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Research Article

Land Use and Land Cover Change, and Woody Vegetation Diversity in Human Driven Landscape of Gilgel Tekeze Catchment, Northern Ethiopia

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Land use and land cover (LULC) change through inappropriate agricultural practices and high human and livestock population pressure have led to severe land degradation in the Ethiopian highlands. This has led to further degradation such as biodiversity loss, deforestation, and soil erosion. The study examined woody vegetation diversity status and the impact of drivers of change across different LULC types and agroecological zones in Gilgel Tekeze catchment, northern Ethiopian highlands. LULC dynamics were assessed using GIS techniques on 1976, 1986, and 2008 satellite images. Vegetation data were collected from 135 sample plots (20 m × 20 m) from five LULC types, namely, forest, shrub-bush, grazing, settlement, and cultivated land, in the three agroecological zones; Kolla, Weyna-Dega, and Dega. Differences in vegetation structure and composition and their relationship to agroecological zones were tested using two-way ANOVA and PCA technique. The results show that vegetation structure and composition significantly differed across all LULC types in different agroecological zones particularly in sapling density, tree height, and shrub height and in each agroecological zone between forest land, shrub-bush land, and settlement area. Overall, Weyna-Dega agroecological zone and the shrub-bush land had more structural and compositional diversity than the other agroecological zones and LULC types.

1. Introduction

The Ethiopian highlands are subjected to important land degradation. Several studies have shown that there were significant land use and land cover changes in the Ethiopian highlands during the second half of the 20th century [1–6]. Most of these studies pointed out that rugged topography, inappropriate agricultural practices, and high human and livestock population pressure have been the main facilitators for the land degradation processes in the highlands [7–9]. Following the pressure on natural resources, the land use and land cover types are changing so rapidly. Around 19th century, about 40% of the land mass of Ethiopia was under forest cover but this figure had gone below 3% before two decades [10]. A study by Tekle and Hedlund [5] reported that open areas and settlements have increased at the expense of shrub land and forests in South Wello of north central highlands. Bewket [2] noted the problem of downstream sedimentation caused by upstream degradation, resulting from land use and land cover changes in the Chemoga watershed, north western highlands, and this has led to extensive flooding and damage on important agricultural lands. Serious trends of land degradation, resulting from the expansion of cultivation on steep slopes at the expense of natural forests, have been observed in the north-western highlands [7].

Similar to other parts of the highlands of Ethiopia, the study area Gilgel Tekeze catchment in North Wello is densely populated area that has resulted in severe degradation of land resources and has low agricultural productivity. In order to compensate for reduced agricultural production due to degradation, cultivation and grazing activities have spread

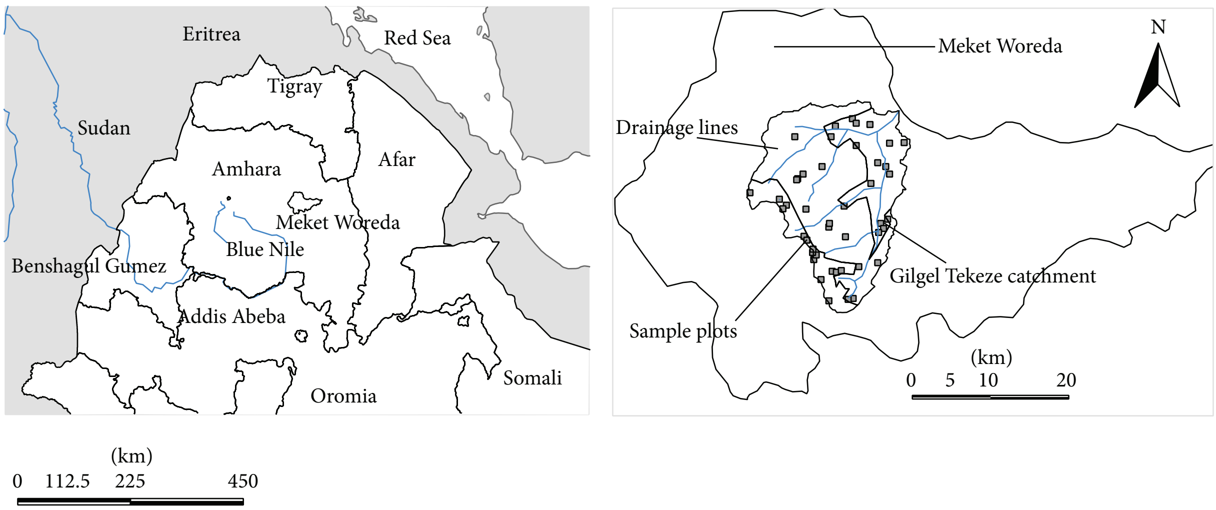


FIGURE 1: Location of study area: Gilgel Tekeze catchment, Amhara Region, Northern Ethiopia.

to steep landscapes at the expense of forest and natural vegetation [8]. The forest areas with native plants have been encroached by exotic species like *Eucalyptus globulus* trees that might lead to poor diversity and final replacement of the high forest to a bush land [11, 12]. This has led to further degradation such as soil erosion, deforestation, and biodiversity loss [13, 14]. Particularly, biodiversity loss has increased at an alarming rate in the highlands [13].

