Hindawi
International Journal of Forestry Research
Volume 2020, Article ID 4597456, 22 pages
https://doi.org/10.1155/2020/4597456

Research Article

Woody Species Structure and Regeneration Status in Kafta Sheraro National Park Dry Forest, Tigray Region, Ethiopia

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Received 20 November 2019; Revised 28 July 2020; Accepted 27 August 2020; Published 18 September 2020

Academic Editor: Anna Źróbek-Sokolnik

The study was conducted in Kafta Sheraro National Park (KSNP) dry woodland natural forest located in Kafta Humera and Tahitay Adiyabo weredas (districts), Western and Northwestern Zones of Tigray regional governmental state, North Ethiopia. The objective of the study was to explore the floristic composition, structure, and regeneration of woody species in the home of *Loxodonta africana* L., *Hippotragus equinus*, *Anthropoides virgo*, *Ourebia ourebi*, *Crocuta crocuta*, *Tragelaphus strepsiceros*, *Phacochoerus africanus*, and unidentified crocodile and fish species. In the park, the vegetation ecology has not been studied up to date which is necessary for conservation. The systematic sampling technique was used to collect vegetation and human disturbance (presence and absence) data from August to December 2018. The vegetation data were collected from 161 plots each with a size of 400 m^2 (20 m × 20 m) for tree/shrub while subplots of size 100 m^2 (10 m × 10 m) and 25 m^2 (5 m × 5 m) for sapling and seedling, respectively, were established in the main plots. Individual tree and shrub diameter at breast height (DBH) ≥2.5 cm and height ≥ 2 m were measured using tape meter and clinometer, respectively. Diameter at breast height (DBH), frequency, density, basal area, and importance value index (IVI) were used for vegetation structure description while the density of mature trees, sapling, and seedling was used for regeneration. A total of 70 woody species (46 (65.7%) trees, 18 (25.7%) shrubs, and 6 (8.6%) tree/shrub) were identified. The total basal area and density of $79.3 \pm 4.6\ m^2 \cdot ha^{-1}$ and 466 ± 12.8 stems$\cdot ha^{-1}$, respectively, were calculated for 64 woody species. Fabaceae was the most dominant family with 16 species (22.9%) followed by Combretaceae with 8 species (11.4%). The most dominant and frequent species throughout the park were *Acacia mellifera*, *Combretum hartmannianum*, *Terminalia brownii*, *Balanites aegyptiaca*, *Dichrostachys cinerea*, *Acacia senegal*, *Acacia oerfota*, *Boswellia papyrifera, Ziziphus spina-christi*, and *Anogeissus leiocarpus*. Abnormal patterns of selected woody species were dominantly identified. The regenerating status of all the woody plant species was categorized as "fair" (18.75%), "poor" (7.81%), and "none" (73.44%). There was a significant correlation between altitude, anthropogenic disturbance (grazing and fire frequency), and density of seedling, sapling, and mature trees. But there was no correlation between gold mining and regeneration population. However, there is a good initiation for the conservation of the park; still, the vegetation of the park was threatened by human-induced fire following intensive farming, gold mining, and overgrazing. Therefore, the study area was the habitat for the population of the African elephant; species with low importance value indices and lack or having few seedling and sapling stage should be prioritized for conservation, and their soil seed banks should be studied further.

1. Introduction

Ethiopia is considered as one of the top twenty-five biodiversity richest countries in the world and hosts the Eastern Afromontane and the Horn of Africa hotspots [1]. There were around 6000 species of higher plants, of which about 10% were endemic plants in the country [2]. The flora is very heterogeneous and has a rich endemic element owing to the diversity in climate, vegetation, and terrain. While six endangered endemic plant species are found in Ethiopia especially in the Ogaden region of the ecosystem only, this is floristically the richest endemism of species in Ethiopia [3].

The diverse topographic factors coupled with the diverse climatic factors have created diverse vegetation types in the country. Consequently, the potential vegetation of Ethiopia is systematically classified into twelve vegetation types [4]. Dry tropical forests or woodlands are one of these classifications that cover about 14% of the total African land surface and represent about 25% of the natural vegetation declined rapidly by the expansion of agriculture, fire, and overgrazing [5]. Dry tropical forests are characterized by a seasonal climate, with a dry season of 4–7 months [6]. Above half of Ethiopia, the land surface is located in dry areas and associated tropical dry forests [7]. However, their vegetation resources are being destroyed increasingly because of anthropogenic disturbance [8]. Thus, the floristic composition, regeneration status, and vegetation structure are crucial elements to clearly visualize the human activities as well as environmental factors affecting the vegetation of a given area [9].

Therefore, understanding the structural pattern and regeneration status of plant species is the immediate measure taken to assess the vegetation dynamics and their destruction factors. Population structure is the distribution of individuals of each species in arbitrarily to provide the overall regeneration profile of the forest based on tree density, height, frequency, diameter at breast height (DBH), species importance value, and basal area [10, 11]. Accordingly, studies on population structure and density of major canopy tree species can help to understand the regeneration status of species as well as management history and ecology of the forest [12]. Examination of patterns of species population structure could provide valuable information about their regeneration and/or recruitment status as well as viability status of the population that could further be employed for devising evidence-based conservation and management strategies [13]. Tree structure also assists to understand forest ecosystems and biodiversity [14]. Assessment of the composition, structure, and regeneration status of species is required to ascertain the successful conservation and management of forest resources [15].

Regeneration is the ability of a cell tissue or organism and an ecosystem to recover from damage and thus a key to sustainable forestry [9]. It is a central component of forest ecosystem dynamics and restoration of degraded forest lands. Sustainable forest utilization is only possible if adequate information on the regeneration dynamics and factors influencing important canopy tree species is available [12]. The regeneration status of species in a community can be accessed from the total population dynamics of seedlings and saplings in the forest community [10, 16]. The overall pattern of population dynamics of seedlings, saplings, and adults of plant species can exhibit the regeneration profile, which is used to determine their regeneration [17]. A population with a sufficient number of seedlings and saplings depicts satisfactory regeneration [18], while an inadequate number of seedlings and saplings of the species in a forest indicates poor regeneration condition [19]. Moreover, the regeneration status of a forest is poor if the number of seedlings and saplings is much less than mature individuals [20]. The anthropogenic disturbances, namely, illegal fire, overgrazing, intensive farming, and firewood collection revealed high degradation of population structure and regeneration status of the trees in the studied forest ecosystem [21]. Assessment and knowledge of soil seed banks, seedling banks, and population structure have some practical importance in developing forest management and conservation strategies [22].

Most of the vegetation resources of the world are concentrated in protected areas [23]. The country's protected areas, such as national parks, are rich with distinctive flora and fauna [24]. Protected areas play a vital role in in situ biodiversity conservation [25, 26]. According to the International Union for Conservation of Nature (IUCN), protected area is defined as "*an area of land and/or sea especially dedicated to the protection of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means*" [23]. In the past few decades, the numbers of protected areas in developing countries are expanding [27]. Ethiopia is one of the few countries that have more than 55 protected areas including 21 national parks which cover 17.1% of the country's land to protect and conserve the natural ecosystems and wildlife heritage [28]. However, the vegetation resources of Ethiopian protected area (national parks) are being destroyed at the highest rate because of habitat degradation or loss, fragmentation due to livestock encroachment, illegal settlement, and agricultural expansion, burning of vegetation for cultivation, mining, and land-use and border conflicts of local communities. Moreover, vegetation cover is being converted to small and large scale farming, timber products are destructed for household fire wood consumpotion and construction purpose and the protected area grasslands are destroyed by free grazing of livestock [29]. In developing countries, it is common to have grazing, logging, and other extractive activities that occur in protected areas by local communities.

Kafta Sheraro National Park (KSNP) was recognized in 2007 as a park, in the Tigray region, North Ethiopia. The park is rich in natural vegetation and has great wildlife resources particularly the home of megaherbivores of the African elephants. But as a result of being a newly established park, it lacks basic information on vegetation ecology. Therefore, for effective management and conservation of the park, there is an urgent need to develop a sound management plan, and this required detailed baseline information on stand structure and seedling and sapling status of woody species. However, Kafta Sheraro National Park to date lacks scientific and essential baseline investigation on vegetation structure and regeneration status that is fundamental for sustainable management and conservation of the park tree species. Therefore, the main objective of this study was to complete the current information gap in woody species of Kafta Sheraro National Park dry forest. The specific objectives of the study were (1) to document the species composition and structure (diameter at breast height (DBH) distribution, height class distribution, density, basal area, frequency, and importance value index), (2) to assess the regeneration status of Kafta Sheraro National Park natural woody species, and (3) to evaluate plots based on human impacts on structure and regeneration status of woody tree species.

2. Materials and Methods

2.1. Description of Study Site. Kafta Sheraro National Park (KSNP) was designated as a park in 2007 (Letter, No. 13/37/82/611) with an area of 2176.43 km^2, while the park was formerly named as "Shire Wildlife (game) Reserve" which was established in 1973 with an estimated area of 750 km^2 governed by Tigray regional governmental state. Blanc et al. [30] reported that Shire Wildlife Reserve is one of the nine elephant's home areas in Ethiopia. Kafta Sheraro National Park is located in Kafta Humera and Tahitay Adiyabo weredas (districts) of Western and Northwestern Zones of Tigray region 1356 km far from Addis Ababa and 490 km from Mekelle city. It is situated in the north of Ethiopia between latitude 14°05′–14°27′ N and longitude 36°42′–37°39′ E. The park is bordered by Eritrea in the north and transverse by Tekeze River (Figure 1). The elevation of the Park Forest varies from 539 to 1130 meters above sea level (m.a.s.l.). The landforms of the areas are heterogeneous in nature and consist of a flat plain, undulating to rolling, some isolated hills and ridges, a chain of mountains, and valleys.

The climate of the area is generally characterized by hot to warm semiarid and with seasonal rainfall. The mean monthly temperature ranges from 28.35°C to 35.1°C. The coolest temperature occurs from July to September while the warmest temperature occurs from March to May. The maximum mean monthly temperature is in March (33.15°C) and May (34.4°C) while the minimum is in both August (28.35°C) and January (28.65°C), respectively. The rainfall pattern is bimodal with two distinct seasons. The short rains occur from May to mid-June and September whereas the long rains occur during July (174 mm) and August (252 mm). The nearby stations of Humera and Shiraro towns of meteorological center record data (1966–2016) [31] were used for rainfall and temperature analysis of the park (Figure 2).

Based on vegetation classification of Ethiopia [4], Kafta Sheraro National Park Forest communities are broadly categorized as Acacia-Commiphora woodland and bushland proper with dominant *Acacia mellifera* and *Balanites aegyptiaca* species; Combretum-Terminalia woodland and wooded grassland with *Terminalia brownii* and *Boswellia papyrifera* as frequent species; and riparian/riverine forest with *Hyphaene thebaica* as dominant species. Selected parts of this study were dominated by *Boswellia papyrifera* species which is a frankincense-producing tree [32]. Thus, the severity and vegetation cover decline are higher in these lowland protected areas because they are remote and have a scarcity of resources [33].

Based on the preliminarily survey, the park is a home for 42 mammals, 9 reptiles, 167 bird species, unidentified fish, and crocodile species [34]. After ten years of research result, the birds count reduced to 158 species [35]. The park is also extremely important and could be the only site in Ethiopia for wintering migratory birds of demoiselle crane (*Anthropoides virgo)* [36]. The presence of large mammals such as African elephant (*Loxodonta africana*), caracal (*Felis caracal*), leopard (*Panthera pardus*), greater kudu (*Tragelaphus strepsiceros*), oribi (*Ourebia ourebi*), waterbuck (*Kobus ellipsiprymnus*), spotted hyena (*Crocuta crocuta*), *crocodile sp*., warthog (*Phacochoerus africanus*), aardvark (*Orycteropus afer*), anubis baboon (*Papio anubis*), grivet monkey (*Chlorocebus aethiops*), and roan antelope (*Hippotragus equinus*) [34] together with the hydrology of Tekeze River makes Kafta Sheraro National Park (KSNP) a significant site for the priority of conservation.

