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Tree Species Diversity and Edaphic Factors Associated with Different Land Uses in Tropical Forest Ecosystems, Tanzania

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Abstract

It has been reported that changes to miombo woodland ecosystems through conversion to other land uses alter tree species diversity and soil properties. The aim was to assess whether the Important Value Index (IVI), Shannon-Wiener diversity index (H'), and soil chemical properties differ between land uses in the Kibutuka miombo woodland ecosystem. IVI and H' were used to indicate tree species dominance and diversity. Statistical analyses were performed in R software. IVI of *Brachystegia* was significantly ($p < 0.05$) higher in the intact forest than in the combined land uses, while tree species of the genera *Combretum*, *Milletia*, and *Diplorhynchus* had significantly ($p < 0.05$) higher IVI in combined land uses than in the intact forest. The intact forest had significantly ($p < 0.05$) higher diversity than the degraded and agricultural lands. The intact forest had significantly ($p < 0.05$) higher soil Ca^{2+}, K^+, and Na^+ than combined land uses. Soil C, N, and P were significantly ($p < 0.05$) higher in intact forests than in the degraded forest. Degradation seen at a landscape scale for vegetation parameters, but not for soil parameters, indicates that the land use change taking place in the Kibutuka miombo woodland ecosystem is recent and the degradation seen in vegetation is still not reflected in the soil properties.

Keywords

Degradation, Dominance, Miombo Woodlands, Soil Chemical Properties

1. Introduction

Deforestation and forest degradation are expanding rapidly in the miombo woodlands of Sub-Saharan Africa. This contributes to global environmental challenges, such as biodiversity loss and climate change [1]. It also seriously affects the provision of several ecosystem services, thereby influencing local livelihoods. Increase in population, demand for forest products and services, agricultural expansion, and wood extraction for energy [2] [3] are some of the major factors increasing the problem by affecting ecosystem processes and functions. In Tanzania, the total annual loss of forest and woodlands is approximately 372,871 ha [4].

Several studies have revealed that miombo woodlands display local variation in abundance and species diversity, mainly influenced by past and present land use and edaphic factors [5] [6]. The presence of tree species in the genera *Brachystegia*, *Julbernardia*, and/or *Isoberlinia* indicates a forest that is typical of miombo woodland [7]. Degraded miombo woodlands are often dominated by *Combretum* species [8] [9] [10] [11]. The majority of studies have been undertaken in intact miombo woodlands only by assessing their vegetation structures, yet most miombo woodlands are affected by human disturbance [12], leading to changes in their vegetation structure and soil properties, especially soil organic matter [9] [13] [14]. In addition, considering the land uses of specific sites, the species diversity and soil chemical properties will always be different [15] [16]. Understanding the impact of land use changes on tree species diversity and soil chemical properties in tropical forests, especially the miombo woodland ecosystems, is important. Berihu *et al.* [17] reported huge losses in soil carbon, soil nitrogen, and other nutrients when the forest was converted to other land use in the drylands of Ethiopia. In another study in Cameroon, Tellen and Yerima [18] reported significant reductions in silt content, moisture content, organic matter, organic carbon, total nitrogen, available phosphorus, pH, cation exchange capacity, and exchangeable bases, but increased bulk density, electrical conductivity, and exchangeable acidity after conversion of natural forest or savanna to farmland.

By studying a miombo woodland of southeastern Tanzania stratified into three land uses, namely intact forest (with very minor or no human activity), degraded forest (with cutting of valuable tree species), and agricultural land (with ongoing agricultural activities or fallow), we aim to fill knowledge gaps concerning vegetation and soil chemical degradation. The aim was to assess whether the Important Value Index (IVI), Shannon-Wiener diversity index (H'), and soil chemical properties differ between land uses in the Kibutuka miombo woodland ecosystem. Therefore, this study provides new data on tree species dominance, diversity, and soil chemical properties in the Kibutuka miombo woodland ecosystem in Tanzania, which is undergoing rapid conversion to sesame cultivation.

