pyramidalis P. Beauv.	Poaceae	Muree	Herb	AA047
Stephania abyssinica Walp.	Menispermaceae	Dube-duxe	Climber	AA95
Syzygium guineese (Willd.) DC.	Mytaceae	Duwancho	Tree	AA114
Taddalia asiatica Lam.	Rutaceae	Gaoo	Shrub	AA018
Tagetes minuta L.	Asteraceae	Bowanhamo	Shrub	AA187
Tamarindus indica L.	Fabaceae	Rokko	Tree	AA016
Tapinanthus globifer (A. Rich.) Van Tiengh.	Loranthaceae	Hamessa	Epiphyte	AA195
Teclea nobilis Del.	Rutaceae	Hadhessa	Shrub	AA12
Terminalia brownii Fresen.	Combretaceae		Tree	AA016
Tribulus terrestris. L.	Zygophyllaceae	Hoqono	Tree	AA049
Triumfetta heterocarpa Sprague & Hutch.	Tiliaceae	—	Shrub	AA050
Typha domingensis Pers.	Typhaceae	—	Creeping	AA051
Vachellia polyacantha subsp. polycantha Willd.	Fabaceae	Latee	Tree	AA148
Vachellia albida (Del.) A. Chev.	Fabaceae	Odoricho	Tree	AA184
Vachellia asak (Forssk.) Willd.	Fabaceae	Xurura	Tree	AA121

Table 1: Continued.

List of species	Family names	Local name	Growth form	Voucher number
Vachellia brevispica Harms.	Fabaceae	Hambressa	Tree	AA17
Vachellia drepanolobium Harms ex Sjostedt.	Fabaceae	Wacho	Shrub	AA180
Vachellia lahai Steud. & Hochst. ex Benth.	Fabaceae	Odoricho	Tree	AA56
Vachellia seyal Delile.	Fabaceae	Wacho	Tree	AA147
Vachellia sieberiana DC.	Fabaceae	Wacho	Tree	AA72
Vachellia tortilis subsp. *spirocarpa* (Hochst. ex A. Rich.)	Fabaceae	Xadacha	Tree	AA53
Vangueria apiculata K. Schum.	Rubiaceae	Burure	Herb	AA015
Vernonia amygdalina Del.	Asteraceae	Hecho	Shrub	AA052
Withania somnifera (L.) Dunal.	Solanaceae	Bulancho	Shrub	AA053
Xanthium strumarium L.	Asteraceae	—	Herb	AA181
Ximenia americana L.	Olacaceae	Huroo	Shrub	AA001
Zanthoxylum chalybeum Eng.	Rutaceae	Gada	Shrub	AA054
Zehneria scabra (Linn.f.).	Cucurbitaceae	Kere	Creeping	AA056

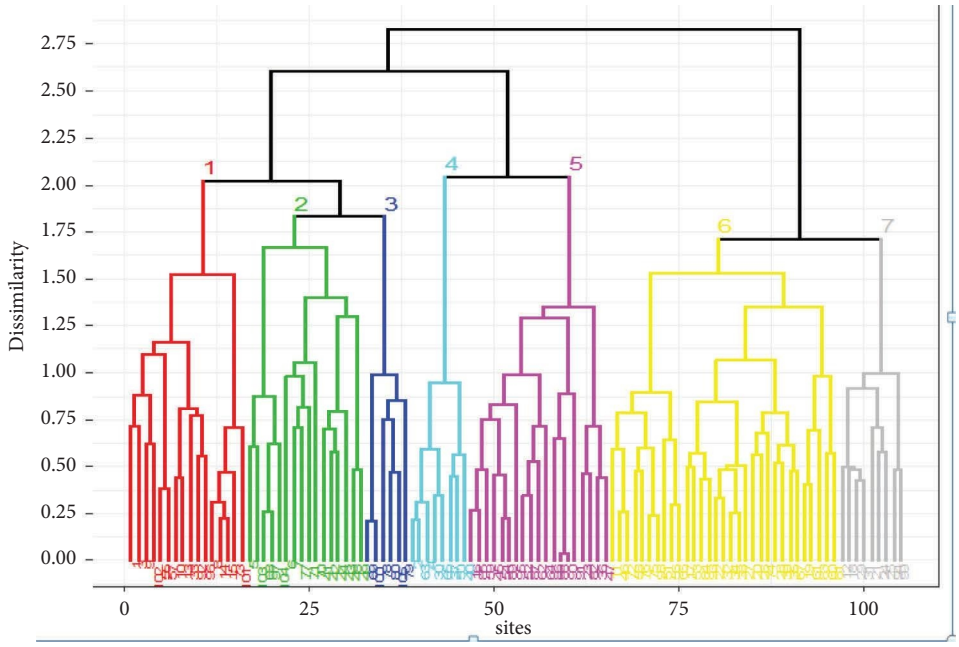


Figure 4: Agglomerative hierarchical cluster indicating seven community types.

dominant species of the community. *Lantana camara* Linn, *Senna septemtrionalis* (Viv.) Irwin & Barneby., *Senna didymobotrya* (Fresen.) Irwin & Barneby, and *Solanum incanum* L. dominated the shrub layers. The underground floras were also dominated by herbaceous species, including *Sida rhombifolia* L., *Xanthium strumarium* L., *Commelina benghalensis* L., *Rumex abyssinicus* Jacq., and *Leucas martinicensis* (Jacq.) Ait.f. The associated species, *Vachellia seyal* and *Vachellia drepanolobium*, are dominantly found in few places at flat lands of waterlogged area. Three exotic tree species, *Eucalyptus camaldulensis, Melia azedarach,* and *Jatropha acerifolia*, were recorded in this community type.

3.2.3. Panicum subalbidum–Cyperus latifolius Community. The community was found at elevation ranges between 1178 and 1195 m.a.s.l at the buffer zone of Lake Abaya. *Schoenoplectus corymbosus* (Roem. & Schult),. *Panicum abyssinicum* A Rich., *Cyperus elegantulus* Steud., *Cyperus rotundus* L., and *Digitaria scalarum* L. were the associated species of the community. The group had a distinctive floristic composition.

3.2.4. Dodonaea angustifolia–Ximenia americana Community. The community type is found at an altitudinal range of 1278–1505 m.a.s.l. at relatively degraded soil on the stony surfaces. *Combretum molle, Balanites aegyptiaca, Acokanthera schimperi* (A. DC.) Schweinf., *Olea europaea* L. subsp. *cuspidata*, *Vachellia tortilis,* and *Vachellia seyal* were found at the upper layers. The group was dominated by *Dodonaea angustifolia*. The herb layer was dominated by *Leucas abyssinica* (Benth.) Briq.

3.2.5. Combretum molle–Combretum collinum Community. This community type is distributed between altitudinal ranges of 1456 and 1596 m.a.s.l. This community type was

Table 2: Mean cover abundance of major species in the community types and significant indicator values at P (<5).