2.2. Sampling Design. A reconnaissance survey was undertaken for this study from August 18 to 25, 2018, to have an impression of the forest sites and vegetation distribution and to decide the reasonable sampling methods. During the surveying period, supportive information was collected from the park administrative office and local households living near the park. Following the survey, the Park Forest was classified into three strata (sites) based on homogeneity in floristic composition and distributional patterns of vegetation classification of Ethiopia: (1) Acacia-Commiphora woodland and bushland community, (2) Combretum-Terminalia woodland community, and (3) riparian/ riverine vegetation community of Kafta Sheraro National Park Forest.

Then a systematic sampling technique was applied in the three strata to collect the woody vegetation data following Kent and Coker [37]. According to species-area curve (minimal area) concept in [38], the plot size was decided. For this study, a total of 32 transect lines were placed at a distance of 0.3 km apart along with the three communities. Along line transects, 161 plots (76 from Acacia-Commiphora, 47 from Combretum-Terminalia, and 38 from riparian strata) each with a size of $20\,m \times 20\,m$ ($400\,m^2$) systematically were established for trees and shrubs approximately at 0.2 km interval. Within the main sampling plot, the subplots of $5\,m \times 5\,m$ ($25\,m^2$) and $10\,m \times 10\,m$ ($100\,m^2$) for seedlings and saplings were established, respectively. All transects and plots were located using a compass and Geographical Positioning System (GPS) of a navigation system.

2.3. Data Collection

Woody vegetation: the detailed vegetation data were collected during flowering and fruiting season from August 26 to December 30, 2018. Trees and shrubs: in the main plot ($400m^2$) area each plant (stem) of all tree and shrub species with a diameter at breast height (DBH) ≥2.5 cm abundance was counted and their circumference was recorded (diameter). Plant species outside plots were also recorded to give a more complete list of species. Height of individual trees and shrubs ≥2 m was recorded for every woody individual plant having a diameter at breast height (DBH) ≥2.5 cm [39]. Diameter at breast height (DBH) was measured using tree caliper and tape

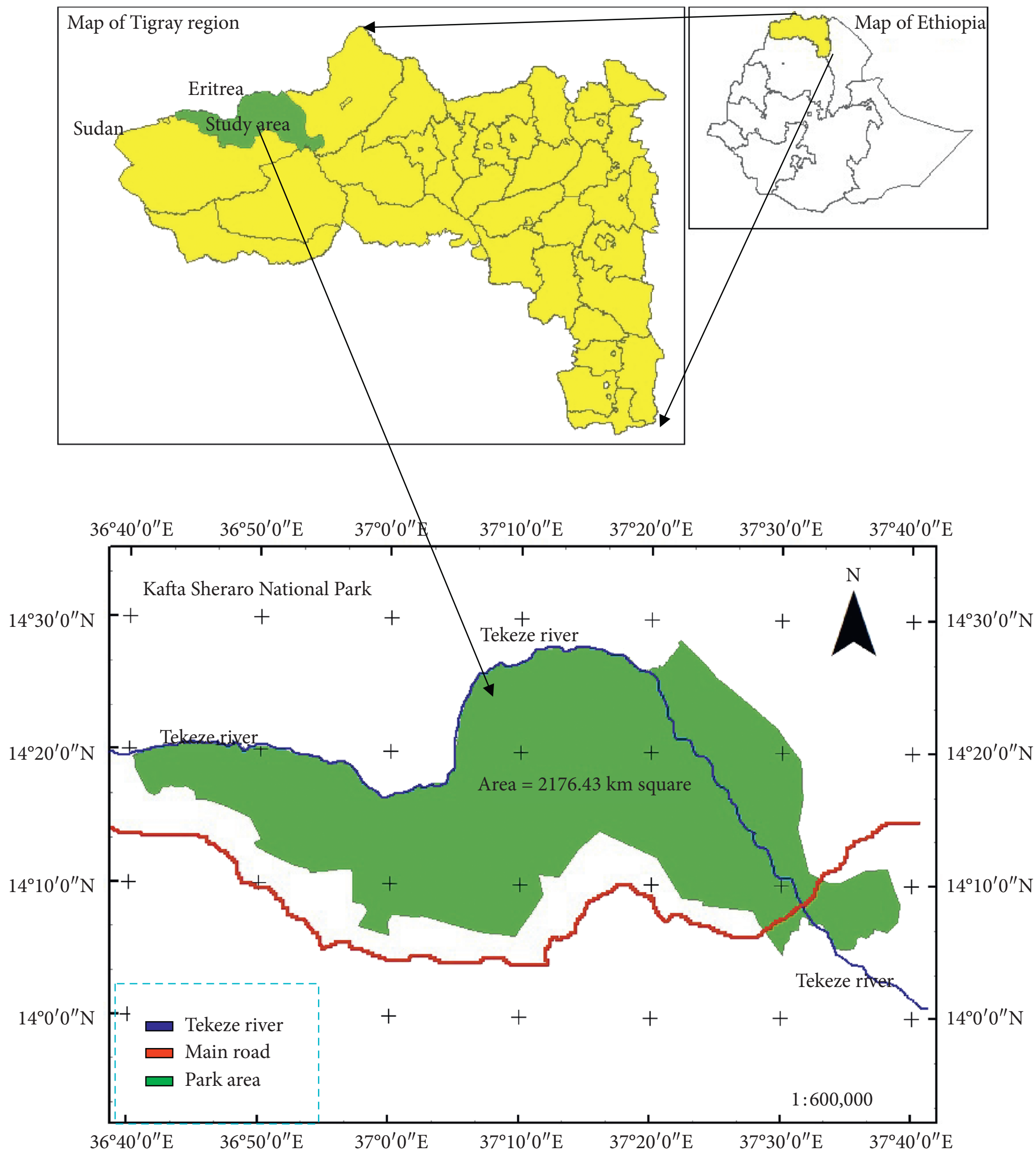

Figure 1: Location of the study site.

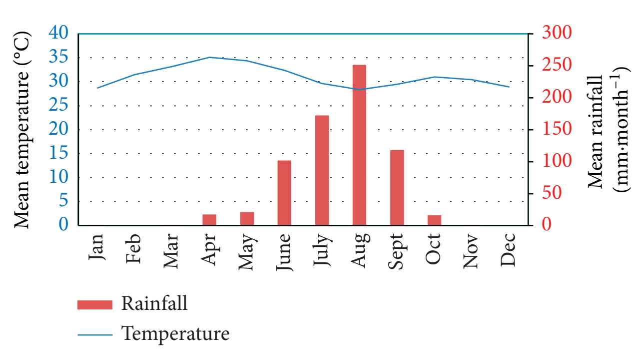

Figure 2: Mean monthly rainfall (mm·month^{-1}) and temperature (°C) of Humera and Shiraro Meteorological Center from 1966 to 2016 (Ethiopian National Meteorological Agency [31]).

meter while height was measured using a clinometer and visual estimation. Trees with multiple stems arising from the ground level were measured individually and developed a common diameter at breast height (DBH) of all stems by summing up their square roots following the guidelines in [40]. Sapling and seedlings: to collect data on the abundance of sapling and seedling of each woody plant species, subplots of 10 m × 10 m (100 m^2) and 5 m × 5 m (25 m^2), respectively, were set up within the main plot. Saplings are young woody plants with a diameter at breast height (DBH) < 2.5 and height >1 m < 2 m whereas seedling woody plants with a diameter at breast height (DBH) < 2.5 cm and height ≤1 m following the techniques described in [41, 42]. The height of each sapling and seedling was measured using a tape meter. During the study period, physiographic variables such as altitude, latitude, and longitude were also measured from the center of each main plot by Geographical Positioning System (GPS).

Anthropogenic disturbance: in addition to recording the physiographic variables (altitude, latitude, and longitude), human disturbances such as grazing intensity, human-induced fire, and gold mining signs were recorded in 161 sampled plots. Based on the reconnaissance survey, grazing intensity, fire frequency, and gold mining were identified as the most pronounced negative impacts in the park. The degree of impact was estimated based on the qualitative presence and absence method. Thus, if any disturbance sign was present in the plot, it was scaled as (presence = one), while if there was no disturbance sign in the plots, it was scaled as (absence = zero).

Plant species identification was started in the field by recording the local name by asking local elders and referring the scientific name identification using Flora of Ethiopia and Eritrea Volume 1–Volume 8 [43–49]. Specimens of identified and unidentified species were collected, pressed, and dried properly, following standard Ethiopian Herbarium (ETH) procedures and taken to Addis Ababa University Herbarium for further confirmation and identification of specimens of those species which could not be identified in the field.

2.4. Data Analysis

2.4.1. Structural Data Analysis. Diameter at breast height, height, basal area, tree density, frequency, and importance value index were used to describe the woody vegetation structure of a given forest. The following formulas were utilized in the Microsoft Excel spreadsheet program and presented in descriptive statistics:

Diameter at breast height (DBH): diameter of woody species was arbitrarily arranged in diameter class intervals by referring the study of Atsbha et al. [49]. Diameter of trees/shrubs of plant species of Kafta Sheraro National Park (KSNP) was classified into nine classes of 10 cm interval: 2.5–10, 10.1–20, 20.1–30, 30.1–40, 40.1–50, 50.1–60, 60.1–70, 70.1–80, and >80.1 cm.

Height: height of individuals' trees/shrub plant species was arbitrarily defined by height class intervals [50]. The height of the park was classified into seven classes of 5 m interval: ≤4, 4.1–9, 9.1–14, 14.1–19, 19.1–24, 24.1–29, and >29.1 m. The densities of individuals falling in the diameter at breast height (DBH) or height classes were summed up.

Frequency of species: the probability of finding a species in a given sample area [37]:

$$\begin{aligned}\text{frequency}\,(F) &= \left(\frac{\text{number of plots in which a species occurs}}{\text{total number of plots laid out in the study site}}\right) \times 100,\\ \text{relative frequency}\,(\text{RF}) &= \left(\frac{\text{frequency of a single species}}{\text{total frequency of all species}}\right) \times 100.\end{aligned} \tag{1}$$

Finally, the frequency was summarized by class interval following the study of Lamprecht [51]. The frequency of the park was arranged into seven classes of 15% intervals: ≤5, 5.1–20, 20.1–35, 35.1–50, 50.1–65, 65.1–80, and >80.1%.

Density of species: it is a count of the numbers of individuals of each species within the quadrat [37]. The sum of individuals per species is analyzed in terms of species density ha^{-1} [52]:

$$\begin{aligned}\text{density}\,(D) &= \frac{\text{number of aboveground stems of a species}}{\text{number of quadrats} * \text{quadrat area}},\\ \text{relative density}\,(\text{RD}) &= \frac{\text{density of a single species}}{\text{total density of all species}}.\end{aligned} \tag{2}$$

Density was arranged by class intervals following the dry forest study of Atsbha et al. [49]. The Park Forest was classified into five density class intervals: ≤2, 2.1–10, 10.1–50, 50.1–100, and >100.1 stems·ha^{-1}.