2. Materials and Methods

2.1. Description of Study Site

This study was conducted in the Kibutuka division, in Liwale district, Lindi region, Tanzania (**Figure 1** upper left). The Kibutuka miombo woodland ecosystem is found within six villages: Kibutuka, Ngumbu, Kitogoro, Kiangara, Kiperere,

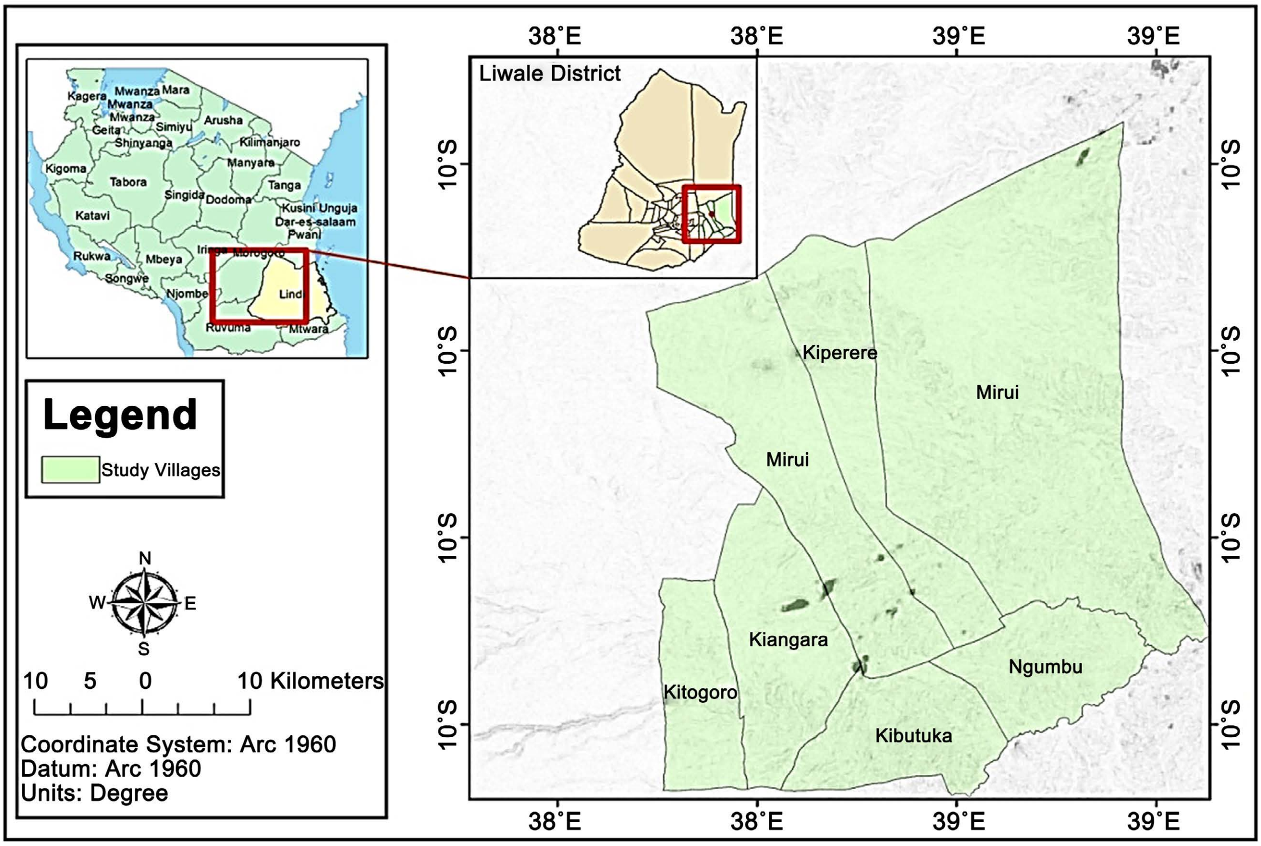

Figure 1. A map of the Kibutuka division, showing the villages containing the miombo woodland ecosystem.