Community	1	2	3	4	5	6	7	IndVal%	P value
Community size*	16	17	6	8	19	30	9		
Vachellia lahai	0.94	0.31	0.00	0.00	0.00	0.00	0.00	12.5	0.121
Rhus natalensis	**3.44**	0.75	0.00	0.50	0.58	1.39	1.11	40	0.001
Vachellia brevispica	**3.62**	0.44	0.00	0.00	0.11	1.16	0.67	63	0.001
Euphorbia tirucalli	2.56	0.00	0.00	0.00	0.05	0.77	0.00	27	0.01
Salvadora persica	0.94	0.12	0.00	0.00	0.00	0.00	0.00	9.13	0.209
Sclerocarya birrea	0.31	0.06	0.00	0.00	0.05	0.00	0.00	22.05	0.021
Boscia subtussulcata Chiov.	0.31	0.06	0.00	0.00	0.00	0.06	0.00	17.77	0.04
Vachellia asak	0.94	0.06	0.00	0.75	0.16	0.00	0.00	15.35	0.127
Buddleja polystachya Fresen.	0.19	0.12	0.00	0,00	0.11	0.03	0.11	4.90	0.817
Grewia bicolour	1.31	0.38	0.00	0.00	0.16	0.77	0.44	24	0.024
Phytolacca dodecandra L'Her	0.31	0.25	0.00	0.25	0.11	0.23	0.00	9.98	0.355
Pennisetum sphacelatum	0.75	0.12	0.00	0.00	0.00	0.29	0.11	4.90	0.285
Vachellia tortilis	1.31	0.38	0.00	0.00	0.16	0.77	0.44	4.94	0.862
Grewia ferruginea	0.12	0.44	0.00	0.12	0.21	0.11	0.11	8.39	0.401
Ficus sur	0.00	**1.75**	0.00	0.00	0.00	0.00	0.00	31.25	0.005
Vachellia albida	0.06	**1.44**	0.00	0.00	0.00	0.67	0.67	24.29	0.018
Vachellia seyal	0.06	1.12	0.00	0.38	0.16	0.56	0.56	21.82	0.022
Vachellia drepanolobium	0.00	0.88	0.00	0.00	0.00	0.00	0.00	18.75	0.035
Combretum rochetianum	0.75	0.94	0.00	0.00	0.05	0.48	0.11	7.21	0.614
Solanum incanum L	0.00	0.19	0.00	0.00	0.05	0.00	0.00	14.64	0.077
Diospyros mespiliformis Hochst. ex A. DC.	0.25	0.50	0.00	0.00	0.11	0.29	0.11	3.2	1.00
Vachellia sieberiana	0.00	0.56	0.00	0.00	0.00	0.00	0.00	6.25	0.542
Panicum maximum Jacq.	0.00	0.00	0.17	0.00	0.00	0.00	0.00	12.12	0.061
Panicum abyssinicum A Rich	0.00	0.00	1.50	0.00	0.00	0.00	0.00	44.82	0.01
Cyperus elegantulus	0.00	0.00	2.00	0.00	0.00	0.00	0.00	6.24	0.066
Panicum subalbidum	0.00	0.00	**5.50**	0.00	0.00	0.00	0.00	66.67	0.001
Cyperus latifolius	0.00	0.00	**3.83**	0.00	0.00	0.00	0.00	50.00	0.001
Digitaria scalarum	0.00	0.00	0.67	0.00	0.00	0.00	0.00	9.85	0.222
Cynodon dactylon	0.00	0.00	0.67	0.00	0.00	0.00	0.00	33.33	0.004
Cyperus rotundus	0.00	0.00	0.17	0.00	0.00	0.00	0.00	33.33	0.153
Panicum trichocladum	0.00	0.00	1.50	0.00	0.00	0.00	0.00	16.66	0.023
Dodonaea angustifolia	0.81	0.19	0.00	**7.12**	1.58	0.84	1.78	58.65	0.001
Ximenia americana	0.94	0.31	0.00	**1.5**	0.37	0.26	0.44	25.36	0.002
Acokanthera schimperi	0.50	0.00	0.00	1.25	0.05	1.00	1.22	14.68	0.16
Combretum molle	0.00	0.06	0.00	1.25	**5.26**	3.68	3.78	35.04	0.002
Combretum collinum	0.50	0.00	0.00	0.05	**2.03**	0.35	1.22	21.22	0.038
Ozoroa insignis	0.00	0.69	0.00	0.38	0.84	0.29	0.56	11.27	0.304
Balanites aegyptiaca	0.19	1.25	0.00	0.88	1.32	0.13	0.22	13.71	0.281
Lannea schimperi	0.00	0.00	0.00	0.00	0.26	0.03	0.00	16.7	0.094
Aloe calidophila	0.50	0.00	0.00	0.00	0.26	0.13	1.00	17.61	0.063
Faurea rochetiana	0.00	0.00	0.00	0.00	0.26	0.03	0.00	4.68	0.714
Jasminum grandiflorum	0.06	0.00	0.00	0.00	0.11	0.19	0.22	8.64	0.337
Lannea triphylla (A. Rich.) Engl.	0.5.0	0.00	0.00	0.00	0.05	0.68	0.78	11.52	0.303
Olea europaea L. subsp. *cuspidata*	1.38	0.31	0.00	2.00	0.21	**3.81**	1.89	27.52	0.016
Ilex mitis	0.19	0.06	0.00	0.75	0.00	**5.06**	2.44	50.46	0.001
Euclea schimperi	0.56	0.12	0.00	0.38	0.21	3.26	2.22	37.35	0.003
Teclea nobilis	0.62	0.00	0.00	0.00	0.00	1.06	0.78	15.23	0.188
Carissa spinarum	000.	0.00	0.00	0.00	0.00	0.13	0.00	6.45	0.549
Schrebera alata	0.00	0.00	0.00	0.00	0.00	0.75	0.00	12.94	0.108
Maytenus arbutifolia	0.00	0.00	0.00	0.00	0.00	0.13	0.00	3.22	0.564
Dichrostachys cinerea	1.31	0.12	0.00	0.38	0.32	0.87	**7.44**	72.24	0.001
Chlorophytum tuberosum	0.50	0.00	0.00	0.00	0.00	0.00	0.67	3.4	1.00
Grewia tenax	0.31	0.12	0.00	0.12	0.26	0.65	0.78	3.2	1.00
Barleria grandis	0.00	0.00	0.00	0.00	0.00	0.06	0.22	17.22	0.037
Calpurnia aurea	0.00	0.00	0.00	0.00	0.05	1.32	0.44	15.45	0.111
Leucas abyssinica	0.06	0.00	0.00	0.12	0.05	0.13	0.33	10.54	0.224

*Community size = Sample size in each community type; bolded values in the table indicate the abundant species in each plant community.

found at a relatively higher altitude in mountainous and stony underground surfaces which may not simply allow germination of tree seeds. The community is dominated by medium size trees and shrubs, including *Ozoroa insignis* Del., *Faurea rochetiana* (A. Rich) Chinov. ex Pichi. Serm., *Acokanthera schimperi,* and *Olea europaea* L. subsp. *cuspidata*. The shrub layers *Osyris quadripartita* Decn., *Dodonaea angustifolia, Asparagus flagellaris,* and *Asparagus racemosus* were the associated species.

3.2.6. Ilex mitis–Olea europaea L. subsp. cuspidata Community. This community occurs at an altitudinal range of 1350–1430 m.a.s.l. The upper canopy is dominated by *Ilex mitis, Olea europaea* L. subsp. *cuspidata*, *Euclea schimperi*, and *Schrebera alata* (Hochst.) Welw. *Ozoroa insignis, Lannea schimperi, Combretum molle, Grewia bicolor,* and *Jasminum grandiflorum* L. subsp. floribundum. (R.Br. ex Fresen.) P.S. Green. were the associated species in the community. The shrub layers were dominated by *Osyris quadripartita, Teclea nobilis, Calpurnia aurea* L., and *Maytenus arbutifolia* (A.Rich.) Wilczeck. The herb layer is dominated by *Barleria grandis, Leucas abyssinica,* and *Spermacoce sphaerostigma.*

3.2.7. Dichrostachys cinerea Community. This plant community is found at an altitudinal range of 1420–1524 m.a.s.l. *Calpurnia aurea, Euclea schimperi, Acokanthera schimperi, Dodonaea angustifolia,* and *Agave tequilana* Web. were the associated species. Climbers *Smilax aspera* and herbaceous species *Barleria grandis, Aloe calidophila, Chlorophytum tuberosum* (Roxb.) Baker., and *Kniphofia pumila* (Aiton) Kunth. were also associated in this community. The community is dominated by *Dichrostachys cinerea* and the species has encroached to other community types in the National Park.