Basal area: it is the area outline of a plant near the ground surface and expressed in m^2·ha^{-1} [37]:

$$\text{basal area (BA)} = \frac{\pi d^2}{4}, \quad \text{where } \pi = 3.14 \text{ and } d = \text{diameter at breast height (m)}. \tag{3}$$

Dominance: the degree coverage of species occupied a space at ground level [52]:

$$\text{dominance} = \text{the mean basal area per species}^{*}\,\text{abundance (no) of the species,}$$
$$\text{relative dominance (RDO)} = \left(\frac{\text{dominance of a single species}}{\text{total dominance of all species}}\right) \times 100. \tag{4}$$

Importance value index (IVI): It indicates the relative ecological importance of a given woody species a particular site [37]:

$$\text{IVI} = \text{relative density (RD)} + \text{relative frequency (RF)} + \text{relative dominance (RDO)}. \tag{5}$$

2.4.2. Species Regeneration Data Analysis. The regeneration status of Kafta Sheraro national park woody species was computed by comparing the density data of seedling and sapling with that of matured trees following the techniques described in [42, 53–55]. The regeneration status was categorized in the following order: "good" regenerating, if present in seedling > sapling > mature tree; "fair" regenerating, if present in mature tree > sapling > seedling; "poor" regenerating, if a species survives only in the sapling stage (even saplings less than, more than, or equal to mature); "none" regenerating, if a species is absent in both sapling and seedling stages but present as mature); "new" regenerating, if a species has no mature but only sapling and/or seedling stages.

2.4.3. Human Disturbance. During the preliminary survey, human-induced fire, gold mining, and grazing by livestock were the most important anthropogenic disturbances identified in Kafta Sheraro National Park (KSNP). The magnitude of the impacts of the disturbance was quantified based on the variables score absence and presence recorded in each plot. The type and degree of anthropogenic disturbance were analyzed for the three strata, and scores of each type of disturbance value obtained from plots were summed and the average was taken following the methods of Gebeyehu et al. [21]. Finally, each site disturbance score had pointed out to show the highest disturbance and low disturbance rates. Three disturbance mean scores indicate almost all the plots of Combretum-Terminalia and riparian vegetation had the presence of disturbance sign and the mean score of 0.74 indicates that most of Acacia-Commiphora site sapling plots had free of disturbance sign (Table 1).

2.4.4. Statistical Analysis. Quantitative data such as the variation of basal area and density of seedling, sapling, and mature tree of all woody species in response to altitude along sampling plots were estimated by the analysis of variance and linear regression fitting model to measure any significant difference. The natural regeneration status in response to altitude and human disturbance variables (grazing intensity, a fire sign, and gold mining) was analyzed using regression and correlation statistical method. All analysis was facilitated using the R statistical package [56]. For qualitative analysis, descriptive statistics were used and these descriptive statistics graphs were performed with the Microsoft Office Excel 2007 software.

3. Result

3.1. Species Composition and Diversity. A total of 2984 individual stems with a diameter at breast height (DBH) of ≥2.5 cm representing 70 woody species belonging to 50 genera and 34 families were identified in Kafta Sheraro National Park (KSNP) Forest. From these species, 46 (65.7%) were trees, 18 (25.7%) were shrubs, and 6 (8.6%) were trees/shrubs as shown in Table 2. Fabaceae was the most dominant family with 16 species (22.9%) followed by Combretaceae with 8 species (11.4%); Tiliaceae and Rhamnaceae have equally four species (11.42%); Capparaceae and Anacardiaceae have three species each (8.58%); Burseraceae, Ebenaceae, Asclepiadaceae, and Apocynaceae have two species each (11.44% from total); and the rest 24 families represented by a single species each (34.32% from total species) Table 3. Out of 70 species, 64 were used for the next analysis and six species were outside plots utilized for

Table 1: Human disturbance variables (mean value) along the vegetation sites (strata).

Vegetation strata	Average altitude (m)	Plots	Grazing	Fire	Gold mining	Disturbance score
Acacia-Commiphora	647.3	76	0.58	0.145	0.013	0.74
Combretum-Terminalia	868.3	48	1.00	1.00	0.73	2.73
Riparian/riverine	597.9	37	1.00	1.00	1.00	3.00

Table 2: Natural regeneration status of woody species in Kafta Sheraro National Park.

S. no.	Scientific name (species)	Family	Hab.	SD	SPD	MD	RS
1	*Acacia albida* Del.	Fabaceae	T	0	0	0.31	None
2	*Acacia etbaica* Schweinf	Fabaceae	T	0	0	0.78	None
3	*Acacia lahai* Steud. & Hochst.ex Benth.	Fabaceae	T	0	0	0.94	None
4	*Acacia mellifera* (Vahl) Benth.	Fabaceae	T	2.2	3.8	69.7	Fair
5	*Acacia oerforta* (Forssk.) Schweinf.	Fabaceae	S	0.9	3	26.4	Fair
6	*Acacia polyacantha* Willd.	Fabaceae	T	0.8	1.6	7.19	Fair
7	*Acacia senegal* (L.) Willd.	Fabaceae	T	0.5	3.8	24.8	Fair
8	*Acacia seyal* Del.	Fabaceae	T	0	0.9	5.31	Poor
9	*Acacia sp.* Mart	Fabaceae	T	0	0	1.72	None
10	*Acacia tortilis* (Forssk.) Hayne.	Fabaceae	T	0	0	1.25	None
11	*Adansonia digitata* (L.)	Bombacaceae	T	0	0	4.22	None
12	*Anogeissus leiocarpus* (DC.) Guill. & Perr.	Combretaceae	T	0	0	11.1	None
13	*Balanites aegyptiaca* (L.) Del.	Balanitaceae	T	1.1	7.7	29.4	Fair
14	*Boscia angustifolia* var. *angustifolia* A. Rich.	Capparaceae	T/S	0	0	1.09	None
15	*Boswellia papyrifera* Hochst. ex A.	Burseraceae	T	0.6	1.7	27.8	Fair
16	*Brucea antidysenterica* J.F.	Simaroubaceae	T	0	0	0.47	None
17	*Buddleja polystachya* Fresen.	Loganiaceae	S	0	0	0.31	None
18	*Burkea africana* Hook.	Caesalpiniaceae	T	0	0	3.28	None
19	*Cadaba farinosa* Forssk.	Capparaceae	S	0	0	0.94	None
20	*Calotropis procera* (Aiton) W.T. Aiton.	Asclepiadaceae	T	0	0	2.19	None
21	*Capparis decidua* (Forssk.) Edgew.	Capparaceae	T	0	0	0.63	None
22	*Carissa edulis* (Forssk.) Vahl.	Apocynaceae	S	0	0	1.72	None
23	*Casuarina equisetifolia* (L.)	Casuarinaceae	T	1.1	4.2	10.8	Fair
24	*Combretum glutinosum* Perr. ex DC.	Combretaceae	S	0	0	4.22	None
25	*Combretum hartmannianum* Schweinf.	Combretaceae	T	0.3	3.3	53.4	Fair
26	*Combretum molle* R. Br. ex G. Don.	Combretaceae	T	0	0.8	18.3	Poor
27	*Combretum sp.* Loefl.	Combretaceae	T	0	0	4.22	None
28	*Commiphora boranensis* K. Vollesen.	Burseraceae	T	0	0	5.00	None
29	*Dalbergia melanoxylon* Guill. & Perr.	Fabaceae	T	0	0.3	7.19	Poor
30	*Dichrostachys cinerea* (L.)Wight and Arn.	Fabaceae	T	0.3	6.4	22.3	Fair
31	*Diospyros abyssinica* (Hiern) F. White	Ebenaceae	T	0	0	2.19	None
32	*Diospyros mespiliformis* Hochst. ex A. DC.	Ebenaceae	T	0	0	4.69	None
33	*Feretia apodanthera* Delile.	Rubiaceae	S	0	0	0.47	None
34	*Ficus sycomorus* (L.)	Moraceae	T	0	0-	0.31	None
35	*Grewia bicolor* Juss.	Tiliaceae	T/S	0	0	4.84	None
36	*Grewia flavescens* Juss.	Tiliaceae	T/S	0	0	2.03	None
37	*Grewia mollis* Juss.	Tiliaceae	T	0	0	0.63	None
38	*Grewia villosa* Willd.	Tiliaceae	S	0	0.5	1.72	Poor
39	*Hyphaene thebaica* (L.) Mart.	Arecaceae	T	1.4	7.8	15.0	Fair
40	*Jasminum abyssinicum* Hochst. ex DC.	Oleaceae	S	0	0	1.25	None
41	*Lannea microcarpa* Engl. & K. Krause.	Anacardiaceae	T	0	0	3.59	None
42	*Leptadenia lanceolata* (Poir.) Goyder.	Asclepiadaceae	S	0	0	0.47	None
43	*Maytenus senegalensis* Forssk.	Celastraceae	T	0	0	0.94	None
44	*Melia azedarach* (L.)	Meliaceae	T	0	0	0.47	None
45	*Moringa stenopetala* (Baker f.) Cufod.	Moringaceae	T	0	0	0.63	None
46	*Nerium oleander* (L.)	Apocynaceae	S	0	0	0.47	None
47	*Otostegia ellenbeckii* Gurke.	Lamiaceae	S	0	0	0.31	None
48	*Parkinsonia aculeata* (L.)	Fabaceae	T	0	0	0.16	None
49	*Pittosporum viridiflorum* Sims.	Pittosporaceae	T	0	0	2.66	None
50	*Plumbago zeylanica* (L.)	Plumbaginaceae	S	0	0.2	0.78	Poor
51	*Ricinus communis* (L.)	Euphorbiaceae	S	0	0	0.63	None

Table 2: Continued.

S. no.	Scientific name (species)	Family	Hab.	SD	SPD	MD	RS
52	*Salvadora persica* (L.)	Salvadoraceae	S	0	0	0.78	None
53	*Sclerocarya birrea* (A. Rich.) Hochst.	Anacardiaceae	T	0	0	2.34	None
54	*Senna singueana* (Delile) Lock.	Fabaceae	S	0	0	0.16	None
55	*Solanum incanum* (L.)	Solanaceae	S	0	0	1.09	None
56	*Sterculia africana* Del.	Sterculiaceae	T	0	0	6.56	None
57	*Stereospermum kunthianum* Cham.	Bignoniaceae	T/S	0	0	3.28	None
58	*Tamarindus indica* (L.)	Fabaceae	T	0	0	9.22	None
59	*Terminalia brownii* Fresen.	Combretaceae	T	0.2	0.3	32.0	Fair
60	*Terminalia laxiflora* Engl. & Diels.	Combretaceae	T	0	0	1.56	None
61	*Terminalia sp.* L.	Combretaceae	T	0	0	1.09	None
62	*Ziziphus mucronata* Willd.	Rhamnaceae	T/S	0	0	2.66	None
63	*Ziziphus spina-christi* (L.) Desf.	Rhamnaceae	T	1.3	2.3	13.6	Fair
64	*Ziziphus mauritiana* Willd.	Rhamnaceae	T/S	0	0	0.63	None
65	*Carica papaya* (L.)*	Caricaceae	T*	—	—	—	—
66	*Citrus aurantifolia* (Christm.) Swingle*	Rutaceae	S*	—	—	—	—
67	*Mangifera indica* (L.)*	Anacardiaceae	T*	—	—	—	—
68	*Rhamnus prinoides* L'Hér*	Rhamnaceae	S*	—	—	—	—
69	*Cordia africana* Lam.*	Boraginaceae	T*	—	—	—	—
70	*Delonix regia* (Boj. ex Hook.) Raf.*	Fabaceae	T*	—	—	—	—
	(Mean ± SE)	—	—	10.7 ±0.4	48.6 ±1.57	466 ±12.8	—

Note. *Plant species recorded outside plots area; Hab. = habit, T = tree; S = shrub; T/S = tree/shrub. MD = mature density (stem·ha^{-1}); SD = seedling density (stem·ha^{-1}); SPD = sapling density (stem·ha^{-1}); regeneration status (RS) (G = good, F = fair, P = poor, and N = none regenerating); 0 = absence of individuals in seedling and/or sapling stages.