and Mirui (**Figure 1** right). The altitude of the Liwale district ranges from 300 to 600 m.a.s.l and it lies between 36˚50' and 38˚48'E, 8˚ and 10˚50'S. The climate of Liwale district is influenced by south-easterly winds in the middle of the year and north-easterly winds at the turn of the year. The temperature ranges from 20˚C to 30˚C and the average is 25˚C over the year. The rainfall pattern is unimodal, with the wetter season starting in mid-November and lasting until mid-April, and a dry season from June to October [19]. According to the Mtwara weather station, the annual rainfall for Liwale ranges from 600 mm to 900 mm. Vegetation is characterized by miombo woodland and the predominant genera are *Brachystegia* and *Julbernardia*, which reach a height of 15 - 20 m, while most of the trees are understory species, 5 - 10 m tall, e.g. *Diplorhynchus condylocarpon* (Müll. Arg.), *Combretum molle* (R. Br. ex G. Don) and *Combretum zeyheri* (Sond.). The soils of Liwale are mainly deep sandy clay soils [20]. Several studies have revealed that the soils of the miombo woodlands are generally leached, sandy, and poor in nutrients [8].

2.2. Sampling Design

The National Forest Resource Monitoring and Assessment (NAFORMA) exercise conducted between 2009 and 2013 established a number of sampling clusters in the Liwale district, which are characterized by miombo woodlands. During this study, four NAFORMA clusters found in the study area were used, and seven clusters were added in order to improve the reliability of the estimates. Figure 2 shows the old NAFORMA clusters (yellow in color) and new clusters (black in color) in the Kibutuka miombo woodland ecosystem. Each cluster comprised 10 circular plots of 15 m radius spaced at an interval of 250 m (Figure 3(a)). Five plots were located in a south to north transect while the other five plots were located west to east. In this study, only three plots in each cluster (plots 4, 7, and 10) (Figure 3(a)) were chosen systematically for data collection, making a total of 33 plots. These plots were later categorized into three land uses (Table 1). In each plot, three sub-plots were demarcated at an interval of 5 m from the plot center (Figure 3(b)) and slope correction was considered during plot layout.

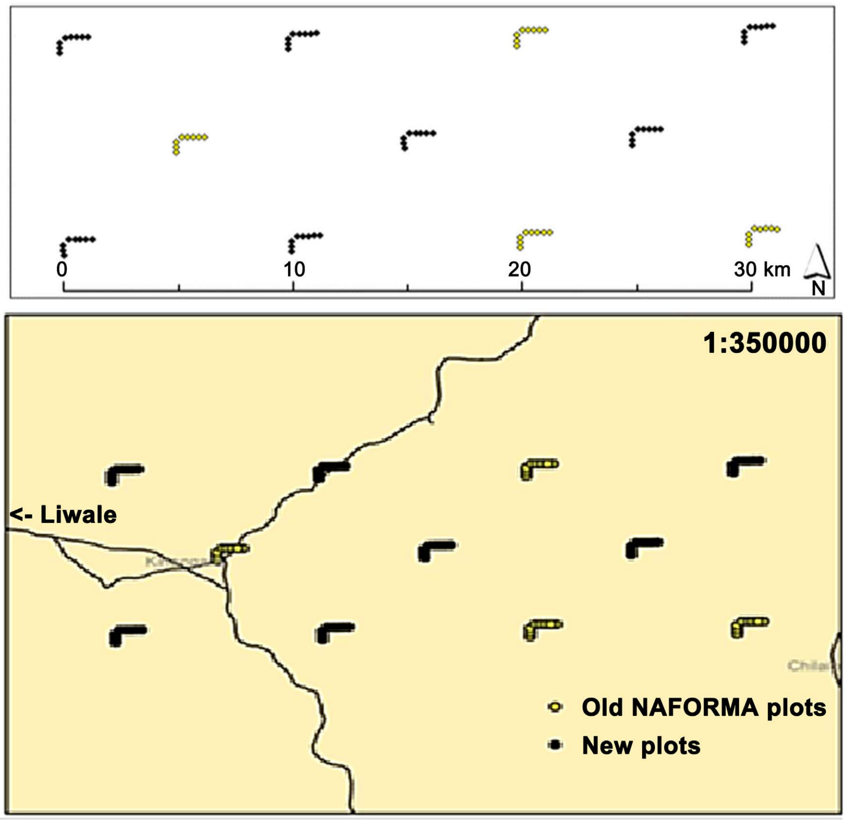

Figure 2. Distribution of the eleven clusters in the Kibutuka miombo woodland ecosystem.