3.2.8. Similarity Indices between Community Types. Sorensen similarity coefficients were analyzed between community types, and results showed there was a weak similarity between plant community types in term of floristic compositions. The highest similarity coefficient of 0.61 was recorded between community one and seven, reflecting 0.39 (39%) dissimilarity in their species composition. Community three was dissimilar from the rest of identified plant community types. 100% dissimilarity is in species composition between community three and community five and community seven (Table 3).

3.3. Species Richness, Evenness, and Diversity of the Plant Community Types. Shannon–Wiener Diversity Index (H') of the vegetation in Loka Abaya National Park found ($H' = 3.46$) indicates good diversity. The species recorded from the National Park were distributed evenly with the Shannon evenness value of 0.67 and small dominancy (0.02). Shannon–Wiener Diversity indices, species richness, and evenness were investigated for seven community types and the results revealed that the plant community types showed differences in their species richness, evenness, and diversity (Table 4). *Ilex mitis–Olea europaea* L. subsp. *cuspidata* community had the highest species richness with 90 species followed by *Ficus sur–Vachellia albida* with 65 species and *Vachellia brevispica–Rhus natalensis* community with 59 species (Table 4). The least species richness was recorded for *Panicum subalbidum–Cyperus latifolius* community. The community is found along a narrow strip of Lake Abaya shore. *Ficus sur–Vachellia albida* community was the most diverse ($H' = 3.603$). The community is found along Billate river bank and other seasonal rivers (Gola) within the National Park. *Vachellia brevispica–Rhus natalensis* community came second ($H' = 3.410$) in terms of species diversity.*Dodonaea angustifolia–Ximenia americana* ($H' = 2.344$) was the least species-diverse community compared to other communities. The result of Shannon evenness or equitability indicated that *Panicum subalbidum–Cyperus latifolius* community was more even ($E = 0.905$), followed by *Ficus sur–Vachellia albida* community type ($E = 0.863$) (Table 4). In addition, the groups were different from each other in terms of Simpson diversity and evenness indices (Table 4).

Table 3: Sorensen similarity coefficients between community types.

Community	C1	C2	C3	C4	C5	C6	C7
C1	1.00						
C2	0.48	1.00					
C3	0.02	0.02	1.00				
C4	0.40	0.43	0.03	1.00			
C5	0.56	0.44	0.00	0.44	1.00		
C6	0.49	0.42	0.06	0.35	0.47	1.00	
C7	0.61	0.49	0.00	0.51	0.58	0.55	1.00

3.4. Vegetation-Environment Relations. The relationship between vegetation and environmental variables was assessed with CCA ordinations. Forward and backward stepwise selection of environmental variables based on their p value indicated that out of 18 potential environmental variables measured, altitude ($r^2 = 0.0548$, $P < 0.01$), slope ($r^2 = 0.0241$, $P < 0.01$), pH ($r^2 = 0.01855$, $P < 0.01$), sodium ($r^2 = 0.01316$, $P < 0.04$), CEC ($r^2 = 0.01424$, $P < 0.03$), magnesium ($r^2 = 0.01282$, $P < 0.04$), potassium ($r^2 = 0.0152$, $P < 0.02$), and soil moisture content (SMC) ($r^2 = 0.01537$, $P < 0.05$) significantly explain the variation in species composition of the communities and their distribution (Table 5).

Monte Carlo global permutation tests showed that the vegetation-environment relationships were revealed by ordination axis 1 and axis 2. The first axis significantly explains the variation in floristic composition at ($p = 0.009^{**}$) followed by second axis ($p = 0.067$) and third axis ($p = 0.097$). The eigen values for the first three CCA axes were found to be 0.6795, 0.4516, and 0.3788, respectively, which represent the contribution of each axis for the explanation of the variations of the species composition. The first two axes are the most important in explaining the variation in floristic data because these two axes explain 74.99% of total variation in species (Table 6).

Table 4: Species richness diversity and evenness among the communities.

C	Richness	Shannon–Wiener (H')	Shannon evenness	Simpson (D)	Simpson evenness
1	59	3.410	0.836	18.373	0.311
2	65	3.603	0.863	25.380	0.390
3	24	2.878	0.905	14.212	0.592
4	25	2.344	0.747	5.551	0.241
5	52	3.214	0.813	14.286	0.274
6	90	3.396	0.754	15.895	0.176
7	57	3.116	0.770	10.761	0.188

Note. C*: community; C1 = *Vachellia brevispica–Rhus natalensis*; C2 = *Ficus sur–Vachellia albida;* C3 = *Panicum subalbidum–Cyperus latifolius;* C4 = *Dodonaea angustifolia–Ximenia americana;* C5 = *Combretum molle–Combretum collinum;* C6 = *Ilex mitis–Olea europaea* L. subsp. *cuspidata;* C7 = *Dichrostachys cinerea.*

Table 5: Environmental variables explaining the variation in species composition.

Variables	*df*	Sums. of sqs	Mean. sqs	*F*. model	R^2	Pr (>*F*)
Altitude	1	2.155	2.15472	6.4738	0.05483	0.01**
Slope	1	0.949	0.94891	2.8510	0.02414	0.01**
pH	1	0.729	0.72914	2.1907	0.01855	0.01**
Na	1	0.517	0.51734	1.5543	0.01316	0.04*
CEC	1	0.560	0.55956	1.6812	0.01424	0.03*
SMC	1	0.604	0.60396	1.8146	0.01537	0.05*
K	1	0.597	0.59746	1.7950	0.01520	0.02*
Mg	1	0.504	0.50379	1.5136	0.01282	0.04*
N	1	0.431	0.43077	1.2942	0.01096	0.22
P	1	0.332	0.33167	0.9965	0.00844	0.34
Ca	1	0.307	0.30714	0.9228	0.00782	0.65
Grazing	1	0.536	0.53551	1.6089	0.01363	0.06
Sand (%)	1	0.454	0.45415	1.3645	0.01156	0.15
Silt (%)	1	0.368	0.36814	1.1061	0.00937	0.42
Clay (%)	1	0.378	0.37834	1.1367	0.00963	0.39
Disturbance through human	1	0.604	0.60356	1.8134	0.01536	0.06.
SOM (%)	1	0.271	0.27074	0.8134	0.00689	0.72
EC	1	0.382	0.38154	1.1463	0.00971	0.29
Residuals	86	28.624	0.3328		0.72834	
Total	104	39.301			1.00000	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

Table 6: The first three axes are the principle axes for explaining the variation in floristic data.