Table 3: Dominant families encountered in Kafta Sheraro National Park (KSNP).

No.	Family	No. of species	Percentage of species
1	Fabaceae	16	22.9
2	Combretaceae	8	11.4
3	Tiliaceae	4	5.71
4	Rhamnaceae	4	5.71
5	Capparaceae	3	4.29
6	Anacardiaceae	3	4.29
7	Asclepiadaceae	2	2.86
8	Burseraceae	2	2.86
9	Ebenaceae	2	2.86
10	Apocynaceae	2	2.86
	Others	24	34.32

the composition list only (Table 2). The Shannon–Wiener diversity (H') mean and equitability (evenness) index values of Kafta Sheraro National Park (KSNP) Forest woody species were $H` = 3.2$ and $J = 0.77$.

3.2. Vegetation Structure

3.2.1. Density and Frequency Distribution of the Plant Species. The total density of Kafta Sheraro National Park woody species was 466 ± 12.8 stems·ha^{-1}. *Acacia mellifera* was the most abundant species with an abundance value of 446 individuals and a density of 69.7 stems·ha^{-1}. *Acacia mellifera*, *Combretum hartmannianum*, *Balanites aegyptiaca*, *Acacia oerfota*, *Boswellia papyrifera*, and *Acacia senegal* have above 150 individuals while *Dichrostachys cinerea* and *Combretum molle* have densities of 100 stems·ha^{-1}and above (Table 4). The woody species density was classified into five class intervals: ≤2, 2.1–10, 10.1–50, 50.1–100, and >100.1 stems·ha^{-1}. 48.4% and 3.125% of species occupied density class ≤2 and 50.1–100, respectively (Figure 3).

The most frequent woody species in the study area were *Acacia mellifera* (71.4%), followed by *Combretum hartmannianum* (59%), *Terminalia brownii* (57.8%), *Balanites aegyptiaca* (46.0%), *Acacia senegal* (42.2%) and *Acacia oerfota* (35.4%), *Boswellia papyrifera* (29.8%), and *Dichrostachys cinerea* (29.2%), while *Acacia albida*, *Parkinsonia aculeata*, and *Otostegia ellenbeckii* each having frequency of 0.62% were rarely observed. The relative frequency of species was between 0.09 and 10.6% with similar orders as their frequencies (Table 4). Kafta Sheraro National Park (KSNP) was arranged in six frequency classes: (1) 65.1–80%, (2) 50.1–65%, (3) 35.1–50%, (4) 20.1–35%, (5) 5.1–20%, and (6) ≤5%. The woody plant species dominantly concentrated in frequency class 6 (<5%). In (1) (65.1–80%) frequency class, the number of species was one (Figure 4).

3.2.2. Basal Area (BA). The total basal area of Kafta Sheraro National Park of woody species with a diameter at breast height (DBH) ≥2.5 cm was 79.3 ± 4.6 m^2·ha^{-1}. *Adansonia digitata* tree species contributed the highest basal area (35.5 m^2·ha^{-1}) followed by *Sterculia africana* (7.86 m^2·ha^{-1}), *Tamarindus indica* (5.52 m^2·ha^{-1}), *Anogeissus leiocarpus* (4.09 m^2·ha^{-1}), *Ficus sycomorus* (3.63 m^2·ha^{-1}), *Acacia lahai* (3.57 m^2·ha^{-1}), *Balanites aegyptiaca* (2.90 m^2·ha^{-1}), *Ziziphus spina-christi* (2.87 m^2·ha^{-1}), and *Burkea Africana* (2.67 m^2·ha^{-1}) (Table 5).

Table 4: Woody species structure and importance value index in Kafta Sheraro National Park.

Species	AD	AB	*D*	RD	*F*	RF	BA	DO	RDO	IVI
Acacia senegal	4.6	159	24.8	5.33	42.2	6.26	0.05	0.301	0.222	11.8
Combretum hartmannianum	9.4	342	53.4	11.5	59	8.74	0.19	2.584	1.911	22.1
Dalbergia melanoxylon	8.4	46	7.19	1.54	17.4	2.58	0.14	0.262	0.194	4.31
Balanites aegyptiaca	38	188	29.4	6.3	46	6.81	2.9	19.59	14.49	27.6
Acacia oerfota	4.1	169	26.4	5.67	35.4	5.24	0.03	0.222	0.164	11.1
Dichrostachys cinerea	3.9	143	22.3	4.79	29.2	4.32	0.03	0.17	0.126	9.24
Grewia bicolor	2.5	31	4.84	1.04	9.94	1.47	0.01	0.016	0.012	2.52
Anogeissus leiocarpus	45	71	11.1	2.38	24.8	3.68	4.09	11.62	8.591	14.7
Sterculia africana	62	42	6.56	1.41	14.9	2.21	7.86	13.2	9.763	13.4
Acacia seyal	5.5	34	5.31	1.14	9.94	1.47	0.06	0.08	0.059	2.67
Maytenus senegalensis	5.6	6	0.94	0.2	2.48	0.37	0.06	0.015	0.011	0.58
Acacia mellifera	4.2	446	69.7	15	71.4	10.6	0.03	0.623	0.46	26
Adansonia digitata	134	27	4.22	0.91	10.6	1.56	35.5	38.31	28.33	30.8
Acacia albida	17	2	0.31	0.07	0.62	0.09	0.56	0.045	0.033	0.19
Jasminum abyssinicum	5.2	8	1.25	0.27	2.48	0.37	0.05	0.017	0.012	0.65
Ziziphus spina-christi	38	87	13.6	2.92	23	3.4	2.87	9.989	7.387	13.7
Tamarindus indica	52	59	9.22	1.98	19.9	2.94	5.52	13.03	9.634	14.6
Casuarina equisetifolia	5.2	69	10.8	2.31	15.5	2.3	0.05	0.149	0.11	4.72
Capparis decidua	4.6	4	0.63	0.13	1.24	0.18	0.04	0.007	0.005	0.32
Grewia villosa	3.6	11	1.72	0.37	4.97	0.74	0.02	0.011	0.008	1.11
Salvadora persica	2.8	5	0.78	0.17	1.86	0.28	0.01	0.003	0.002	0.45
Ziziphus mauritiana	9.8	4	0.63	0.13	1.24	0.18	0.19	0.03	0.022	0.34
Feretia apodanthera	7.5	3	0.47	0.1	2.48	0.37	0.11	0.013	0.01	0.48
Hyphaene thebaica	17	96	15	3.22	21.1	3.13	0.61	2.352	1.74	8.09
Calotropis procera	6.9	14	2.19	0.47	5.59	0.83	0.11	0.064	0.047	1.34
Boswellia papyrifera	11	178	27.8	5.97	29.8	4.42	0.25	1.794	1.327	11.7
Terminalia brownii	36.4	205	32	6.87	57.8	8.56	2.06	13.28	9.82	25.2
Grewia flavescens	5.5	13	2.03	0.44	6.21	0.92	0.06	0.033	0.025	1.38
Moringa stenopetala	5.8	4	0.63	0.13	1.24	0.18	0.11	0.018	0.013	0.33
Acacia lahai	42	6	0.94	0.2	2.48	0.37	3.57	0.857	0.634	1.2
Diospyros mespiliformis	13	30	4.69	1.01	9.32	1.38	0.35	0.42	0.311	2.7
Burkea africana	37	21	3.28	0.7	7.45	1.1	2.67	2.243	1.659	3.47
Ficus sycomorus	43	2	0.31	0.07	1.24	0.18	3.63	0.291	0.215	0.47
Combretum glutinosum	8	27	4.22	0.91	5.59	0.83	0.13	0.136	0.1	1.83
Combretum molle	6	117	18.3	3.92	11.2	1.66	0.07	0.335	0.247	5.83
Nerium oleander	2.5	3	0.47	0.1	1.24	0.18	0.01	0.002	0.001	0.29
Cadaba farinosa	5.4	6	0.94	0.2	1.24	0.18	0.06	0.014	0.01	0.4
Leptadenia lanceolata	4.6	3	0.47	0.1	1.86	0.28	0.03	0.004	0.003	0.38
Terminalia laxiflora	8.7	10	1.56	0.34	1.24	0.18	1.05	0.419	0.31	0.83
Solanum incanum	2.6	7	1.09	0.23	1.86	0.28	0.01	0.004	0.003	0.51
Grewia mollis	4.8	4	0.63	0.13	1.86	0.28	0.04	0.007	0.005	0.42
Lannea microcarpa	11	23	3.59	0.77	8.7	1.29	0.25	0.232	0.172	2.23
Commiphora boranensis	7.2	32	5	1.07	4.35	0.64	0.72	0.922	0.682	2.4
Stereospermum kunthianum	6.9	21	3.28	0.7	6.21	0.92	0.1	0.08	0.059	1.68
Pittosporum viridiflorum	9	17	2.66	0.57	3.73	0.55	0.42	0.047	0.034	1.16
Boscia angustifolia	6.4	7	1.09	0.23	1.86	0.28	0.08	0.022	0.016	0.53
Acacia sp.	11	11	1.72	0.37	2.48	0.37	0.25	0.109	0.08	0.82
Ziziphus mucronata	2.9	17	2.66	0.57	6.21	0.92	0.02	0.011	0.008	1.5
Acacia polyacantha	5.9	46	7.19	1.54	4.35	0.64	0.07	0.126	0.093	2.28
Acacia etbaica	11	5	0.78	0.17	1.24	0.18	0.22	0.045	0.033	0.38
Acacia tortilis	12	8	1.25	0.27	1.86	0.28	0.27	0.088	0.065	0.61
Parkinsonia aculeata	8.4	1	0.16	0.03	0.62	0.09	0.14	0.006	0.004	0.13
Ricinus communis	4.1	4	0.63	0.13	0.62	0.09	0.03	0.005	0.004	0.23
Melia azedarach	4.6	3	0.47	0.1	1.24	0.18	0.04	0.005	0.004	0.29
Carissa edulis	5.4	11	1.72	0.37	1.86	0.28	0.07	0.033	0.024	0.67
Combretum sp.	8.9	27	4.22	0.91	2.48	0.37	0.16	0.174	0.129	1.4
Sclerocarya birrea	19	15	2.34	0.5	3.11	0.46	0.7	0.419	0.31	1.27
Terminalia sp.	7.6	7	1.09	0.23	1.24	0.18	0.11	0.032	0.024	0.44
Diospyros abyssinica	8	14	2.19	0.47	2.48	0.37	0.30	0.226	0.167	1
Brucea antidysenterica	15	3	0.47	0.1	1.24	0.18	0.12	0.053	0.039	0.32

Table 4: Continued.

Species	AD	AB	*D*	RD	*F*	RF	BA	DO	RDO	IVI
Plumbago zeylanica	2.5	5	0.78	0.17	1.86	0.28	0.01	0.002	0.002	0.45
Otostegia ellenbeckii	2.5	2	0.31	0.07	0.62	0.09	0.004	0.008	0.006	0.16
Senna singueana	2.5	1	0.16	0.03	0.62	0.09	0.002	0.007	0.005	0.13
Buddleja polystachya	2.6	2	0.31	0.07	1.24	0.18	0.003	0.011	0.008	0.26
Total	—	2984	466 ±12.8	100	—	100	79.3 ±4.6	—	100	300

AD = average diameter (cm); AB = abundance (individual stems); *D* = density (stems·ha^{-1}); RD = relative density (%); *F* = frequency (%); RF = relative frequency (%); BA = basal area (m^2·ha^{-1}); DO = dominance; RDO = relative dominance (%); IVI = importance value index (%).