Table 1. Distribution of plots in different land use types in the Kibutuka miombo woodland ecosystem.

Land use type	Number of plots
Intact forest (with very minor or no anthropogenic activities)	10
Degraded forest (with cutting of valuable tree species)	11
Agricultural land (with ongoing agricultural activities or fallow)	12
All land uses combined (at a landscape scale)	33

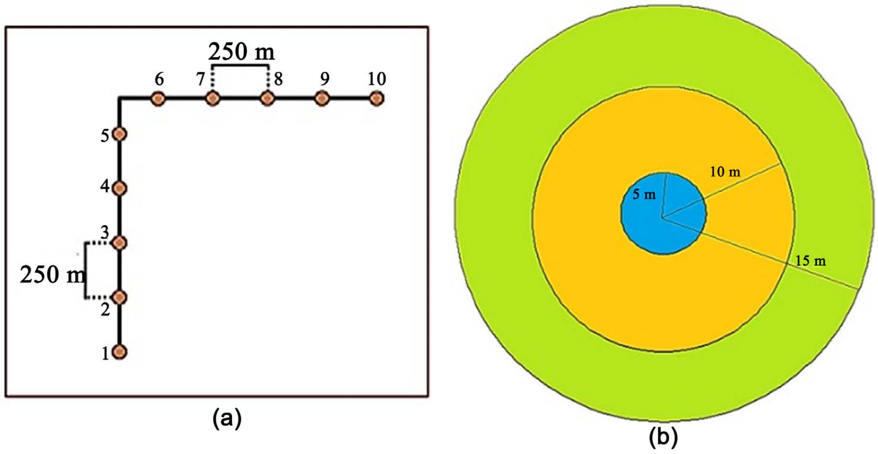

Figure 3. (a) Cluster and (b) plot design in the Kibutuka miombo woodland ecosystem.

2.3. Data Collection

A hand-held GPS (Map76cx) was used to record the geographical location and altitude of each plot. In each sampling plot, we used the NAFORMA protocol, in which four points located systematically at the main cardinal points of the compass (north, south, east, and west) were identified. A soil mini-pit was excavated at each point to 20 cm depth with at least one vertical surface that was used for volumetric soil sampling. The collected soil samples were placed into a clearly labeled paper bag to create a composite sample. The total weight of the soil sample was measured using a digital weighing scale to the nearest gram. In each sub-plot, all plant species with Diameter at Breast Height (DBH) ≥ 5 cm were measured, counted, and identified by their botanical names. If plants could not be identified in the field, voucher specimens were collected and then identified in the Tanzania National Herbarium. We used the measurement criteria shown in Table 2.

2.4. Data Analysis

Tree species diversity measurements were calculated using the following formula: Importance Value Index (IVI) = Relative density + Relative frequency + Relative dominance. The IVI is commonly used in ecological studies to indicate the ecological importance of a tree species in a given ecosystem [21] [22]. Munishi *et al.* [23] concluded that dominance in terms of IVI is a good parameter to use as it gives an indication of species that are important elements of the miombo. Density = Number of species/Total area sampled while Relative density = Density of a species/Total density of all species × 100. Frequency = Area of plots in which a species occurs/Total area sampled while Relative frequency = Frequency of a species/Total frequency of all species × 100. Dominance = Total basal area of a species/Total area sampled while Relative dominance = Dominance of a species/Total dominance of all species × 100.

Analysis of Variance (ANOVA) in R software version 3.5.1 was used to compare IVI of tree species in different land use types [24]. Differences were considered

Table 2. DBH measurements within a sample plot.