Axis	CCA1	CCA2	CCA3	Total
Eigen value	0.6795	0.4516	0.3788	0.76
Proportion explained	45.05	29.94	25.11	0.24
Cumulative proportion	45.05	74.99	100	1

3.4.1. Correlation of Environmental Variables with Ordination Axis. The canonical coefficient of measured environmental variables with CCA axes is given in Table 7. The strong and positive correlations with the first CCA axis were for altitude ($r^2 = 0.94$; $P < 0.001$), sand ($r^2 = 0.85$; $P < 0.001$), and slope ($r^2 = 0.83$; $P < 0.001$). The second CCA axis was significantly correlated with sodium ($r^2 = -0.83$, <0.001), silt ($r^2 = 0.60$, <0.001), and pH ($r^2 = -0.49$, <0.001) (Table 5). The first axis is a gradient of altitude, while the second axis is a gradient of exchangeable Na.

Table 7: Correlation of environmental variables with CCA axis.

Vectors	CCA1	CCA2	r^2	Pr (>*r*)
Altitude	0.94150	−0.33702	0.6908	0.001***
Ca	0.29556	−0.95532	0.0762	0.019*
CEC	−0.55509	−0.83179	0.1298	0.002**
Clay	−0.87871	0.65410	0.4773	0.056
EC	0.75633	0.99542	0.0589	0.052
Disturbance through human	0.09559	0.99542	0.0290	0.196
K	−0.37297	−0.92784	0.1129	0.058
Grazing	−0.99988	−0.01579	0.1129	0.003**
Mg	0.23004	−0.97318	0.0354	0.126
N	−0.28242	0.95929	0.2012	0.013*
Na	−0.55568	−0.83140	0.5782	0.001***
P	−0.84577	−0.53354	0.0036	0.808
pH	−0.86941	−0.49409	0.5303	0.001***
Sand	0.85074	−0.52558	0.1626	0.001***
Silt	−0.79671	0.60436	0.1701	0.001***
Slope	0.83777	−0.54603	0.2046	0.001***
SMC	−0.99933	−0.03649	0.2578	0.001***
SOM	0.99528	−0.0970	0.0757	0.013*

Codes: 0 "***" 0.001 "**" 0.01 "*" 0.05 "." 0.1 "" 1. Permutation: free; Number of permutations: 999.

In addition, CCA examines the relationship between species distribution and the distribution of associated environmental variables and related individual species to all major environmental variables. The ordination diagram of CCA displays sites, species, and environmental variables. The results of CCA ordination of species and sample plots constrained by environmental variables show the main features of the distributions of species along the environmental variables. In the current study area, altitude, Na, and pH of the soil with long arrows influence the distribution species as compared to other environmental variables under evaluation (Figure 5). In the current study, several species exist in the same direction to altitude, which means that they are being influenced by altitude. Species highly and positively correlated with altitude are *Vachellia lahai, Vachellia polyacantha* subsp. polycantha, *Acokanthera schimperi, Asparagus flagellaris, Calpurnia aurea, Carissa spinarum, Capparis tomentosa, Cassipourea malosana, Combretum collinum, Combretum molle, Dodonaea angustifolia, Dichrostachys cinerea, Euclea schimperi, Ficus thonningii,*

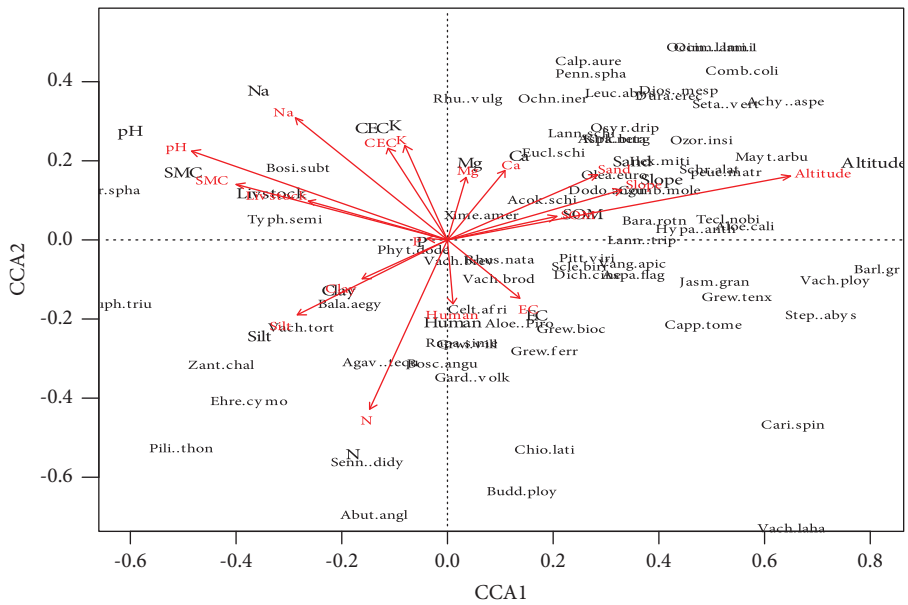


Figure 5: Ordination diagram showing the result of CCA analysis of 105 quadrats and species and 18 environmental variables.

Grewia tenax, Ilex mitis, Lannea schimperi, Mimusops kummel, and *Olea europaea* L. subsp. *cuspidata,* while *Ficus sur, Vachellia brevispica, Cyperus latifolius, Rhus natalensis, Salvadora persica, Panicum subalbidum, Panicum maximum,* and *Panicum hygrocharis* are correlated with sodium and pH.

Forward and backward stepwise selection of environmental variables only indicates responsible variables for variation of species distribution and community composition. There is no way to know which of the measured environmental variables are responsible for the significant difference among community types. Tukey honest significant differences (Tukey HSDs) multiple comparison procedure provides a tool to perform multiple comparisons of the treatment to isolate those factors that are responsible for the differences.

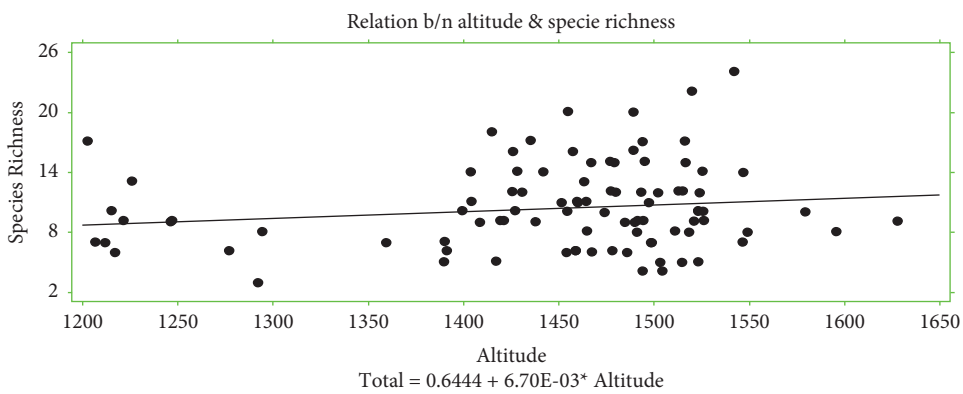
3.4.2. Analysis of Variance (ANOVA) among Community Types. Analysis of variances (ANOVA) was performed to see if there is any significant variation among the community types with respect to measured environmental variables using the Tukey test (Table 8). The results revealed that significant variation between community types was found for altitude, sodium, pH, sand, cation exchange capacity, potassium, slope, and soil moisture content at ($p < 0.05$). No significant differences were found among community types in terms of calcium, electric conductivity, disturbance through humans, magnesium, silt, nitrogen, and soil organic matter. Some of the measured environmental variables, including ecological disturbance of livestock through grazing and % clay, were pronounced at the community level. Those variables are important to design community level conservation strategies. Table 8 shows that plant community five is significantly different from communities one and three in terms of altitude but there were no statistical differences between communities two, four, and seven in terms of altitude. Exchangeable sodium in the soil is higher in plant community three; no significant difference was found among other plant community types. Plant community three is found surrounding Lake Abaya at lower elevation and slope gradients. Soil pH is also an important environmental variable that influences species distribution and plant community. The highest pH recorded at plant community three (Table 8). The analysis on soil particle size distribution indicated that clay and sand showed significant variation among community types except silt content (Table 8). Sand content of the soil was significantly higher in *Dodonaea angustifolia–Ximenia americana* (community four), while statistically no significant difference was found among communities four, five, six, and seven. Some of the variable was pronounced at the community level, for example, the assessment result of ecological disturbance through grazing significantly influences community three but no significant differences were found between communities one, two, four, six, and seven.