Many of these changes have been discerned by digital data processed from the satellite images and Arial photographs at appropriate scale and quality which have also been supplemented with data from field observation, field interviews, and discussions with local people and key informants. Indexes [13] and models [15] of biodiversity can then be applied to indicate whether the land use and land cover changes were sustainable or unsustainable in respect to woody vegetation structure and composition. Despite Gilgel Tekeze catchment is one of the highly populated and tributary of Tekeze river, it lacks attention of scientific information on land use and cover change. Such analyses are very important for the future planning and decision-making in the development and implementation of environmental rehabilitation programs. Besides, it contributes to fill the gaps on scientific information in the forestry sector of Ethiopia [16] in general and particularly in the northern Ethiopian highlands [17]. The present research study was carried out with the following objectives (a) to evaluate land use and land cover change from 1973 to 2008, (b) to investigate woody vegetation structure and composition across various land use and land cover types in different agroecological zones, and (c) to study the patterns in woody vegetation structure and composition along agroecological zones.

2. Material and Methods

2.1. Study Area. The study was conducted on Gilgel Tekeze catchment in Meket District, Amhara Regional State, and Northern Ethiopia (Figure 1). It covers an area of 352 km^2 and extends from 11°41′23″ to 11°56′05″ North and from 38°40′30″ to 38°51′59″ East. The study area is an extension of the typical agroclimatic profile of mount Abuna Yosef, which is situated about 45 km northeast of the study area and extends from the cold and wet upper zones (Wurch, 4260 m) to the hot and dry lower zones (Kolla, 1656 m) of the Gilgel Tekeze river. The area extends from south to north over elevations of 2970 m.a.s.l and 1656 m.a.s.l.

Geologically, the area belongs to the Trapp series of Tertiary volcanic eruptions. Its topography is typical of volcanic landscapes, which were later deeply incised by streams, resulting in the current diversity of landforms. The slope ranges from nearly flat (<2%) to those which are extremely steep (>83%). The area is a part of the northeastern Ethiopian highlands, dominantly covered by basic and ultrabasic rocks (basalt, hornblende, serpentinite, and peridotite), and pyroclastic rocks both consolidated and unconsolidated [18]. The soils have developed from volcanic ashes and reworked materials resulting from Tertiary volcanic eruptions and sedimentation processes. According to the FAO soil classification [19], Vertisols and Leptosols are the dominant soil types of the area. The Vertisols are found in the upper- and low-lying of the middle catchment of the study area. Leptosols are mainly found in the hillsides and lower catchments. As a result of degradation, the soils on steep slopes appear to have been downgraded to Regosols and Cambisols.

Due to the relief differences, the Meket district has a wide range of agroecological zones. According to the local classification, the agroecology zones of the district are Kolla (warm, semiarid lowlands, 1300 to 1800 m a.s.l.), Weyna Dega (mild, subhumid highlands, 1800 to 2400 m a.s.l.), Dega (cool, humid highlands, 2400 to 3200 m a.s.l.), and Wurch (cold, humid highlands, over 3200 m a.s.l.) [20]. The Kolla (warm), Weyna Dega (mild), and Dega (cool) agroecological zones cover 17%, 69%, and 14% of the catchment, respectively. The study area experiences mean annual temperature and rainfall ranging from 15°C to 17°C and from 934 to 1342 mm, respectively. About 50% of the annual rainfall falls between

Table 1: Descriptions of LULC categories for the study area.