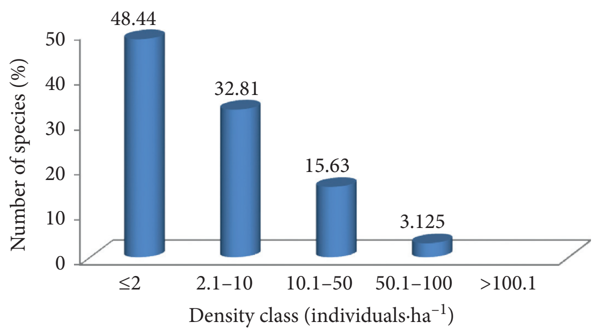

Figure 3: Density of all woody plant species by size class in Kafta Sheraro National Park.

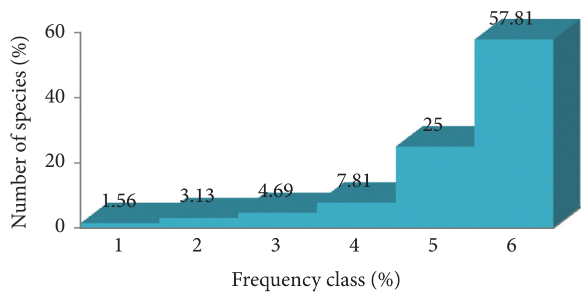

Figure 4: Woody plant species frequency classes' distribution of Kafta Sheraro National Park (KSNP). (1) 65.1–80%, (2) 50.1–65%, (3) 35.1–50%, (4) 20.1–35%, (5) 5.1–20%, and (6) ≤5%.

The regression analysis relationship of all mature trees basal area along altitude showed statistical nonsignificance ($p = 0.67$) between plots (Figure 5).

3.2.3. Importance Value Index (IVI). The importance value index (IVI) of woody species in Kafta Sheraro National Park ranged from 0.13% to 30.8%. About 18.71% of the importance values index was contributed by twelve species. The highest importance value index (IVI) was documented for *Adansonia digitata* (30.8%) followed by *Balanites aegyptiaca* (27.6%), *Acacia mellifera* (26.0%), *Terminalia brownii* (25.2%), *Combretum hartmannianum* (22.1%), *Anogeissus leiocarpus* (14.7%), *Tamarindus indica* (14.6%), *Ziziphus spina-christi* and *Sterculia africana* (27.4% each), *Acacia senegal* (11.8%), and *Boswellia papyrifera* (11.7%), and *Acacia oerfota* (11.1%) had their importance value index (IVI) value above ten which were the most important species in the forest (Table 4). The tree species in the forest were grouped into five classes based on their importance value index (IVI) values for conservation priority as follows: (1) >15.1%, (2) 10.1–15%, (3) 5.1–10%, (4) 1.1–5%, and (5) ≤1%. 46.9% of species were found in importance value index (IVI) class ≤1% while the lowest importance value index (IVI) was in class of >15.1% (Figure 6).

3.2.4. Diameter at Breast Height (DBH) Distribution of Tree and Shrub Species. The general diameter at breast height (DBH) and height class distribution of woody species density in the park showed an inverted J-shaped structure. The distribution of trees and shrubs was categorized into nine diameter at breast height (DBH) class: 2.5–10 cm, 10.1–20 cm, 20.1–30 cm, 30.1–40 cm, 40.1–50 cm, 50.1–60 cm, 60.1–70 cm, 70.1–80 cm, and >80.1 cm. The majority of individuals are distributed in the first DBH class 2.5–10 cm (Figure 7). Twenty individuals of *Anogeissus leiocarpus*, *Sterculia africana*, and *Adansonia digitata* had a diameter at breast height (DBH) of 70 cm and above. In Kafta Sherraro National Park (KSNP), the highest diameter at breast height was recorded for fourteen individuals of *Adansonia digitata* (110–146 cm).

3.2.5. Height Class Distribution of Tree and Shrub Species. Tree height distribution was classified into seven classes: ≤4 m, 4.1–9 m, 9.1–14 m, 14.1–19 m, 19.1–24 m, 24.1–29 m, and >29.1 m. There was a higher number of tree and shrub individuals in the height class ≤4 m, which accounts for about 1711 stems (264 individuals·ha^{-1}) (33.7%) of the total height classes. There were a higher number of tree/shrub individuals in the height class below 14 m which accounts for 81% of the total population height classes. Species such as *Anogeissus leiocarpus*, *Adansonia digitata*, *Tamarindus indica*, *Sterculia africana*, *Diospyros mespiliformis*, and *Balanites aegyptiaca* had 39 individuals having above 15 m height. The highest height was recorded for a species *Anogeissus leiocarpus* (30 m) (Figure 8).

3.2.6. Population Structure of Selected Tree Species. The analysis of population structure of Kafta Sheraro National Park individual tree species in nine diameters at breast height (DBH) classes dominantly showed eight patterns of population structure.

Table 5: The ten most dominant tree species to basal area (BA) in Kafta Sheraro National Park.

No.	Scientific name	Density (stems·ha^{-1})	Average DBH (cm)	Basal area (m^2·ha^{-1})	Relative BA (%)
1	*Adansonia digitata*	4.22	134	35.5	44.8
2	*Sterculia africana*	6.56	61.8	7.86	9.91
3	*Tamarindus indica*	9.22	52.0	5.52	6.96
4	*Anogeissus leiocarpus*	11.1	44.9	4.09	5.16
5	*Ficus sycomorus*	0.31	43.0	3.63	4.58
6	*Acacia lahai*	0.94	42.2	3.57	4.50
7	*Balanites aegyptiaca*	29.4	37.9	2.90	3.66
8	*Ziziphus spina-christi*	13.6	37.6	2.87	3.62
9	*Burkea africana*	3.28	36.7	2.67	3.37
10	*Terminalia brownii*	32.0	36.4	2.06	3.35

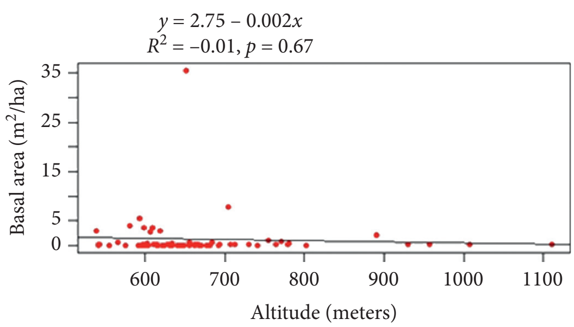

Figure 5: Pattern of basal area (m^2·ha^{-1}) along altitudinal difference (m) in Kafta Sheraro National Park (KSNP).

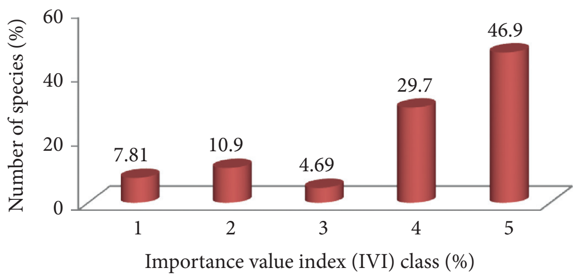

Figure 6: Importance value index class of tree and shrub species in Kafta Sheraro National Park. (1) >15.1%, (2) 10.1–15.0%, (3) 5.1–10.0%, (4) 1.1–5.0%, and (5) ≤1.0%.

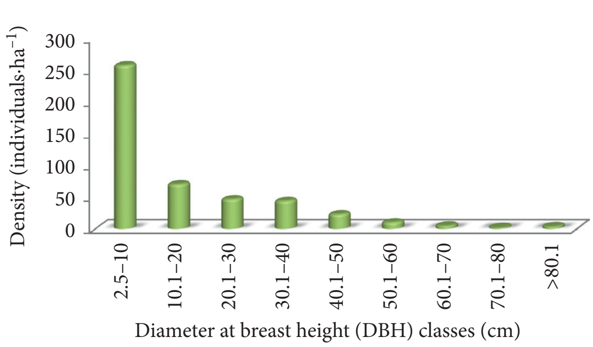

Figure 7: Diameter class distribution of woody species in Kafta Sheraro National Park.

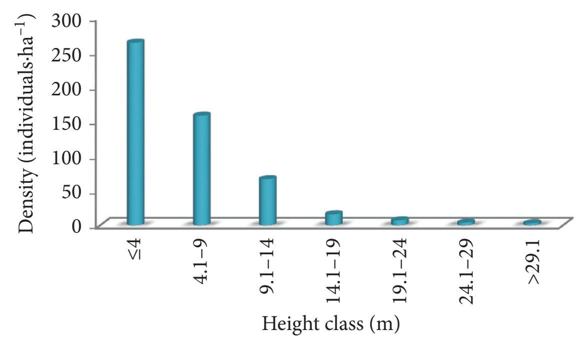

Figure 8: Height class distribution of woody species in Kafta Sheraro National Park.

(1) Individual species are concentrated only in the first diameter at breast height (DBH) class (2.5–10 cm) but absent in the rest classes and the representative species was *Acacia mellifera* (Figure 9(a)). Additional species in this group are *Acacia senegal*, *Dalbergia melanoxylon*, *Acacia oerfota*, *Acacia seyal*, and *Dichrostachys cinerea*.

(2) The species are concentrated only in the first (2.5–10 cm) and second (10.1–20 cm) diameter at breast height (DBH) classes. Species in this category were *Combretum hartmannianum* and *Boswellia papyrifera* (Figure 9(b)).

(3) The distribution showed an Inverted J-shaped structure in which the highest proportion of individuals were present in lower diameter at breast height classes and the only species was *Anogeissus leiocarpus* (Figure 9(c)).

(4) The distribution showed a J-shaped structure in which a higher proportion of individuals were present in higher diameter at breast height classes and the trend decreased towards the lower diameter classes. Species in this pattern were *Ziziphus spina-christi* and *Tamarindus indica* (Figure 9(d)).

(5) The distribution was bell-shaped in which a higher proportion of species were present in an intermediate diameter class and the trend decreased in lower and higher diameter classes. Species in this category were *Balanites aegyptiaca* and *Terminalia brownii* (Figure 9(e)).