3.4.3. Environmental Characteristics of Plant Community. Summary of measured environmental parameters for each of the community groups is given in (Supplementary file 1). Community one was found at a mean altitude (mean ± SE) of 1365 ± 33 m.a.s.l. So, the community is found at a wider altitudinal range. The average particle size distribution was sand 37.77%, silt 36.31%, and clay 25.31% which showed that soil in the community had a textural class of clay loam. The highest clay content (32 ± 2.35%), with Sta.err 2.35%), was recorded in community type two in the river side sand. The average pH value of 7.06 indicated that the group occurs at neutral soil. Group three occurs at a mean elevation of 1183 ± 2.5 m.a.s.l, which is the lowest of all groups within a narrow elevation range. The soil group three had average particle size

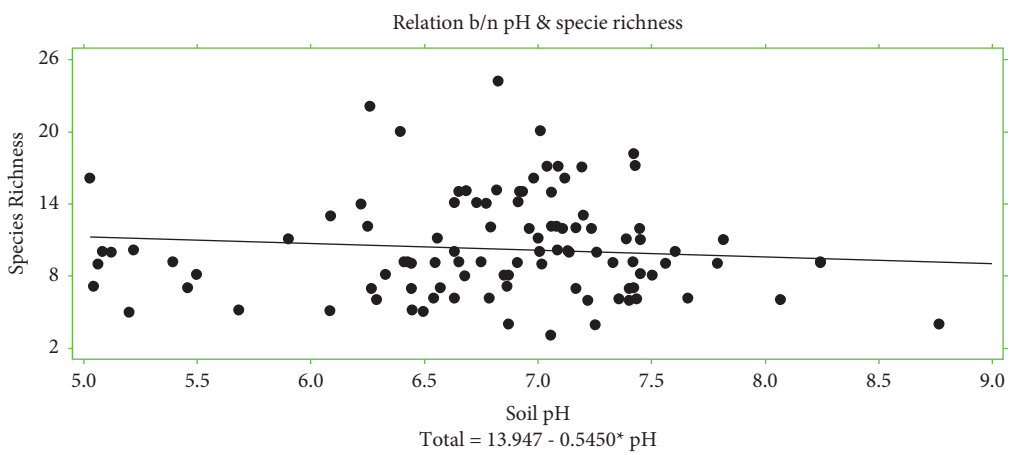
Table 8: Tukey's multiple range test between environmental variables and community types (1–7).

Community	1	2	3	4	5	6	7
Altitude	1365^{c}	1273^{abc}	1183^{d}	1429^{abc}	1484^{a}	1405^{ab}	1460^{abc}
Calcium	19.5^{ns}	17.0^{ns}	18.4^{ns}	17.91^{ns}	17.82^{ns}	18.07^{ns}	15.82^{ns}
Cation exchange capacity	25.31^{ab}	21^{b}	34^{a}	22.76^{ab}	19.44^{ab}	27.00^{ab}	21.33^{ab}
Clay	25.9^{abc}	32^{a}	29.31^{ab}	18.12^{c}	23^{bc}	25.40^{bc}	21.44^{bc}
Electric conductivity	0.83^{ns}	0.84^{ns}	0.51^{ns}	0.81^{ns}	0.76^{ns}	0.77^{ns}	0.88^{ns}
Disturbance through human	0.37^{ns}	0.23^{ns}	0.01^{ns}	0.25^{ns}	0.1^{ns}	0.40^{ns}	0.11^{ns}
Potassium	3.58^{a}	3.32^{ab}	3.98^{a}	3.09^{ab}	3.39^{ab}	3.41^{a}	2.24^{b}
Grazing	1.0^{ab}	$0.88b^{ab}$	1.8^{a}	0.87^{ab}	0.31^{b}	0.84^{ab}	0.77^{ab}
Magnesium	6.61^{ns}	6.78^{ns}	7.72^{ns}	7.15^{ns}	6.12^{ns}	5.78^{ns}	7.24^{ns}
Nitrogen	0.3^{ns}	0.17^{ns}	0.2^{ns}	0.24^{ns}	0.3^{ns}	0.2^{ns}	0.22^{ns}
Sodium	1.26^{b}	1.08^{b}	10.34^{a}	0.58^{b}	0.76^{b}	1.82^{b}	0.53^{b}
Phosphorous	9.04^{ns}	9.77^{ns}	9.46^{ns}	8.79^{ns}	9.39^{ns}	9.53^{ns}	9.07^{ns}
pH	6.95^{b}	7.06^{b}	8.86^{a}	7.01^{b}	6.45^{b}	6.89^{b}	6.30^{b}
Sand	37.75^{ab}	34.52^{b}	31.3^{b}	50.75^{a}	48.42^{a}	44.78^{a}	48.44^{a}
Silt	36.31^{ns}	34^{ns}	39.66^{ns}	31.12^{ns}	27.31^{ns}	29.96^{ns}	27.88^{ns}
Slope	9.56^{bc}	11.23^{abc}	4.66^{c}	16.75^{a}	12.89^{ab}	11.31^{ab}	13.11^{ab}
Soil moisture content	0.18^{b}	0.2^{b}	0.51^{a}	0.09^{b}	0.19^{b}	0.16^{b}	0.2^{b}
Soil organic matter	4.95^{ns}	4.47^{ns}	2.96^{ns}	5.26^{ns}	4.5^{ns}	5.16^{ns}	5.11^{ns}

Different letters within each row indicate significant differences at $p < 0.05$.

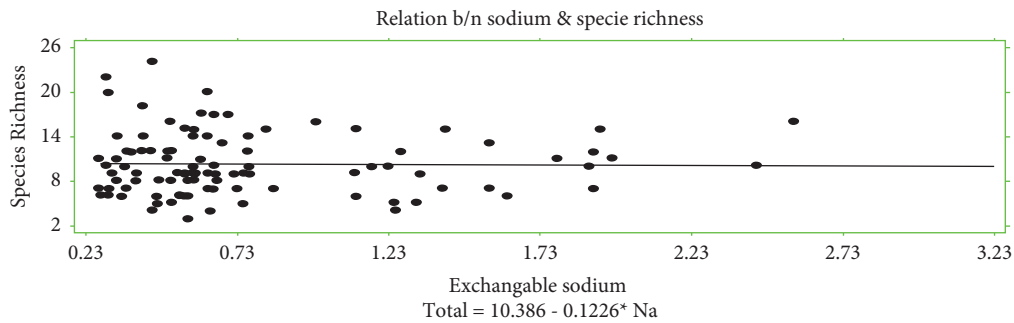


(a)



(b)

Figure 6: Continued.