Land use land cover	General description
Forest land (both natural and plantation)	Area covered with shrubs forming closed canopies and trees including Asst (*Erica arborea*) and others, which are relatively tall and dense trees, include scattered remnant *Juniperus procera*, *Ficus vasta*, and *Ficus sur*. Besides, plantations both indigenous and mainly exotic (*Eucalyptus globulus* and *Cupressus lusitanica*) trees that are planted in hillsides, mountains, and degraded areas.
Shrub-bush land	Areas with more than 50% shrub canopy (mixed with some trees) and less than 50% herbaceous and grass covers.
Grazing land	Areas with more than 50% covered grasses (mixed with some shrubs) and less than 50% herbaceous and have bare lands usually used for grazing.
Cultivated land	Areas of land ploughed/prepared for growing rain fed crops. This category includes areas currently under crop, fallow, and land under preparation.
Settlements	Area of homestead which is surrounded by some shrubs and boundary planting trees (mainly *Eucalyptus globulus*).
Bare Land	Area under degraded grass lands and with some areas that are bare ground (rocks).
River bed gravel and rocks (Flood plains)	River beds which include sands, gravel, and bed rocks.

July and August. March and April are the hottest months and September is the coldest month.

In the study area, patchy remnants of old-aged Afromontane forests are found almost only around the Churches. These churchyards are covered with indigenous trees of mainly *Juniperus procera*, *Olea europaea*, *Ficus vasta*, *Prunus africana*, *Acacia abyssinica*, *Cordia africana*, and *Podocarpus falcatus*. The upper catchment (mainly Dega Agroecological zone) contains planted tree species in the form of homestead, farm boundary woodlot plantation. Species include *Eucalyptus globulus*, *Cupressus lusitanica, Eucalyptus camaldulensis*, *Chamaecytisus palmensis*, *Acacia decurrens*, *Acacia saligna, Grevillea robusta,* and *Schinus molle*.

2.2. Land Use and Land Cover Dynamics. The study area has been defined to have seven land use and land cover (LULC) categories based on Tegene [21] supplemented with field observation, namely, forest land, shrub-bush land, grazing land, cultivated land, settlement, bare land, and river bed gravel and rock (flood plain) as described in Table 1.

To classify and verify these major LULC, training sites were developed and prefield image processing was done using color composite of bands 4, 5, and 3 in RGB transformation of unsupervised and supervised methods with the help of classifiers for recent image (SPOT 5 imagery) of year 2008. Field verification and data collection were made on the training sites using global positioning system (GPS); with more than 350 readings for the year 2008 and 255 reading for the year 1986 from the field, topographic map, and old photos supplemented by dwellers information. The classification of older images (1976, MMS imagery) was based on integration of unsupervised classification and visual signature editions [22], involving the spectral values of the recent image that led us to signature collection for supervised classification. Then a class separability test was performed to evaluate the significance of difference (degree of separability) between LULC classes [23]. The supervised maximum likelihood classification algorithm was used for all the images, which is generally recognized as the best classifier technique [24]. After classification was performed, an accuracy assessment was taken for the years 1986 (TM imagery) and 2008 with the reference pixels of 155 and 265, respectively, using error matrix to evaluate the accuracy of classification.

2.3. Vegetation Sampling Techniques. For the vegetation census, a stratified random sampling procedure was used in this study. Five strata were defined according to classified LULC types in three agroecological zones, namely, (i) forest land, (ii) shrub-bush land, (iii) grazing land, (iv) settlement land, and (v) cultivated land. However, land use and land cover types, bare land, and floodplains were not included for the assessment because of the poor availability of woody vegetation. Data collection was conducted from November 2008 to February 2009. The estimated variables of the woody vegetation (trees and shrubs) were plant species richness, plant height, and dead trees. Trees and shrubs were classified based on height; namely, rooted, woody, and self-supporting plants ≥ 3 m in height were classified as trees, whereas rooted, woody, self-supporting, and multistemmed or single-stemmed plants greater than 1 m but <3 m in height were classified as shrubs [25].

A total of 135 plots (20 m $\times$ 20 m) were sampled in the study sites, that is, nine plots (three plots in each similar three LULC) in five LULC types and 45 plots in each agroecological zone. Quadrants were established and marked permanently using a plastic ribbon attached to four wooden pegs until the end of the study. The numbers of living stems and dead stumps were counted and recorded while the heights of all woody species were measured using a hypsometer and 6 m graduated pole, and a handheld GPS was used to mark the location of each sampling plot. Plant identification was done by referring Manuals [26–28]. For species that were difficult to identify in the field, herbarium specimens were collected, pressed, dried, and transported to the National Herbarium in the Department of Biology, Addis Ababa University, Ethiopia, for proper identification. Collected data were summarized and tested for normality using the Kolmogorov-Smirnov test, and data for tree density, shrub density, sapling density, and

Table 2: Area of land use and land cover types for 1976, 1986, and 2008 in Gilgel Tekeze catchment.