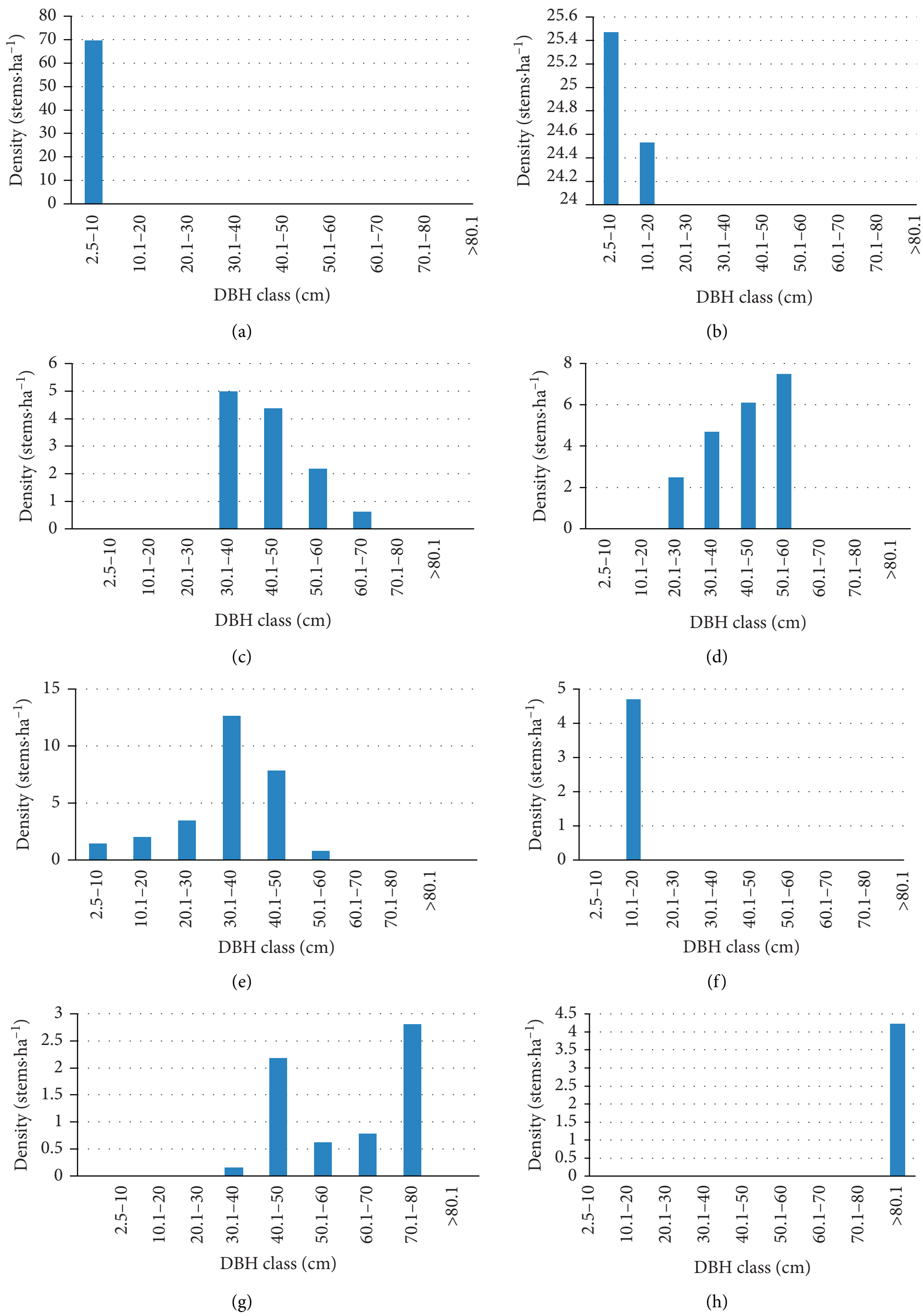

Figure 9: Representative population structure patterns of each tree species in Kafta Sheraro National Park. (a) *Acacia mellifera*, (b) *Combretum hartmannianum*, (c) *Anogeissus leiocarpus*, (d) *Tamarindus indica*, (e) *Balanites aegyptiaca*, (f) *Diospyros mespiliformis*, (g) *Sterculia africana*, and (h) *Adansonia digitata*.

(6) This pattern occurred in the second diameter class (10.1–20 cm) and the only representative species was *Diospyros mespiliformis* (Figure 9(f)).

(7) Irregular distribution over diameter classes. Some of diameter classes had a small number of individuals while other diameter classes had a large number of individuals and even some of them were

missed. The known species is *Sterculia africana* (Figure 9(g)).

(8) The diameter at breast height (DBH) occurred only in the large class. *Adansonia digitata* was the only representative species that occur in the ninth (>80.1 cm) diameter class (Figure 9(h)).

3.3. Regeneration Status of Woody Species. A total of 378 individuals of which seedlings 68 stems (2.023%) and saplings 310 stems (9.22%) belong to 64 woody species were counted from all plots. Twelve woody species had both seedling and sapling stages; five species had the only sapling while 47 species lack both stages. Woody species having seedling were *Acacia senegal*, *Combretum hartmannianum*, *Balanites aegyptiaca*, *Acacia oerfota*, *Dichrostachys cinerea*, *Acacia mellifera, Ziziphus spina-christi*, *Casuarina equisetifolia*, *Hyphaene thebaica*, *Boswellia papyrifera, Terminalia brownii*, and *Acacia polyacantha*, while tree and shrub species having sapling were *Acacia senegal*, *Combretum hartmannianum*, *Dalbergia melanoxylon, Balanites aegyptiaca*, *Acacia oerfota, Dichrostachys cinerea*, *Acacia seyal*, *Acacia mellifera, Ziziphus spina-christi*, *Casuarina equisetifolia*, *Grewia villosa*, *Hyphaene thebaica*, *Boswellia papyrifera*, *Terminalia brownii*, *Combretum molle*, *Acacia polyacantha*, and *Plumbago zeylanica*. Relatively higher sapling density was exhibited by species such as *Hyphaene thebaica* (16.1%) followed by *Balanites aegyptiaca* (15.8%), *Dichrostachys cinerea* (13.17%), *Casuarina equisetifolia* (8.64%), and *Acacia senegal* (7.82%) (Table 2).

The regeneration status of the forest was examined by comparing mature tree density with regenerating populations (seedlings and saplings) of species. The total density of seedlings and saplings had 10.7 ± 0.4 and 48.6 ± 1.57 individuals' ha^{-1}, respectively, which is lower than mature tree density (466 ± 12.8) (Figure 10(a); Table 2)). Kafta Sheraro National Park tree/shrub species showed different regeneration categories including "fair" regenerating (18.75%), "poor" regenerating' (7.8%), and "none" regenerating (73.45%) conditions, respectively. But "good" and "new" regenerating statuses of the tree species were totally absent (Figure 10(b)). Twelve species, namely, *Acacia mellifera*, *Acacia oerfota*, *Acacia polyacantha*, *Balanites aegyptiaca*, *Acacia senegal*, *Boswellia papyrifera*, *Casuarina equisetifolia*, *Combretum hartmannianum*, *Dichrostachys cinerea*, *Hyphaene thebaica*, *Terminalia brownii*, and *Ziziphus spina-christi* had "fair" regenerating status. *Dalbergia melanoxylon*, *Acacia seyal*, *Grewia villosa*, *Combretum molle*, and *Plumbago zeylanica* were "poor" regenerating woody species (Table 2).

The correlation density of seedlings and saplings with environmental factors showed a significant relation. Altitude was one of the basic environmental factors affecting plant regeneration of Kafta Sheraro National Park (Table 6). As a result, the variations of sapling and seedling density across altitudes were statistically significant throughout the plots of vegetation strata. The regression analysis revealed that the density of seedling species showed a slightly increasing trend significantly along with increasing altitude ($p = 0.00026$) (Figure 11(a)). Similarly, the density of sapling of all the species was increased as altitude increased ($p < 0.001$) (Figure 11(b)).

3.4. Environmental (Altitude and Human Disturbance) Factors versus Regeneration Status. In the present analysis, human disturbances and altitudinal factors were compared with the density of seedlings, saplings, and mature trees using the Pearson correlation coefficient (r). The correlation result generally showed both negative and positive relationships (Table 6). Altitude had a significantly weak negative relationship ($r = -0.035$ and -0.335, $p = 0.022$) with a density of seedling and mature tree, while a positive relationship ($r = 0.016$) with a density of sapling. Similarly, grazing had a significant negative correlation coefficient ($r = -0.021$ and -0.342, $p = 0.0139$) with a density of seedling and mature trees whereas positive relation with a density of sapling. Fire ($p = 0.014$) also exhibited a negative relationship with a density of seedling, sapling, and mature trees. However, gold mining showed a disturbance sign in the plots and statistically had no significant (weak) correlation ($p = 0.77$) relationship with a density of seedling, sapling, and mature trees (Table 6). Consequently, the cumulative human disturbance variables (grazing, fire, and gold mining) were highly significant ($p < 0.001$) over regenerating population density (seedlings and saplings).

Mature tree density showed a weak negative ($r = -0.017$) relation to the density of seedling and positive ($r = 0.008$) correlation with sapling (Table 6). This indicates that the competition of mature plants for resources influences the population density of seedling and sapling.

4. Discussion

4.1. Woody Species Structure

4.1.1. Density Distribution of Plant Species. The total density of woody species of the study was 466 ± 12.8 individuals$\cdot ha^{-1}$ (64 species) which is lower than Babile Elephant Sanctuary: 1319 stems$\cdot ha^{-1}$ (67 species) [57], Nechisar National Park: 887 stems$\cdot ha^{-1}$ (118 species) [58], Zege Peninsula: 3318 stems$\cdot ha^{-1}$ (113 species) [59], Sire Beggo :1845 stems$\cdot ha^{-1}$ (121 species) [41], Tara Gedam and Abebaye: 3001 stems$\cdot ha^{-1}$ and 2850 stems$\cdot ha^{-1}$ (143 species), respectively [22], Wof Washa Forest: 698.8 stems$\cdot ha^{-1}$ [60], Kahtasa Forest: 505 stems$\cdot ha^{-1}$ [21], and Yemrehane Kirstos Church Forest: 506.6 stems$\cdot ha^{-1}$ [61] of Ethiopia. Higher density values were also reported in other dry tropical forest countries: 515 stems$\cdot ha^{-1}$ [42] and 537.3 ± 74.8 stems$\cdot ha^{-1}$ [62]. The densities of tree species variation in forests were reported due to variation in species composition, age structure [63], and the degree of disturbance [64].

Acacia mellifera, Combretum hartmannianum, *Terminalia brownii*, *Combretum molle*, *Balanites aegyptiaca*, *Acacia oerfota*, *Boswellia papyrifera*, *Acacia senegal*, and *Dichrostachys cinerea* occupied above 50% of the total stem density and relatively those species had higher seedling and sapling density in the study area. Moreover, these species

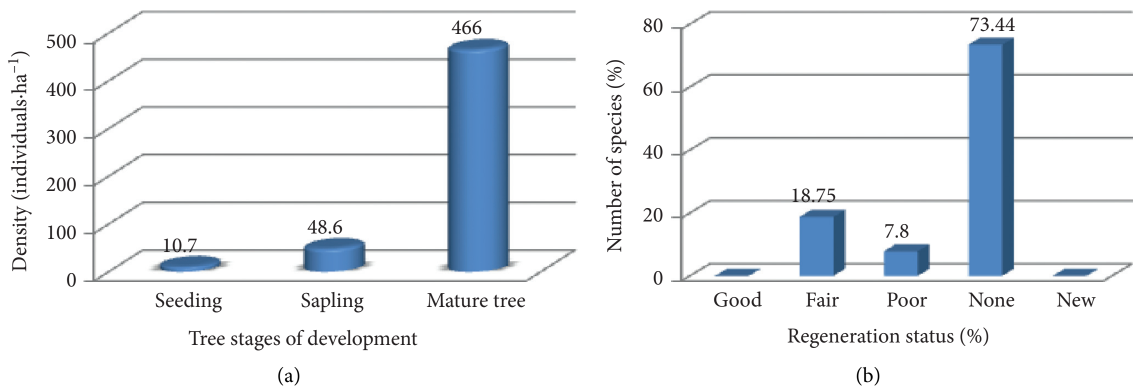

Figure 10: Density of seedling, sapling, and mature tree species (a) and regeneration status (b) of woody plants in Kafta Sheraro National Park Forest.

Table 6: Pearson correlation coefficient (r) between the density of seedling, sapling, and mature tree (stem·ha^{-1}) and environmental factors (human disturbances and altitude).

Attributes	AL	GR	F	GM	SD	SPD	MD
Altitude ($p = 0.022$)*	1.000						
Grazing ($p = 0.0139$)*	0.182	1.000					
Fire ($p = 0.014$)*	0.330	0.351	1.000				
Gold mining ($p = 0.77$)^{ns}	0.498	0.422	0.724	1.000			
#seedling density	−0.035	−0.021	−0.081	−0.115	1.000		
#sapling density	0.016	0.003	−0.025	−0.045	−0.042	1.000	
#mature tree density	−0.335	−0.342	−0.407	−0.382	−0.017	0.008	1.000

* $p < 0.05$, ns = nonsignificant; SD = seedling density; SPD = sapling density; MD = mature density; AL = altitude; GR = grazing; F = fire; GM = gold mining.