Plot radius (m)	Tree DBH (cm)
5	$5 \geq DBH \leq 10$
10	$10 > DBH \leq 20$
15	$DBH > 20$

to be statistically different when $p \leq 0.05$. Tree species richness was estimated as the number of tree species found in the 0.071 ha plot (Figure 3 right, *i.e.* 15 m radius = 15 × 15 × 3.14/10,000 = 0.071 ha) in each land use type for the 33 sampled plots. The Shannon Wiener diversity index was computed as $H' = -\sum_{i=1}^{s}(pi)(\ln pi)$ where $Pi = ni/N$ (ni = the number of individuals in a single species i, N = the total number of individuals in the community for all species), H' = the Shannon-Wiener diversity index. A larger value of H' indicates greater species diversity and vice versa. The index considers both species richness (the number of different species present in a community) and species evenness or dominance [25].

Air-dried soil samples were passed through a 2 mm sieve to remove stones, gravel, and fine and coarse roots. Soil Organic Carbon (SOC) was determined by the Walkley-Black dichromate wet oxidation method, Total Nitrogen (TN) content was determined using the Micro-Kjeldahl method, while available Phosphorus (P) was determined by the Bray P-1 method. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined using an Atomic Absorption Spectrophotometer (AAS) while sodium (Na^{+}) and potassium (K^{+}) were determined using a Flame Emission Spectrophotometer (FES). After extraction of exchangeable bases, the residual soil was washed with ethanol and then the remaining ammonium ions (NH_4^+) were extracted with 10% Sodium chloride (NaCl) for determination of CEC by titration [26]. Soil pH was measured using a Beckman's glass electrode pH meter after 10 g of the soil sample was suspended in 25 mL distilled water (1:2.5 ratio of soil to water). Pairwise t-tests were used to compare importance value indices, Shannon-Wiener diversity indices, and soil properties between intact forest, degraded forest, agricultural land, and combined land uses in R software version 3.5.1 [24] with $p \leq 0.05$ considered significant.

3. Results

3.1. Dominant Tree Species in Terms of IVI in Different Land Use Types in the Kibutuka Miombo Woodland Ecosystem

The most dominant tree species based on IVI in the different land use types are shown in Table 3. The IVI for typical miombo woodland tree species from the genus *Brachystegia* was significantly ($p < 0.05$) higher in the intact forest than in the combined land uses, while the IVIs for tree species in the genera *Combretum*, *Milletia*, and *Diplorhynchus* were significantly ($p < 0.05$) higher in the combined land uses than in the intact forest.

Table 3. Tree species dominance in terms of IVI compared between intact forest and degraded forest, agricultural land, and combined land uses in the Kibutuka miombo woodland ecosystem.

Dominant tree species	Intact forest	Degraded forest	Significance	Agricultural land	Significance	Combined land uses	Significance
Combretum molle	7.4	14.1	***	17.7	**	13.1	***
Combretum zeyheri	3.1	9.5	***	11.5	***	10.5	***
Brachystegia boehmii (Taub.)	9.7	7.3	***	-	*	8.5	*
Diplorhynchus condylocarpon	2.7	2.7	NS	14.7	***	6.7	***
Milletia stuhlmannii (Taub.)	4.1	5.1	***	-	***	4.6	NS
Brachystegia speciformis (Benth.)	6.2	2.8	***	-	***	4.5	*
Combretum collinum (Fresen.)	3.5	3.2	NS	5.3	***	4.0	*
Markhamia obtusifolia (Baker)	3.2	1.9	NS	-	***	2.6	NS
Combretum binderianum (Kotschy)	2.1	1.9	***	2.9	***	2.3	***
Other species	58.4	51.5		47.9		43.2	

***Significant at $p < 0.001$, **Significant at $p < 0.01$, *Significant at $p < 0.05$ and NS: Not Significant.

3.2. Tree Species Diversity in Different Land Use Types in the Kibutuka Miombo Woodland Ecosystem

The Shannon-Wiener diversity indices associated with the different land uses are shown in Table 4. Intact forest is significantly ($p < 0.05$) more diverse than degraded forest and agricultural land. At landscape level (combined land uses), the Shannon-Wiener diversity index was significantly ($p < 0.05$) higher than for intact forest.

3.3. Soil Chemical Properties in Different Land Use Types in the Kibutuka Miombo Woodland Ecosystem

The mean values and significant differences between soil chemical properties associated with different land uses are presented in Table 5. All soil chemical properties except Mg^{2+} and soil pH were significantly ($p < 0.05$) higher in intact forests compared to degraded forest and agricultural land. In the combined land uses, Ca^{2+}, K^{+}, and Na^{+} were significantly ($p < 0.05$) different from intact forest.