Land use	1976		1986		2008	
	Area (ha.)	Area (%)	Area (ha.)	Area (%)	Area (ha.)	Area (%)
Forest land	1704	4.84	859.52	2.44	1624	4.61
Shrub-bush land	11809	33.52	6125.82	17.39	5168	14.7
Grazing land	2867	8.14	1808.06	5.13	432.7	1.23
Cultivated land	17839	50.63	22893.5	64.98	23296	66.12
Settlement	759.7	2.15	2597.55	7.37	4278	12.11
River bed gravel and rock (flood plain)	168.8	0.48	285.63	0.81	320.4	0.91
Bare land	85.5	0.24	662.92	1.88	113.9	0.32
Total	35233	100	35233	100	35233	100

Table 3: Land use and land cover changes for periods 1976–1986, 1986–2008, and 1976–2008.

Land use	Periods of net change			Annual rates of change (%)		
	1976–1986	1986–2008	1976–2008	1976–1986	1986–2008	1976–2008
	Area (%)	Area (%)	Area (%)	Area (%)	Area (%)	Area (%)
Forest land	−2.4	2.17	−0.23	0.24	0.1	0.007
Shrub-bush land	−16.13	−2.72	−18.85	1.613	0.12	0.59
Grazing land	−3.01	−3.9	−6.91	0.301	0.18	0.22
Cultivated land	14.35	1.14	15.49	1.435	0.05	0.48
Settlement	5.22	4.77	9.99	0.522	0.22	0.31
River bed gravel and rock (flood plain)	0.33	0.1	0.43	0.033	0.004	0.01
Bare land	1.64	−1.55	0.09	0.164	0.07	0.003

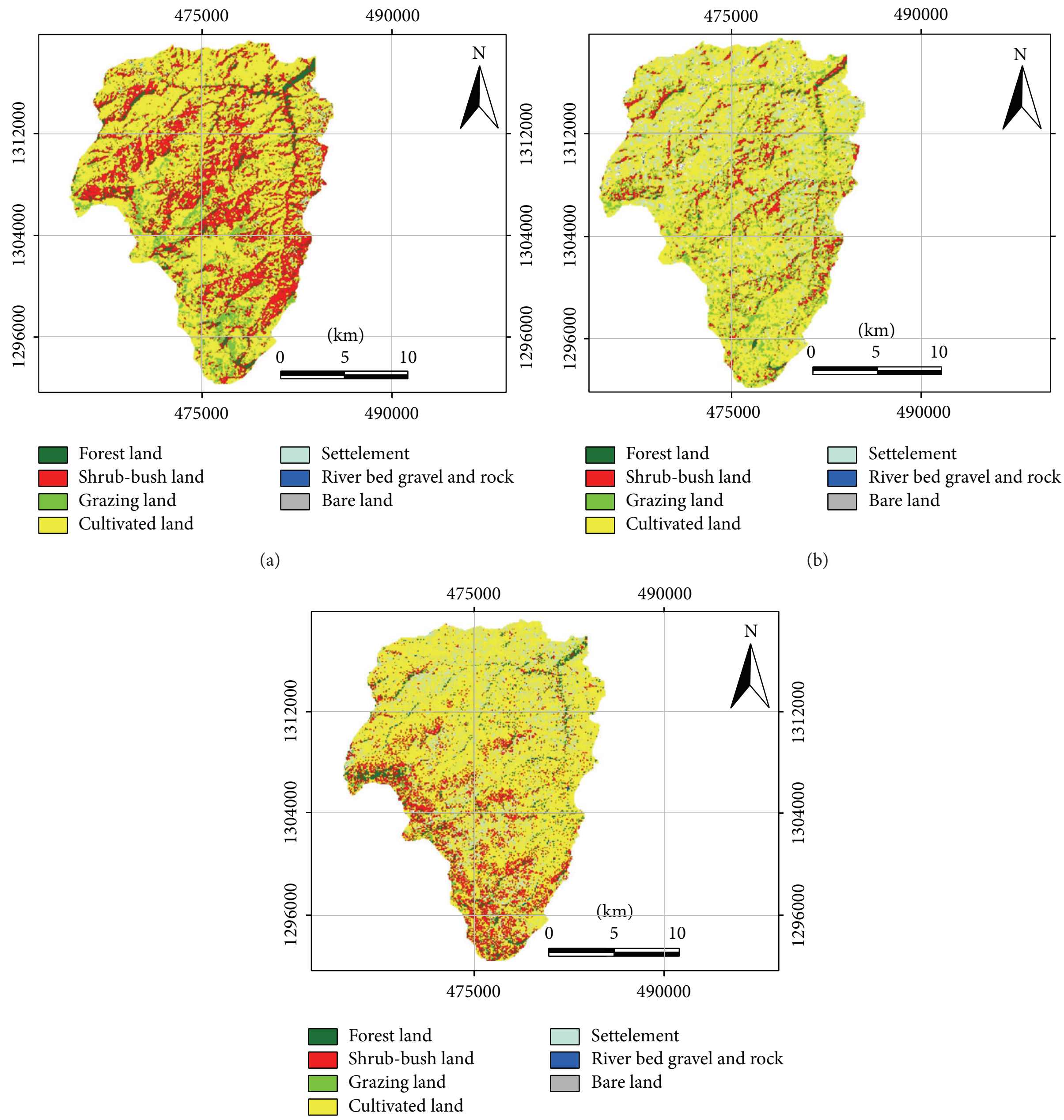
dead trees were found to be not normally distributed; hence, data were normalized using $\log_{10}(x + 1)$ transformation [29]. Species diversity in different land use and land cover areas was determined by calculating the Shannon-Weiner (H') diversity index [30]. Differences in vegetation structure and composition were tested using two-way analysis of variance (ANOVA), at 5% level of significance using the Statistical Package for Social Sciences (SPSS) version 19 for Windows [31]. Post hoc analysis for variables with significant differences was carried out using Tukey's Honestly Significant Difference (HSD). Furthermore, principal component analysis (PCA) was performed to determine the underlying patterns of the vegetation data using the 135 sample plots in JMP-5 version 5 for Windows.