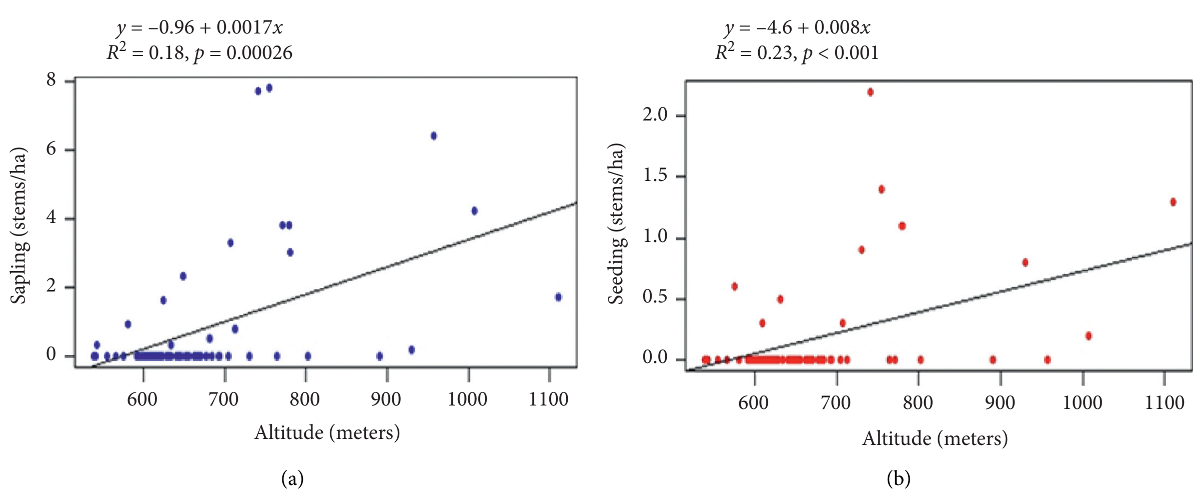

Figure 11: Scatter plots with least squares regression line showing the relationship between patterns of sapling (a) and seedling (b) density (stems·ha^{-1}) per plot and altitude (m).

are probably due to their resistance to drought and disturbance [65]. The absence of seedlings in some of the canopy trees of *Sterculia africana* and *Adansonia digitata* highly attributed to disturbance, seed predation, and habitat unsuitability. Disturbance and seed predation have played a sound role in reducing the seedling population of woody species [66].

4.1.2. Frequency Distribution. Frequency contributes to indicate homogeneity and heterogeneity of vegetation of a given species [67]. The study site has high species heterogeneity because the higher percentage numbers of species were found in the lower frequency class than in the higher class. According to Burju et al. [50], low value in lower frequency and high value in higher frequency class indicate similar species composition. To the reverse low percentage number of species in the higher frequency classes, a high degree of floristic heterogeneity was reported [11, 41, 61]. The variation in density and frequency between species may be attributed to habitat differences, habitat preferences among the species, species characteristics for adaptation, degree of exploitation, and conditions for regeneration [22]. In the park, important portions of the species were rare. Therefore, the study site has the existence of high floristic heterogeneity.

4.1.3. Basal Area of Trees and Shrubs. The basal area of all woody vegetation of Kafta Sheraro National Park ($79.3\,m^2{\cdot}ha^{-1}$) is much higher than the dryland forest areas of Ethiopia and other countries: Nechisar National Park ($49.45\,m^2{\cdot}ha^{-1}$ [58], Babile Elephant Sanctuary ($17.8\,m^2{\cdot}ha^{-1}$) [57], Sire Beggo ($19.3\,m^2{\cdot}ha^{-1}$) [41], Grat-Kahsu ($8.25\,m^2{\cdot}ha^{-1}$) [49], Abebaye Forest ($49.45\,m^2{\cdot}ha^{-1}$) [22], Ecuador-Peru ($3.7–37.71\,m^2{\cdot}ha^{-1}$) in deciduous and ($3.45–56.72\,m^2{\cdot}ha^{-1}$) in semideciduous forest [68], South Nandi Forest ($26.8 \pm 12.0\,m^2{\cdot}ha^{-1}$) [62], Wof Washa Forest ($55.9\,m^2{\cdot}ha^{-1}$) [69], Yemrehane Kirstos ($72\,m^2{\cdot}ha^{-1}$) [61], virgin tropical forests in Africa ($23–37\,m^2{\cdot}ha^{-1}$) [51], Katarniaghat Wildlife Sanctuary ($35.9\,m^2{\cdot}ha^{-1}$) [19], Gibbon Wildlife Sanctuary ($9.62\,m^2{\cdot}ha^{-1}$) [70], Adelle ($26\,m^2{\cdot}ha^{-1}$) and Boditi Forest ($23\,m^2{\cdot}ha^{-1}$) [71], Jibat ($59.79\,m^2{\cdot}ha^{-1}$) [50], Komto Forest [72], Bhadra Wildlife Sanctuary ($18.09\,m^2{\cdot}ha^{-1}$) [73], and woodlands of Metema (42.54, $m^2{\cdot}ha^{-1}$) [74]. But it was less than moist forests of Berbere Forest ($87.49\,m^2{\cdot}ha^{-1}$) [39], Belete Forest ($103.5\,m^2{\cdot}ha^{-1}$) [75], Tara Gedam ($115.36\,m^2{\cdot}ha^{-1}$) [22], and Kimphe Lafa Forest ($114.4\,m^2{\cdot}ha^{-1}$) [20].

The highest basal area from individual tree species in the study was contributed by *Adansonia digitata* ($35.5\,m^2{\cdot}ha^{-1}$) while the highest density was by *Acacia mellifera* species (69.7 individuals$\cdot ha^{-1}$). This indicates that species with the highest basal area do not necessarily have the highest density and the vice versa is also true. This was indicated that the size difference between species is common in natural vegetation [11, 17]. Based on the regression analysis, the basal area exhibited relatively higher value in the lower altitude. The probable reason was due to water access in riverine forest and good conservation practices in Acacia-Commiphora site (lower altitude). Moreover, selective cutting of trees is increasingly exercised in Combretum-Terminalia strata (higher altitude).

4.1.4. Importance Value Index (IVI). The importance value index is useful to compare the ecological significance of species [51]. Importance value index is also the degree of dominancy and abundance of a given species in relation to the other species in the area [37]. The importance value index (IVI) of woody species in the study area was generally comparable to other areas of woody vegetation study of Ethiopia [22, 65]. For example, *Ilex mitis* species had the highest value of 27.7% in Jibat Forest [50] and 34.6% in Belete Forest [75]. 30% of woody species of the study area had an importance value index (IVI) of 1 and lower than 1 which was categorized under the rarest list. Some of the least importance value index species were *Maytenus senegalensis, Acacia albida*, *Jasminum abyssinicum*, *Salvadora persica*, *Ziziphus mauritiana*, and *Feretia apodanthera*. As "Hedberg" stated, the least important plant species are usually common in open woodlands and savanna ecosystems [45]. Moreover, the importance value index (IVI) can also be used to prioritize species for conservation, and species with high importance value index value need less conservation efforts, whereas those having low importance value index need high conservation efforts. The lowest importance value index may indicate woody species are threatened and need immediate conservation [57]. Likewise, species having both the least importance value index (IVI) value and poor regeneration status in a given forest need to be prioritized for conservation [22].

4.1.5. Population Structure of Trees and Shrubs. Diameter at breast height (DBH) and height are important indicators of forest reproduction and health status [76]. The general pattern of the park diameter showed an inverted J-shaped distribution where species frequently had the highest frequency in low diameter classes and a gradual decrease towards the higher class. Inverted J-shape pattern is a normal population structure and shows the existence of species in healthier condition. Similar results were reported in Ethiopia by [39, 49, 58, 71, 75]. However, the general pattern does not clearly show trends of population dynamics and recruitment processes of individual species [21, 41]. The other seven discontinuous (there were complete absences of individuals in some classes and fairly representative of the individual in other classes) patterns showed in Kafta Sheraro National Park (KSNP) Forest. Irregular (discontinuous) distribution patterns were reported in Ethiopia by [10, 71, 74, 77]. Therefore, generally assessing the population structure has been helped to provide an initial idea about the regeneration status of woody plants in a studied forest [78].

4.2. Regeneration Status of Woody Plants. The pattern of population dynamics of seedlings, saplings, and adults of a plant species can exhibit the regeneration profile, which is used to determine their regeneration status [79]. Many reports stated that the regeneration status of given natural vegetation is considered as none regenerating if a species is absent in both sapling and seedling stages but present as mature tree/shrub [54, 55]. Therefore, the regeneration status of Kafta Sheraro National Park (KSNP) was considered as "none" regenerating status as mature (88.76%) > sapling (9.22%) > seedling (2.02%). The regeneration and recruitment condition of woody species is one of the major factors that are useful to assess their conservation status [80]. The population structure, characterized by the presence of a sufficient population of seedlings, saplings, and adults, indicates the successful regeneration of forest species [79]. However, climatic factors and biotic interferences influence the regeneration of species in any vegetation area [54]. Tree species which had no seedlings and saplings exhibited discontinuous population structures [21].

The "poor" and "none" regenerating categories which constitute around 81.25% of the woody plants in Kafta Sheraro National Park (KSNP) have many important and useful tree species. For example, tree/shrub species, namely, *Sterculia africana*, *Acacia seyal*, *Adansonia digitata*, *Hyphaene thebaica*, *Burkea africana*, and *Grewia flavescens* are a source of feed for African elephant (*Loxodonta africana* L.) and other plants in the study such as *Boswellia papyrifera* have economic value. "Poor" and "none" regenerating categories of woody species were reported in Berbere Forest (32.26%) [39], Grat-Kahsu Dryland Forest (26.56%) [49], Gibbon Wildlife Sanctuary (25%) [27], Wof Washa (48%) [60], and South Nandi forest (16.2%) [62]. Even in a temperate mixed forest of India, the regenerating status was reported 15% of species from a total composition exhibited none regeneration condition [81].

The regeneration status of the tree species in Kafta Sheraro National Park (KSNP) dominantly falls under "poor" and "not regenerating" status. Such situation might have occurred through the existing of disturbances such as overgrazing [82–84], firewood collection, fire, mining, and poor biotic potential of tree species which either affect the fruiting or seed germination or successful conversion of seedling to sapling stage as reported in Ethiopia forests [21, 22, 77]. Similarly, in other tropical dry forests, the above-listed disturbances were reported [85]. Moreover, young stages of any individual species are more vulnerable to any kind of environmental stress and anthropogenic disturbances [10], and regeneration of a particular species is usually affected by anthropogenic and natural factors [62]. Poor regenerating leads poor reproduction and hampered regeneration either due to the fact that most trees are not producing seeds as a result of their old age or there has been a loss of seeds by predators after reproduction [86]. The absence of seedlings and saplings of tree species indicates an urgent need for a targeted forest management plan to enhance regeneration [21, 41]. High herbaceous cover played a major role in preventing successful seed germination, seedling establishment, growth, and survival [87].

4.3. Human Disturbances and Altitudinal Difference Impact on Tree Regeneration. Correlation and regression analysis of the study revealed that the density of seedling, sapling, and mature woody tree/shrub species was significantly correlated with altitude.