(c)

Figure 6: (a–c) Linear relationship between explanatory environmental variables and species richness.

distribution of sand 31.3%, silt 39.66%, and clay 31.3% and thus had the textural class of silt clay loam. The highest mean sodium (10.34 ± 6.26 ppm) was recorded in this community (Supplementary file 1). The highest mean disturbance (1.8 ± 0.4) through grazing pressure was recorded in community three. Group four had the highest mean sand content of 50.75%, silt of 31.12%, and clay of 22.31%, respectively, which showed the community's textural class of sandy clay loam. The mean slope of the community was 16.75 ± 2.3%. Group five was located relatively at higher elevation 1484 m.a.s.l. The highest mean of CEC 27.44 ± 1.83) was recorded in community six (Supplementary file 1).

3.4.4. Linear Relationship between Species Richness with Explanatory Environmental Variables. Species count (the total number of plant species recorded in each sample plots) has shown positive correlation with altitude at $r^2 = 0.038$ ($P < 0.05$). In this particular study, species richness is greater at an intermediate elevation range between 1400 m and 1550 m.a.s.l. (Figure 6(a)). Richness decreases with both extremes of altitude. Knowing the pH of the soil will quickly allow you to determine whether the soil is suitable for plant growth and what nutrients will be most limiting. In this study, the negative relationship between soil pH and species richness is at $r^2 = 0.015$ ($P < 0.05$) (Figure 6(b)). Relatively better richness was found from pH value of 6.5–7.5 (Figure 6(b)). At pH values <5, the soil became acidic which causes essential nutrient especially nitrogen and phosphorous to be bound in compounds that plants cannot use [13]. Sodium also has shown negative correlation with species richness at $r^2 = 0.025$ ($P < 0.05$) (Figure 6(c)). The figure shows that few plant species tolerate salt concentration above 0.75. Majority of species grown on soil with sodium concentration ranges from 0.23 to 0.75 meq/L. which shows that few species tolerated sodium concentration above 1.73 meq/L.

3.5. Correlation between Environmental Variables. Results of Pearson's product-moment correlation coefficient between the whole measured environmental variables are presented in Supplementary file 2. Altitude was positively correlated with soil organic matter but nitrogen was not. The correlation among these variables that significantly explain the variation in species distribution is presented in Table 9. Highly significant positive correlations were observed between altitude with slope and sand at ($P < 0.001$). In addition, sand content and slope gradients were also positively correlated. However, highly significant negative correlation is observed between altitude with sodium and pH of the soil at ($P < 0.001$). Altitude was also negatively correlated with soil moisture content. Highly significant positive correlation was found between pH, CEC, and Na at ($P < 0.001$). Sand is negatively correlated with soil moisture content (Table 9).

3.6. Phytogeographic Comparisons. In the current study, a total of 198 plant species were recorded from the vegetation of Loka Abaya National Park. Attempts were made to compare floristic similarity of current study area with other studies conducted in Ethiopia assuming that the samplings are relatively completed. The result shows that the current study area contains relatively similar species distribution to vegetation of Nechisar National Park found within Gamo Gofa floristic region (Table 10).

4. Discussion

4.1. Floristic Composition. The studied National Park was diverse in terms of species richness with 198 plant species. Total count of species is also important for both fundamental and applied ecological research studies and further for designing managements of protected area that maximized the species diversity of the region. Different vegetation types and associated species occurred in the National Park. Friis et al. [57] divided the vegetation of Ethiopia into twelve major types for the purpose of land use planning, natural resources management, and conservation of biodiversity. These vegetation types host their own unique species but also share several common species. Some vegetation types and associated species occurred in this National Park. The Riverine Vegetation (RV) is represented at the Loka-Abaya National Park by characteristic species like *Syzygium guineese, Tamarindus indica, Diospyros mespiliformis, Vachellia albida, Ficus sur, Ficus sycomorus, and Mimusops kummel* were recorded in this vegetation type as reported by Firrs et al.

Table 9: Pearson's product-moment correlation coefficient between environmental variables which significantly explain the variation in species distribution and community composition.

Variables	Altitude	CEC	K	Mg	Na	Sand	Slope	SMC
Altitude	1.00							
CEC	-0.18^{ns}	1.00						
K	-0.12^{ns}	0.16^{ns}	1.00					
Mg	-0.11^{ns}	0.15^{ns}	-0.02^{ns}	1.00				
Na	-0.35^{***}	-0.01^{ns}	0.14^{ns}	0.13^{ns}	1.00			
pH	-0.47^{***}	0.42^{***}	0.07^{ns}	0.23^{*}	0.57^{***}			
Sand	0.42^{***}	-0.20^{*}	-0.05^{ns}	0.04^{ns}	0.00^{ns}	1.00		
Slope	0.50^{***}	-0.10^{ns}	-0.08^{ns}	0.02^{ns}	-0.13^{ns}	0.24^{**}	1.00	
SMC	-0.17^{ns}	-0.00^{ns}	-0.07^{ns}	0.06^{ns}	0.00^{ns}	-0.19^{*}	-0.13^{ns}	1.00

$^{***} = p < 0.001$; $^{**} = p < 0.01$; $^{*} = p < 0.05$; ns = not significant.

Table 10: Comparison of vegetation of LANP with other similar vegetations.

Sources	*N*	*a*	*b*	*c*	Ss	Altitude	Vegetation
Masresha et al., 2015	124	46	124	78	0.30	2180–2470	Alemsaga
Shimelse et al., 2010	208	63	139	149	0.31	1108–1690	Nechisar
Soromessa et al., 2004	198	45	153	161	0.22	600–1900	G/Gofa
Berhanu, 2017	212	43	146	169	0.21	1830–2660	Awi
Current study	198	198	0	0	1.00	1178–1650	L/Abaya

[57], *Vachellia* (Acacia)-*Commiphora* woodland and bushland (VCB) vegetation is represented at the Loka-Abaya National Park by characteristic species such as *Vachellia tortlis subsp. spirocarpa*, *Balanites aegyptiaca*, *Combretum molle*, and *Combretum collinum* as reported by Institute of Biodiversity Conservation [2]. The vegetation was also represented by dry evergreen Afro-montane forest and grassland complex (DAF). The presence of lake Abaya bordering the National Park help to contains some components of vegetation from Freshwater Lakes, Lake Shores, and Marsh and Flood-plain Vegetation (FLV) which was reported by Friis et al. [57]. This vegetation is represented at the Loka-Abaya National Park by characteristic species such as *Panicum subalbidm, Phyllanthus amarus,* and *Cyperus usitatus*. *Panicum subalbidum, Phyllanthus amarus* Schum. & Thonn., and *Cyperus usitatus* L. are some of the species found in this vegetation. The number of individual species present in the study area is the result of existence of diverse habitats and physiographic nature of the area with permanent and seasonal rivers and presence of Lake Abaya and associated wetland, flood plain, mountain, valley, slopes, and disturbance level which made the vegetation diverse and rich in species. Furthermore, species count indicates a clue for biodiversity potential of that particular area that helps to strengthen the conservation of individual plant species. Furthermore, species count can be a relatively unambiguous measure of biological diversity of different areas assuming the sampling is relatively complete [23].

The recorded plant species in the studied National Park were higher than Dello Menna woodland vegetation with 171 species [58], broad-leaved deciduous woodlands of Metema with 87 species [22], and Alemsaga with 124 species [59]. However, the species richness of current study area is less than the vegetation of Gamo Gofa with 216 species [4] and Nechisar National Park with 208 species [28]. Several factors and their complex interaction may be responsible for such variation in species richness from site to site. According to Maestre [60], these differences in species richness are primarily a function of differences in site productivity, habitat heterogeneity, and/or disturbance factors. In general, plant species richness is scale-dependent, that is, the species lists increase in size as larger areas are surveyed [61].