4. Discussion

4.1. Tree Species Dominance

The genera *Combretum*, *Brachystegia*, and *Diplorhynchus* were the dominant tree species in the Kibutuka miombo woodland ecosystem (Table 3). This study suggests that the most important tree species in intact miombo woodlands (the genera *Brachystegia*, *Julbernadia*, and/or *Isoberlinia*) are declining due to ongoing human pressure in the Liwale district. This indicates that the Kibutuka miombo woodland ecosystem is currently being degraded due to clearing woodlands for agricultural (sesame) cultivation and as a source of energy. A major proportion of this degradation of *Brachystegia* and *Julbernadia* in this ecosystem

Table 4. Tree species richness and Shannon-Wiener diversity indices compared between intact forest and degraded forest, agricultural land, and combined land uses in the Kibutuka miombo woodland ecosystem.

Land use categories	Tree species richness	H'	Significance
Intact forest	96	3.96	
Degraded forest	78	3.63	**
Agricultural land	53	2.66	***
Combined land uses	102	4.06	*

***Significant at $p < 0.001$, **Significant at $p < 0.01$, *Significant at $p < 0.05$ and NS: Not Significant.

Table 5. Mean values of soil chemical properties compared between intact forest and degraded forest, agricultural land, and combined land uses in the Kibutuka miombo woodland ecosystem.

Soil properties	Intact forest	Degraded forest	Significance	Agricultural land	Significance	Combined land uses	Significance
SOC (%)	0.98	0.82	***	0.83	***	0.88	NS
Total N (%)	0.04	0.02	***	0.03	NS	0.03	NS
P ($mg\cdot kg^{-1}$)	11.25	5.97	*	10.98	NS	9.40	NS
CEC ($cmol\cdot kg^{-1}$)	21.73	21.13	NS	17.05	***	19.97	NS
Ca^{2+} ($cmol\cdot kg^{-1}$)	15.93	9.07	***	12.14	***	12.38	**
Mg^{2+} ($cmol\cdot kg^{-1}$)	3.72	4.03	NS	3.31	NS	3.68	NS
K^{+} ($cmol\cdot kg^{-1}$)	0.97	0.67	***	0.56	***	0.73	***
Na^{+} ($cmol\cdot kg^{-1}$)	0.19	0.11	***	0.16	***	0.15	***
pH in H_2O	5.96	5.99	NS	5.86	NS	5.94	NS

***Significant at $p < 0.001$, **Significant at $p < 0.01$, *Significant at $p < 0.05$ and NS: Not Significant.

is due to their use as firewood, poles, timber, and charcoal production. Furthermore, these tree species are known to have low recovery rates after major disturbances because of their poor dispersal ability and short-lived seeds [27].

In this study, tree species in the genera *Combretum* and *Diplorhynchus* were found to dominate both degraded woodlands and agricultural land. The results of this study are similar to those reported by other scholars, namely that dominance of *Combretum* species often characterizes areas with high land use pressure, where the species becomes the fastest growing and most dominant trees in the early stages of succession [8] [10] [11]. Furthermore, Ribeiro *et al.* [28] and Ryan and Williams [9] reported that *Combretum* species tend to occupy more disturbed areas. In this study, agricultural land included fallow areas, where tree species in the genera *Combretum* and *Diplorhynchus* were found to dominate (Table 3). The dominance of tree species of *Combretum*, *Milletia*, and *Diplorhynchus* in combined land uses indicates that the vegetation of the Kibutuka miombo woodland ecosystem is degrading.

4.2. Tree Species Diversity

In general, the Kibutuka miombo woodland ecosystem has high tree species diversity. An ecosystem with a value of H' greater than 2 is regarded as having an intermediate to high species diversity [27] [29]. The high species diversity in the Kibutuka miombo woodland ecosystem may be due to the presence of riverine vegetation, as one-third of our survey plots were close to rivers or streams. In addition, it may be due to the high tree species richness in intact forests and the dominant *Combretum*, *Milletia*, and *Diplorhynchus* species found in degraded forests and agricultural land. The tree species diversity recorded in this study is relatively high but within the range of other miombo woodlands in Tanzania (**Table 6**).