Altitude was the most important factor shaping the species communities [88]. It is also among the strongest determinants of community composition and influencing the spatial distribution of species in dry Miombo woodlands [89]. In Walga riparian vegetation, 42% of the variation in species richness per plot was observed by altitudinal difference [90]. But in the present study, the degree of altitude relation with seedlings and mature trees/shrubs was weak negative while weak positive with a sapling. This is due to the multiple anthropogenic factors influencing the natural regeneration of the Park Forest. The main pronounced observed factors were livestock grazing, human-induced fire, and gold mining. Similar findings were reported from dry forest areas of Southern Tigray region and other countries, Desa'a Forest of Tigray region [91], Hugumburda Forest of Tigray region [92], Wof Washa Highlands of Ethiopia [69], and temperate forests in Chile [93]. Intensive anthropogenic disturbances, including fire, logging, and livestock have the potential to degrade the composition and availability of structural attributes in forests [90, 94].

Human-induced fire for farm expansion declines the stand structural regeneration of species in the study area (Figure 12(c)). The density of seedling and saplings were negatively correlated with fire. Periodic fire following expansion of farming remove heavy forest communities and this leads to reduce tree seeds and to emerge seasonal herbacious species. Fire is generally assumed to kill seedlings and saplings of woody plants because the majorities are small and therefore lack strong physical protection, such as thick bark, against fire. In Ethiopia, scientific reports related to negative impacts of fire were limited; however, according to Gebreegziabher [95], fire was a major threat to Desa'a Forest of Southern Tigray region where 1000 and 350 ha forest lands were destroyed in 1970 and 1998, respectively.

However, fire influence research on woody vegetation regeneration of Ethiopia is still scarce; a number of studies found that fire in tropical forests of the world increased the mortality of young trees and degrade the whole forest structure. For example, in Amazonian forest, frequent fires influenced negatively the composition and structure of saplings in three times burned and 16 years regenerating site survey [96]. The fire changes in species composition were associated with changes in forest structure because it may affect the species composition of forests because trees species suffer varying rates of mortality from fire [97]. It also caused extensive top kill to immature plant species [98], reducing the abundance and richness of seedlings and saplings by killing these young individuals [99]. The fire also directly reduced seedlings and saplings density and diversity [100]. Young plants are fire-sensitive because of reduced diameter, canopy base height, and thin bark [101]. Over a 13-year period study in mixed-oak forests of the United States of America (USA), repeated fires on stand structure and tree regeneration altered the stand structure by reducing the density of large saplings having a diameter of 3.0–9.9 cm [102]. The fire had altered the early seedling regeneration pathway by shifting the seedling communities away from the initial adult community composition [101]. For example, in Pugu Forest Reserve, Kenya, after five years of fire incident, plant species did not regenerate [103]. A single fire event can significantly affect diversity and regeneration of trees due to stem mortality in the lower size class of dry deciduous forest [104] because small individuals' forest tree species are less tolerant of fire than savanna species [105]. In addition to seedling and sapling disturbance, frequent fire negatively affected plant structure and basal area and declined large plants above 50% [96].

Livestock grazing significantly correlated with a density of seedlings, saplings, and mature trees. Grazing was affected by the regeneration status of vegetation by browsing or breaking adult plant shoots and leaves. Moreover, cattle foot

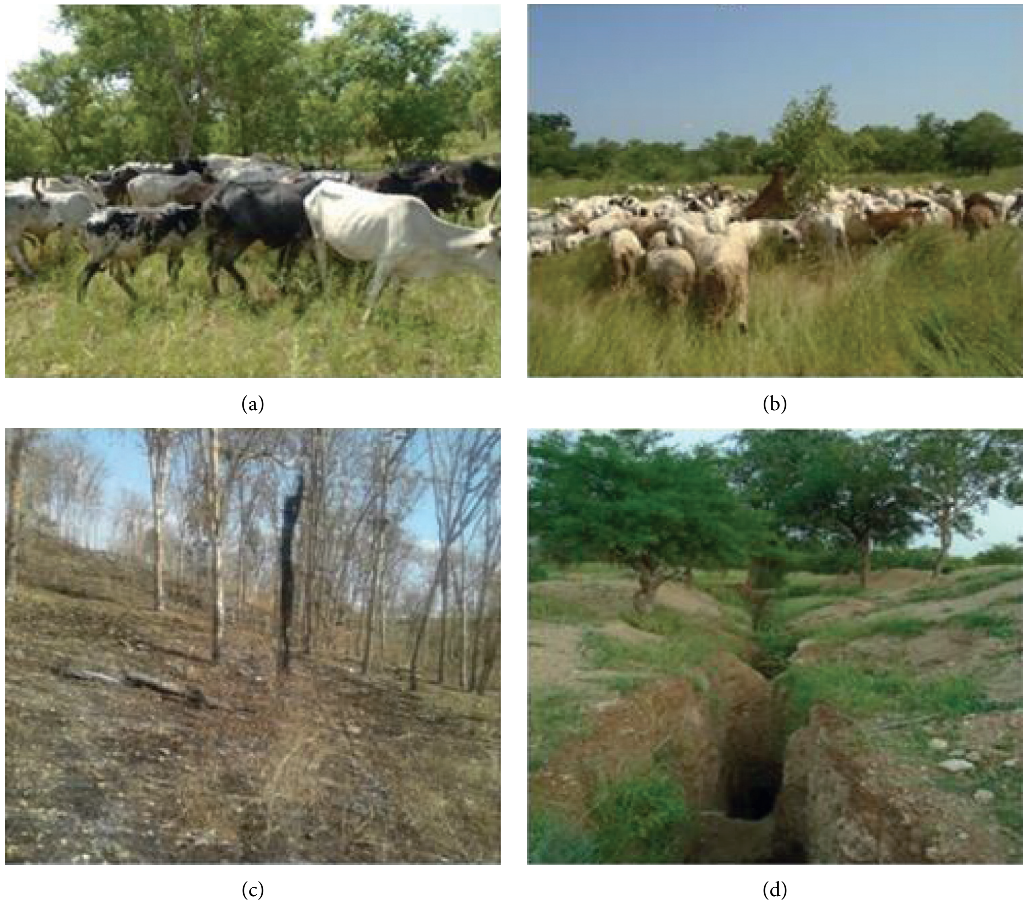

Figure 12: Photographs showing human-induced disturbances inside Kafta Sheraro National Park Forest: (a, b) Livestock browsing and grazing; (c) human-induced fire influence in *Boswellia papyrifera* dominated site; (d) traditional gold mining.

trampling and sheep browsing had a negative impact on seedlings, saplings, and lower herbaceous plants (Figures 12(a) and 12(b)). Livestock grazing may also a threat to the regeneration of tree species in open flat dryland forests such as Kafta Sheraro National Park. Grazing is often cited as an important predictor of plant regeneration, from different Ethiopia dry forests: the widening of canopy gaps that arise from deforestation and livestock pressure in Desa'a Forest of Tigray region has hampered the regeneration and recruitment of shade-loving tree species [106]. It also contributed negatively to the establishment of seedlings through intensive browsing [66]. Regenerated seedlings have been trampled by free-grazing animals in open dry areas [82]. The results of uncontrolled grazing intensity change the species composition [21]. Excessive livestock grazing was also the main threat in riparian plant communities of Walga [90]. The duration of livestock in the forest increased the degree of negative impact on vegetation attributes. For example, livestock use Desa'a Forest on average for eight months per year [91]. Thus, livestock free grazing throughout the year as well as trampling subsequently altered the species seedling [107].

The negative impact of grazing broadly reported from a number of studies of tropical and temperate forests of the world. Extensive grazing impedes the natural regeneration of forests by affecting their structure and diversity in the tropical dry forests [108]. In addition to browsing on the vegetation, cattle can prevent the growth of new seedlings but did not significantly change the diversity and structure of mature forest in Ecuador-Peru [68]. Both the diversity and structure of the forests have been significantly influenced by cattle grazing in two protected areas of Costa Rica [109]. In Central America, intensive cattle's grazing reduces the capacity of seeds to germinate and that can generate spiny and unpalatable forests [110]. Grazing clearly affects the densities of seedlings and saplings [83, 84]. In Chile, grazing significantly affected the regeneration of a single species of *Araucaria araucana* [111]. Livestock had a stronger negative effect on forest regeneration in comparison with the logging of temperate forests [112].

Gold mining was another human-induced factor by digging the vertical soil profile of the park approximately 25–30 m downward (Figure 12(d)). In addition to uprooting the plant root, traditional gold mining had also a negative contribution to extinguishing a fire in the forest area by the gold miner in order to prepare their daily food. However, the traditional gold mining showed a clear mean disturbance sign in almost all plots; statistically, there was no significant correlation between gold mining and density of seedling and sapling. There were no previous research studies related to traditional gold mining impact on plant regeneration, except the study done on the negative impact of gold mining on the population of wildlife in Kafta Sheraro National Park [113]. Therefore, it was very difficult to compare and contrast this human disturbance factor (mining) with other research findings.

The structural attributes of the stem density of trees were another internal influence on the regeneration of species. In the present study, the densities of mature trees had a significant effect on regenerating population (seedlings and saplings) dealing with high competition by adult trees causing a strong negative effect on the survival of seedlings and saplings. The result was in harmony with tropical forests [114]. Resources competitive interactions among plant species determine the regeneration process of species [84].

5. Conclusion and Recommendation

The study encountered 70 species from 34 families and 50 genera of woody plant species. Surveying on the structure and regeneration status of tree species would provide baseline information and an instrument for the development of successful conservation strategies in Kafta Sheraro National Park (KSNP) Forest. Population structure of the most common species of trees and shrubs revealed different types of irregular patterns, addressing a high variation among species population dynamics within the forest and an indication for low regeneration conditions. The irregular patterns of species indicated the absence of plant populations in various diameter classes. This clearly shows tree species in different stages of development are the abnormal status of population structure. The regeneration status of the tree species of the study site dominantly showed "poor" and "none" regeneration status (81.25%) but only 18.75% trees/shrubs species falls under "fair" regenerating" status because of the density (stems·ha^{-1}) of mature trees > sapling > seedling.

The variation in population structure and regeneration status of the park indicates the long time past disturbance of individual species and the whole resources of the park. The importance value index (IVI) values revealed that the most ecologically and economically important woody species in the forests are in poor regeneration status due to the activities of human disturbance variables, particularly livestock browsing and grazing and human-induced fire following extensive cultivation and traditional gold mining. These factors lead to a decline in the density of seedling and sapling of common tree species which are economically and ecologically important in the Park Forest. Additionally, altitude is also another determinant natural factor positively correlated with the regeneration of seedling and sapling.

Therefore, the regeneration status of the woody plant species in the park was generally categorized under poor and none regenerating condition; research development is needed on soil seed bank and propagation method of each tree species to stimulate regeneration on targets species of *Sterculia africana*, *Adansonia digitata*, *Tamarindus indica*, *Acacia seyal*, and *Burkea africana*. The park was the habitat for different types of wildlife particularly for the population of the African elephant (*Loxodonta africana* L.); government and community must give conservation and management priority for species with importance value index (IVI) less than 1%, species with no seedling, and families represented by only one species. Design conservation strategies for those economically important tree species such as *Boswellia papyrifera* are needed for their effective productivity, and this contributes to the conservation and development of other related tree species in the park.

Data Availability

The data used to support the findings of the study are available upon request via personal email or official website.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors express their deep gratitude to Kafta Sheraro National Park "SCOUTS" for their unlimited assistance during four-month fieldwork. Without their devoted assistance, the field data collection in such remote and harsh environment would have been impossible. This study was financially supported by Ethiopian Wildlife Conservation Authority (Enhanced Management and Effectiveness of Ethiopia's Protected Area Estate Project) starting from vegetation data collection to paper accomplishment.

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