3. Results and Discussion

3.1. Land Use and Land Cover Change Detection. The land use and land cover analysis indicates that forest land and shrub-bush land have decreased by 2.4 and 16.13 percent, respectively, between the years 1976 and 1986, while cultivated and settlement land have increased by 14.35 and 5.22 percent, respectively (Tables 2 and 3). This suggests that the forest and shrub-bush lands were declining at an average rate of 0.24 and 1.61 percent per annum, respectively, while cultivated land and settlement areas increased at the rate of 1.44 and 0.52 percent per annum over the ten-year period. This change shows that the rate of decline of the natural vegetation cover in the catchment is increasing as population and area under settlement are rising. There are different factors accounting for this trend, namely, population pressure and drought, as reported from interviews and discussion with local villagers in the catchment and experts of the district agricultural and rural development office.

The second period (1986–2008) data shows that forest lands increased by 2.17 percent as compared to the first period (1976–1986) which is associated to the 1985/86 drought in the area and there was a huge campaign in this part of the country for planting trees and constructing terraces in the hillslopes. Similarly cultivated land, settlements, and flood plain showed, respectively, positive increments. On the other hand, shrub-bush land and grazing land decreased by 2.72 and 3.9 percent, respectively. It is noted that the expansion of cultivated land and settlement occurred mainly at the expense of shrub-bush land and grazing land during the period 1976–2008.

Generally the LULC image (Figure 2) and data (Table 2) of three periods indicate both conversion and modification of LULC types. The area under shrub-bush land and grazing land declined by 18.85 and 6.91 percent, respectively, during the period 1976–2008, whereas cultivated land and settlement expanded by 15.49 and 9.99 percent, respectively. The shrub-bush land and grazing land decreased by 0.59 and 0.22 percent per annum, while cultivated land and settlement increased by 0.48 and 0.31 percent per annum, respectively (Table 3). It should be noted that compared to the periods of 1976–1986 both the contracting and expanding rates are decreased. This could be due to shortage of land to expand (cultivated land) at the expense of other LULC (forest, shrub-bush, and grazing land) and land rehabilitation programs in the study area through plantation and exclosures (areas



(c)

Figure 2: Land use and land cover maps of Gilgel Tekeze catchment for the years 1976 (a), 1986 (b), and 2008 (c).

of natural vegetation on degraded lands protected from the intrusion of humans or livestock).

The main finding in this study shows that there is a major decline in forest cover particularly natural forests. Most forest areas that were covered by native plants previously now have exotic plants dominantly with *Eucalyptus globulus* trees and shrub-bush land which is in line with Tegene [21] and Tekle and Hedlund [5], who reported 58 percent decline in forest cover of Derekolli catchment and 51 percent decline of the forest cover in Kallu district of southern Wello. However it is contrary to the work of Wøien [32] and Crummey [33] who reported a substantial increase in the forest cover in the Wello region as a whole at 1998 more than in the 1930s. The patterns observed in the Gilgel Tekeze catchment are thinning of natural forest and consequent change to shrub-bush land and grazing land particularly in the hillside and along the rivers.