The analysis of individual species of the study area showed that only three exotic species were recorded in native vegetation. These exotic species only found in the sample were associated with Billate riverside vegetation. This revealed that water is an important route for the introduction of new species, including invasive alien species to native vegetation. Tererai [62] reported that the expansion of exotic species in native vegetation is changing the structure and composition of native plant communities. Evan [63] pointed out that indigenous species are ecologically more valuable than exotics for the conservation of native flora and fauna as well as for the conservation of water resources. According to Tererai [62], incidences of pest and disease are also one of the ecological impacts of introduction of exotic species in native vegetation. It is generally accepted that managing the distribution of exotic species to native vegetation while preventing the introduction of invasive species is the best way to reduce total ecological impacts of exotic and invasive alien species. Therefore, it is important to maintain the riparian buffer strips at the level of the management unit for monitoring the introduction and expansion of exotic as well as invasive alien species to native vegetation in the National Park and surrounding water body. Among the documented species, only three species were red listed Ethiopian plant species found in the studied park as reported by Vivero et al. [64]. According to Kelbessa et al. [65], these endangered species may be able to

tolerate some disturbances and adversely impacted by habitats clearance. They need habitats or community level conservation strategies to ensure their existence in the National Park.

The botanical family Fabaceae was represented by the highest number of species followed by Euphorbiaceae. The dominance of family Fabaceae was reported in several studies conducted in Ethiopia (see [3, 6, 28]). This may partly be explained by its dominancy in the Ethiopian flora. Woldearegay et al. [66] noted that the dominancy of the family Fabaceae could also be attributed to its efficient and successful dispersal strategies as well as better adaptation to a wide range of ecological conditions in and outside the country. The family Fabaceae is also recognized to contain species of great economic importance which include pulse crops, forage, medicinal and ornamental plants, plants of great significances for charcoal, and timber production, and those plants that have ability to fix nitrogen in association with symbiotic bacteria [67]. Euphorbiaceae generally represented by woody species which is a common character to all tropical forests vegetation [68]. Regarding growth form, the highest number of woody species recorded in the current study was partly explained by the entire vegetation of the National Park that is dominated by woodland and forestland.

4.2. Species Diversity among Plant Community. Management, conservation, and monitoring of changes over time are often meaningful when carried out at the level of plant communities [69]. By identifying different plant communities, we are identifying different ecosystems at a particular hierarchical level as noted by Brown et al. [70]. The classification of vegetation into plant community types would make the future management of the vegetation feasible and facilitate the choice of appropriate management regimes for each plant community types [58]. Moreover, the classification helps to identify ecologically sensitive areas to give conservation priority. The identified plant community types were different in terms of Shannon–Wiener (H') diversity index and Simpson diversity and evenness indices. Simpson diversity focused on most abundant species opposed to Shannon–Wiener (H') which considers species richness and evenness values.

The second highest Shannon–Wiener (H') diversity index ($H = 3.410$) value was obtained by community one. This may be attributed by the community occurred at wider altitudinal ranges as compared to other plant community types. The dominancy of both diagnostic species *Vachellia brevispica* and *Rhus natalensis* may be explained by the coppicing ability after cutting or burring as reported by Bekele [71]. *Ficus sur–Vachellia albida* community two occurred along permanent and seasonal rivers. The group maintains the highest species diversity index ($H = 3.610$) values. In dry environments, the riverine systems are regulated by water and nutrient inputs from the upper slopes. These inflows of water and minerals from upper slope may contribute to high species diversity as reported by Aynekulu [72]. The associated species of the community *Vachellia seyal* and *Vachellia drepanolobium* are dominantly found in few places at flat waterlogged area. This confirms the report of Woldu and Nemomissa [73], who noted that *Vachellia drepanolobium–Vachellia seyal* community type occurs in depressions that may be waterlogged during the rainy seasons. Friis et al. [74] confirm that the riverine vegetation shares species from other adjacent vegetation types.

The plant community three had a distinctive floristic composition and the least species richness as compared with other communities. This may be explained by the community that occurred at a fluctuating environment that allows few plant species that have a special physiological adaptation to grown under such environmental conditions. Comparatively less species richness of wetland community was reported Zewdie et al. [75]. Low species diversity index ($H = 2.878$) value was recorded in group four. This may be due to the overdominance of *Dodonaea angustifolia* as a result of its pioneer nature. *Dodonaea angustifolia* can establish itself on degraded land once the disturbance has ceased [76]. Community five occurred at relatively higher but narrow elevation range with mean ± SE (1484 ± 0.54). During vegetation, the inventory observed selective removals of species for charcoal production as evidenced by the existence of stubs and illegal charcoal production site/pits sample associated with the community. Maintaining a high canopy cover may create a better soil moisture environment for a successful regeneration and seedling establishment. The removal of the canopy species also affects the regeneration of native species while favoring the spread of colonizing shrub and herb species. This clearly affects diversity and structure of the community as reported by Kouami et al. [77]. The highest species richness (90 species) was recorded at plant community six. This may be due to a larger sample size because as sample size increases, the chance of recording more species is higher. The community accommodates a large number of common wild edible plant species, including *Balanites aegyptiaca, Grewia bicolor, Euclea schimperi, Rhus natalensis, Lannea schimperi,* and *Ximenia americana*. Group seven was dominated by *Dichrostachys cinerea* and the species has encroached to other community types [13, 28]. It needs management and monitoring attentions.

4.3. Community-Environment Relation. According to He et al. [78], understanding relationships between environmental variables and vegetation distribution helps us to apply these findings in management and conservation of vegetation resources. In the current study, 74.99% of total variation in species composition was explained by measured environmental variables. This indicated that the measured environmental variables had a large impact on the distribution species. The remainder might be explained by other environmental factors that might not be included in this analysis or partly may be influenced by biotic factors, such as competition and facilitation as noted by [79]. According to Adel et al. [80], the primary objective of plant ecology is to understand the factors controlling local distribution of plant species and communities composition. Therefore, understanding the distribution pattern of vegetation along with the causal factors in particular areas is important for conservation and restoration. In the

current study, seven plant community types were significantly different in terms of altitude, percent sand, clay, slope, ecological disturbances through grazing, potassium, soil pH, exchangeable sodium, soil moisture content, and cation exchange capacity (CEC) at $p < 0.05$.

Plant community five occurred at high elevations. Similar results were reported on the role of altitude on community composition [1, 5, 7, 9, 11]. Altitude is an important environmental factor that affects radiation, atmospheric pressure, moisture and temperature because it strongly influences the length of growing season associated with temperature. All these have a strong influence on the recruitment, growth, and development of plants and the distribution of vegetation types [1, 9]. Therefore, it is significant in vegetation restoration as reported by Adel et al. [80]. Soil texture plays an important role in determination of vegetation groups because soil texture controls dynamics of soil organic matter or organic matter decomposition and formation as well as influences infiltration, moisture retention, and the availability of water and nutrients to plants [78, 81]. Percent clay was found to be higher at *Ficus sur–Vachellia albida* (community two) which was found along permanent and seasonal rivers as well as on flood plains in the National Park. The community accommodates few exotic tree species which have a potential for changing the structure and composition of this native plant community. In addition, the community occurred is light-textured soil which is particularly sensitive to wind and water erosion and thus should be handled carefully to maintain vegetation cover and prevent soil erosion. Therefore, it is important to maintain the riparian buffer strips at the level of the management unit for monitoring the introduction and expansion of exotic as well as invasive alien species to native vegetation in the National Park and surrounding Lake Abaya and to manage the soil from erosion.