A study by Malimbwi *et al.* [30] revealed that among the environmental factors, human-induced disturbances such as charcoal production, honey collection, illegal tree harvesting, agricultural activities, shifting cultivation, and grazing, together affect plant diversity. Giliba *et al.* [27] also reported that climatic and edaphic variability and anthropogenic activities are other factors associated with differences in species diversity in any forest ecosystem.

All the previous studies listed in **Table 6** were mainly conducted in intact forests. Their Shannon Wiener diversity indices are greater than 2, representing the threshold for "medium to high" tree species diversity in the miombo woodlands of Tanzania. However, in this study (**Table 4**), even the degraded forest and agricultural land including fallow (with scattered trees) had Shannon-Wiener diversity indices greater than 2, indicating high tree species diversity. Therefore, studying tree species diversity in miombo woodland ecosystems, degraded and agricultural lands, and/or fallow requires further investigation.

Table 6. Tree species diversity in the Kibutuka miombo woodland ecosystem in comparison to other studies of miombo woodland ecosystems in Tanzania.

Source	Species richness	Shannon-Wiener diversity index
This study (2023)	102	4.06
Nkonoki and Msuya [31]	95	4.17
Giliba *et al.* [27]	110	4.27
Mwakalukwa *et al.* [15]	88	3.44
Mbwambo [32]	-	3.44
Christoganus [33]	57	3.09
Njana [34]	82	3.40
Mafupa [35]	46	2.90
Mohamed [36]	-	3.10
Jew *et al.* [11]	-	3.44
Chamshama *et al.* [7]	102	3.10 to 3.30
Nduwamungu [37]	-	3.26 to 3.79
Zahabu [38]	-	2.90 to 3.10

4.3. Soil Chemical Properties

All values of soil chemical properties associated with all land use (**Table 5**) were found within the normal range. Land use history helps to explain soil degradation due to land use change [16]. However, degradation of soil chemical properties may take more time to manifest than changes in land use and vegetation cover. The Kibutuka miombo woodland ecosystem had soils with pH values within the normal range in all land uses (**Table 5**) and similar to the value of 5.68 recorded by [39] at Angai miombo woodland in the same district. The majority of soils in the tropics and sub-tropics are slightly acidic and have a mean pH value of 5.9, which is favorable for the growth of plants [40] [41]. The study by [39] found that soils in the Angai miombo woodland are clayey and more fertile, which is similar to the findings of the current study. Rennestad and Gassesse [42] reported that nutrient levels in intact miombo woodlands and adjacent recently cultivated land (which includes a few trees) did not differ significantly, indicating that recent degradation has not caused changes in soil chemical properties. On the other hand, Berhu *et al*. [17] reported huge losses of soil carbon, soil nitrogen, and other nutrients when the forest was converted to other land uses in drylands in Ethiopia. In another study in Cameroon, Tellen and Yerima [18] reported significant reductions in silt content, moisture content, organic matter, organic carbon, total nitrogen, available phosphorus, pH, cation exchange capacity, and exchangeable bases, but increased bulk density, electrical conductivity, and exchangeable acidity after conversion of natural forest or savanna to farmland.

5. Conclusion

In the intact forests, *Brachystegia* spp. dominates, whilst at a landscape level, the most dominant tree species are from the genera *Combretum*, *Milletia*, and *Diplorhynchus.* This indicates that vegetation in the Kibutuka miombo woodland ecosystem is degrading due to ongoing land use change. However, the soils in the Kibutuka miombo woodland are not degraded despite the land use change taking place. This could indicate that the land use change or degradation is recent or mild. We conclude that, with about one-third of the landscape remaining as intact forest, one-third as degraded forest, and the remaining one-third (and expanding) as agricultural land, there is vegetation degradation at the landscape level. Furthermore, the degradation seen in vegetation at the landscape scale is not yet reflected in the soil's chemical properties. Further degradation and increased land use change (deforestation) will probably be associated with soil degradation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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