The change from reduction of more natural vegetation (natural forest and shrub-bush land) to expanded cultivated land was more of conversion and high change of this type was observed between 1976 and 1986. These findings again well agree with that of Zeleke [34] and Teketay [35], who reported 39.42 and 24.2 percent increase of cultivated land for Dembecha area of Gojam and head stream of Abbay watershed, Blue Nile basin between 1957 and 1982, respectively. In contrast with that of Tekle and Hedlund [5], who indicated an increase of 2.4 percent for Kallu district in the period of 1957–1986, FAO [19] concluded that significant conversion to cropland did not take place since 1957 as most of the land suitable for cultivation was already in use. On the other hand, in the period of 1986–2003 there was little change in the area of cultivated land, which very well agrees with that of Tegene [21] and Zeleke [34]. The cultivated land in the period 1986–2003 of the Gilgel Tekeze catchment recorded an expansion of 1.14 percent and the study by Tegene [21] and Zeleke [34] also reported an expansion of less than 1.5 and 3.5 percent, respectively.

Moreover, the expansion of settlements in the area (Figure 2) was also observed mainly as the expense of both cultivated land and grazing land and this also agrees with Aerts et al. [13] who reported an increase of rural settlement by 17.1 and 13.2 percent for the periods 1957–1986 and 1982–2001, respectively. Settlement in the Gilgel Tekeze catchment showed the increase of 5.22 and 4.77 percent for the periods 1976–1986 and 1986–2008, respectively. This is in contrary to Tegene [21] who reported less expansion.

3.2. Woody Vegetation Structure and Composition across Land Use and Land Cover Types in Different Agroecological Zones. The inventory of woody plants across five different LULC types in three agroecological zones has identified different woody plant species composition representing different families in the study area. A total of 79 different woody plant species representing 49 families were recorded in the five LULC types in three agroecological zones. Out of the total families recorded, 31 families contain indigenous woody species and the remaining 18 families comprise exotic species. Fabaceae and Rosaceae are identified as the dominant families in all LULC types and agroecological zones. The result of woody plant composition inventory across different agroecological zones reveals the presence of 21 plant species representing 18 families in Dega, 51 plant species representing 31 families in Weyna Dega, and 45 plant species representing 32 families in Kolla agroecological zone. In terms of plant structure or life forms, the percentages of trees recorded were 65, 42, and 40 in Dega, Weyna Dega, and Kolla agroecological zones, respectively, while the proportion of shrubs was 34, 57, and 59 and the rest were woody herbs. The dominant woody species of the plant communities in Dega include *Eucalyptus globulus*, *Juniperus procera*, *Cupressus lusitanica*, and *Grevillea robusta*. The dominant woody species in Weyna Dega are *Cordia africana*, *Eucalyptus camaldulensis*, *Euclea racemosa,* and *Dodonaea angustifolia*, while *Acacia etbaica*, *Acacia saligna*, *Commiphora africana,* and *Boswellia papyrifera* were found dominant in Kolla agroecological zone.

In Dega agroecological zone, the total number of species and families in LULC class cultivated land was low, that is, 6 and 4, whereas settlement had maximum of 23 and 14, respectively. In Weyna Dega, the species and families were 11 and 23 in grazing land (low), while forest land had maximum of 24 and 25, respectively. LULC type grazing land contained the lower, that is, 13 species and 8 families, and shrub-bush land had maximum of 19 and 26, respectively in Kolla agroecological zone. However density and dead tree did not follow the same trend as the total number of species and families. Forest land and settlements had the higher tree and sapling density while grazing and cultivated land exhibited the lowest tree, shrub, and sapling density in each agroecological zone (Table 4). In terms of the number of dead trees, settlement land ranked first, and followed by forest land.

Tukeys HSD test ($F_{4,30} = 2.69$; $P < 0.05$) shows that vegetation structure and composition significantly differed across LULC types in different agroecological zone, particularly in the following variables, namely, sapling density, tree height, and shrub height (Table 4). Most of the variables including tree density and shrub density in Dega significantly differed, while the two agroecological zones Weyna Dega and Kolla did not show significant difference in most variables. The variables tree density, dead tree, and woody species diversity in forest land of Dega agroecological zone showed significant difference with Weyna Dega and Kolla forest lands. In contrary, the variables shrub density, sapling density, tree height, and shrub height showed significant difference in forest land of three agroecological zones. In terms of shrub-bush land, the variables dead tree and woody species diversity differed significantly in three agroecological zones, while no significant difference was recorded in tree height and shrub height variables. On the other LULC types of three agroecological zones, significant differences were recorded more on tree density, shrub density, and woody species diversity (Table 4).