Plant community three was influenced by ecological disturbances through grazing, potassium, exchangeable sodium, soil moisture content, and soil pH. The higher ecological disturbances through grazing were recorded in this group. The grazing pressure may lead to the formation of a new plant community type which may be fragile to change. This may cause further damaging in this indispensible habitat and associated biodiversity. The loss of lake-associated wetland through grazing pressure is evidenced from report of Dadi [82] at other Rift Valley's Lake Hawassa. The phenomena that lead to the compaction of wetland by livestock affect infiltration capacity of the soil, hence affecting the hydrological system and balance of the wetland itself. This also leads to accumulation of silt in lake water, resulting in the degradation of water quality for aquatic organisms and human consumption, so the community needs attention for conservation. Exchangeable sodium is exceptionally higher in plant community three, while no statistically significant difference was obtained among other plant community types. Such high concentration of exchangeable sodium may be due to the absence of proper drainage systems for water at flatland and some samples associated with this community were found on unusually bole soil. Such soil is abundant in the Central Rift Valley and contains high amount of common salt (NaCl) as reported by Tolla et al. [83]. Contrary to this finding, the higher sodium concentration of grassland and woodland vegetation of Gambella, southwest Ethiopia, was reported [9] due to the fire incidences that remove the humus and cause accumulation of soluble salts. The amount of salinity can have negative effects on species that are related to increase environmental drought, increased osmotic pressure of the soil solution, and ion toxicity, which limit the water and nutrients that can be absorbed by plant roots [84]. Soil pH is also an important environmental variable that influences species distribution and plant community composition. The highest pH was recorded in plant community three which was found at Lake Abaya-associated wetland that means the group had the lowest acidity (pH) of all communities recognized in this study. Similar results were reported by Dong et al. [85] who noted that pH is an important soil chemical property that influences wetland plant communities. Bowers and Lowen [23] summarized that soil pH affects the growth of plants and the distribution of vegetation types by its effect on the availability of mineral nutrients and decomposition of organic matter.

Community four was found on higher slopes and higher percent sand. Soromessa et al. [4] reported that slope was also an important environmental element, which influences plant distribution, runoff, and drainage, thereby also determining the nutrient, depth, and water content of the soil. Plant establishment becomes increasingly difficult with increasing slope steepness due to reduced soil depth and increased water drainage [80]. Potassium is also another significant environmental variable that affects species distribution and plant community composition. In the current study's results, potassium is significantly higher at plant communities one and six. The presence of potassium in the soil makes it easy to transport the water and nutrients in the soil, and it plays a major role in the regulation of photosynthesis, carbohydrate transport, protein synthesis, and other phytosociological processes that are important for plant growth and survival. In addition, existence of potassium in the soil makes easy to transform the water and nutrients in the soil.

4.4. Linear Relationship between Species Richness and Some Environmental Variables. Understanding the determinants of species richness is central to many questions in both pure and applied ecology as noted by Zhang et al. [86]. The examination of the linear relationship between species richness and some influential environmental variables such as altitude, soil pH and exchangeable sodium showed the weak positive correlation between species richness with altitude. Similar to this, the richness of both herbaceous and woody species is positively correlated with altitude as reported by Dale et al. [19]. Conversely, Kebede et al. [87] noted that both species richness and abundance were negatively correlated with altitude. Negative correlation was observed between species richness and soil pH. Knowing the pH of the soil will allow you to quickly determine whether the soil is suitable for plant growth and what nutrients will be most limiting. Relatively better richness was found from pH value 6.5–7.5. At pH values <5, the soil became acidic which causes essential nutrient especially nitrogen and phosphorous to be bound in compounds that plants cannot use. Negative relationship

between species richness and very high concentration of sodium in the soil, such as soil required plant species, have a special physiological adaptation [23].

The relationship between environmental variables indicated that highly significant positive correlations were observed between altitude with slope and sand at $P < 0.001$. Woldu and Backeus [9] noted that altitude is positively correlated to slope. Similarly, positive correlation between altitude and slope was reported [1]. In addition, a positive correlation between sand content and slope was observed. However, highly significant negative correlation was found between altitude and ecological disturbances through grazing, sodium, and pH of the soil at $P < 0.001$. Weak positive relation between altitude and total nitrogen content and altitude is negatively correlated with soil moisture content. Altitude is positively or negatively correlated with different environmental variables indicating that altitude is one of the most important environmental variables that influences survival, growth, and distribution of plant species. Highly significant positive correlation was found between pH, CEC, and Na at $P < 0.001$. Naghi et al. [83] reported that foot slopes reduced the movement of soil water, causing the accumulation of soluble cations and resulting in soils with higher pH.

Floristically, the current study area contains relatively similar species distribution to vegetation of Nechisar National Park [28] found at Gamo Gofa floristic region. This may be associated with similarity in the altitudinal range between the two national parks which is separated by the Lake Abaya. It is also that the two areas have a similar bimodal rainfall pattern with the mean annual rainfall 919.08 mm being recorded in Nechisar and 857.86 mm recorded in the currently studied national park.

5. Conclusion

The vegetation of Loka Abaya National Park accommodates a large number of species from broader, *Vachellia–Commiphora* woodland, and dry evergreen Afromontane forest, and grassland complex (DAF) vegetation types of Ethiopia. Knowledge of these species is essential for planning operations that aim to manage, conserve, and monitor changes that occur over time in the individual taxa and the entire vegetation of the National Park. The National Park partly covered the upper, middle, and bottom portions of Lake Abaya, subwatershed, helped to improve lake water quality for aquatic ecosystem through flood control, and called immediate conservation attention. The vegetation was also classified into seven community types; perhaps, understanding the current state of plant communities is the most appropriate means to restore, conserve, or manage. Species distribution and community composition was influenced by elevation, percent sand and clay, slope, ecological disturbances through grazing, potassium, soil pH, exchangeable sodium, soil moisture content, and cation exchange capacity. The knowledge of vegetation along with the causal factors in particular areas is also important to design the conservation and restoration plan. In addition, to conserve a large number of species, it is important to establish a biodiversity conservation corridor between the studied park and surrounding agroforestry land use. Moreover, further research should be conducted to understand the resources use pattern of local community living around the National Park which is important for planning species level conservation strategies.

Data Availability

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

Ethical Approval

The study was approved by Addis Ababa University, Department of Plant Biology and Biodiversity Management and Southern Agricultural Research Institute.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors played a vital role to accomplish this manuscript. Assegid Assefa developed the idea of the research, designed the research method, identified the plant, performed statistical analysis, and wrote the manuscript. Professor Tamrat Bekele, Professor Sebsebe Demissew, and Professor Tesfaye Abebe contributed significant input to the successful completion of the manuscript by supervising the study, giving consistent and inspiring guidance, sharing valuable suggestions, making constructive comments, and helping with reviews on the manuscript preparation.

Acknowledgments

We are grateful to staff of Loka Abaya National Park office for facilitation of this research work. Hawassa University College of Agriculture and Hawassa Agricultural Research Center are also highly acknowledged for their assistances during laboratory soil analysis. Special thanks go to Addis Ababa University's National Herbarium for species identification.

Supplementary Materials

Supplementary File 1. Mean and standard errors of the environmental parameters to characterize the community types. Supplementary file 2. Pearson's product-moment correlation coefficient between measured environmental variables. (*Supplementary Materials*)

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