Analysis of variance within each agroecological zone showed significant difference in tree density, shrub density, tree height, and shrub height variables between forest land and shrub-bush land LULC types in Dega agroecological zone, but in the other LULC types these variables did not show significant differences. Besides, significant differences were recorded in sapling density and dead tree variables in all LULC types of Dega agroecological zone. In Weyna Dega (Table 4(b)), LULC types showed significant differences in sapling density, woody species diversity, and dead tree, while the variables shrub density, tree height, and shrub height did not show significant differences in most LULC types. Significant differences were obtained for tree density, shrub density, and sapling density between the different LULC types in Kolla, while species diversity and shrub height among most of LULC types in Kolla agroecological zone did not show significant differences (Table 4(c)).

The study reveals that tree species diversity was higher in shrub-bush land which is not as much protected like the forested area, that is, natural forest and plantation. This finding is contrary to the widely accepted perception that diversity is low in poorly managed areas exposed to grazing and settlement. However, the perception is supported by our results in Weyna Dega area that species richness and diversity were higher in the forest land than in shrub-bush land and other LULC (Table 4(b)).

This finding suggests that disturbance factors and agroecological zones may have a significant effect on plant communities, and their composition and functioning are important factors to consider when studying biodiversity [35, 36], and anthropogenic disturbances may be more pronounced

Table 4: Vegetation attributes for sample plots across different land use and land cover types in Dega (a), Weyna Dega (b), and Kolla (c). Agroecological zone and significant levels from two-way ANOVA with equal sample size tests.

(a)

Variable	Agroecological Zone—Dega (D)					$F4,30$	P value
	Forest land (FLD)	Shrub-bush land (SBLD)	Grazing land (GLD)	Settlement land (SLD)	Cultivated land (CLD)		
Tree density in Ha	1619.42 ± 129.45^{a}	283.33 ± 89.26^{cd}	130.58 ± 25.81^{cd}	1050 ± 85.22^{b}	270.83 ± 191.51^{cd}	2.69	<0.0001
Shrub density in Ha	291.67 ± 82.50^{de}	850 ± 100.17^{b}	272.25 ± 87.81^{de}	308.33 ± 119.25^{de}	277.08 ± 100.17^{de}	2.69	<0.0001
Sapling density in Ha	183.25 ± 20.41^{efg}	113.92 ± 20.81^{bcdef}	69.47 ± 10.38^{fg}	147.2 ± 27.43^{a}	0^{g}	2.69	<0.0001
Dead tree in Ha	77.75 ± 27.42^{cd}	27.75 ± 3.89^{e}	44.25 ± 6.18^{de}	137.08 ± 15.06^{b}	5.58 ± 7.89^{e}	2.69	<0.0001
Tree height (m)	10.15 ± 1.59^{a}	1.86 ± 0.07^{c}	3.1 ± 0.31^{bc}	3.14 ± 0.41^{bc}	4.33 ± 3.29^{bc}	2.69	<0.0001
Shrub height (m)	1.67 ± 0.277^{ab}	1.4 ± 0.10^{ab}	1.59 ± 0.17^{ab}	1.33 ± 0.09^{abc}	1.0 ± 0.22^{bc}	2.69	0.0113
Woody species diversity (H′)	1.11 ± 0.27^{e}	1.5 ± 0.04^{bcde}	1.25 ± 0.06^{de}	1.19 ± 0.10^{e}	2.0 ± 0.33^{a}	2.69	0.5794

Values with different superscript letters within rows differ significantly (Tukey's HSD; $P < 0.05$).

(b)

Variable	Agro-Ecological Zone—Weyna Dega (WD)					$F4,30$	P value
	Forest land (FLWD)	Shrub-bush land (SBLWD)	Grazing land (GLWD)	Settlement land (SLWD)	Cultivated (CLWD)		
Tree density in Ha	1150 ± 55.67^{b}	366.67 ± 37.82^{c}	227.75 ± 39.82^{cd}	377.75 ± 32.18^{c}	93.75 ± 85.23^{cd}	2.69	<0.0001
Shrub density in Ha	425 ± 122.71^{cd}	1291.67 ± 75.73^{a}	705.5 ± 122.55^{bc}	483.33 ± 69.08^{cd}	437.5 ± 26.52^{cd}	2.69	<0.0001
Sapling density in Ha	183.25 ± 20.41^{b}	113.92 ± 20.8^{bcdef}	69.42 ± 10.38^{cdefg}	147.25 ± 27.43^{bcd}	0^{g}	2.69	<0.0001
Dead tree in Ha	41.75 ± 8.98^{de}	91.75 ± 8.15^{bc}	20.42 ± 5.19^{e}	34.25 ± 5.76^{de}	13.9 ± 4.01^{e}	2.69	<0.0001
Tree height (m)	7.91 ± 1.31^{ab}	2.5 ± 0.14^{c}	2.06 ± 0.28^{c}	2.57 ± 0.17^{c}	2 ± 1.78^{c}	2.69	<0.0001
Shrub height (m)	1.7 ± 0.09^{a}	1.76 ± 0.24^{a}	1.71 ± 0.14^{a}	1.66 ± 0.26^{ab}	0.75 ± 0.25^{c}	2.69	0.0113
Woody species diversity (H′)	$2. \pm 0.33^{a}$	2.54 ± 0.14^{ab}	2.28 ± 0.11^{abc}	2.59 ± 0.21^{a}	2.07 ± 0.29^{abcde}	2.69	0.5794

Values with different superscript letters within rows differ significantly (Tukey's HSD; $P < 0.05$).

(c)

Variable	Agro-Ecological Zone—Kolla (K)					$F4,30$	P value
	Forest land (FLK)	Shrub-bush land (SBLK)	Grazing land (GLK)	Settlement land (SLK)	Cultivated land (CLK)		
Tree density in Ha	936.08 ± 23.97^{b}	388.92 ± 20.80^{c}	169.47 ± 27.54^{cd}	175 ± 40.82^{cd}	55.58 ± 39.89^{d}	2.69	<0.0001
Shrub density in Ha	$386.1 \pm 68.19d^{e}$	1333.33 ± 105.60^{a}	414.25 ± 16.63^{cd}	361.08 ± 25.74^{de}	$86.08 + 30.68^{e}$	2.69	<0.0001
Sapling density in Ha	327.75 ± 21.84^{a}	155.5 ± 37.45^{bc}	66.67 ± 6.84^{defg}	119.42 ± 28.27^{bcde}	33.33 ± 23.57^{efg}	2.69	<0.0001
Dead tree in Ha	35.5 ± 1.95^{de}	209.25 ± 18.93^{a}	20.33 ± 14.55^{e}	8.33 ± 11.79^{e}	28.67 ± 17.06^{e}	2.69	<0.0001
Tree height (m)	4.27 ± 0.37^{bc}	2.17 ± 0.12^{c}	1.93 ± 0.19^{c}	1.03 ± 0.05^{c}	4.6 ± 3.28^{bc}	2.69	<0.0001
Shrub height (m)	1.6 ± 0.06^{ab}	1.41 ± 0.09^{ab}	1.25 ± 0.09^{abc}	1.73 ± 0.06^{a}	1.3 ± 0.04^{abc}	2.69	0.0113
Woody species diversity (H′)	2.61 ± 0.75^{a}	2.67 ± 0.11^{a}	2.25 ± 0.09^{abcd}	$2.54 + 0.21^{ab}$	$1. \pm 0.29^{e}$	2.69	0.5794

Values with different superscript letters within rows differ significantly (Tukey's HSD; $P < 0.05$).

outside forested areas [37]. Similarities across the LULC strata were found in sapling density, shrub density, and dead tree density, whereas, tree density, tree height, and shrub height differ across agroecological zones.

The varying levels of disturbance in different LULC categories have an effect on plant biodiversity. In the unprotected areas, vegetation losses can be a result of selective extraction of forest and woodland resources for purposes such as fuel wood, construction materials, and other nonwood forest products [37, 38]. The study conducted in Sekota district of Amhara region [39] very well confirms the fact that the main reason for destruction of woody vegetation was the ever increasing population pressure. In addition Semegne [40] in Bella-Welleh watershed (Sekota) near to the study area pointed out that, population pressure is the cause of the observed land use and land cover changes and total number of household increased by 205 percent between 1965 and 1982. In line with this study, the Gilgel Tekeze catchment settlement accounts the increase of 2.15, 7.57, and 12.14 percent for the years of 1976, 1986, and 2008, respectively (Table 3).

It has been reported that the structural complexity of an ecological community is positively correlated with the diversity of plant life [35]. Protected and developed areas such as exclosures are often assumed to be the best way to conserve plant diversity and maintain intact woodland/forest composition and structure [36]. This ultimately determines biodiversity at various scales, providing habitat for unique wildlife species that require unique and variable forage and cover opportunities or "niches" for survival and reproduction.

3.3. Patterns in Woody Vegetation Structure and Composition. Figure 3 shows a PCA biplot of sample plots and measured variables in the study area. Axis 1 explained 77.33% of the variance in vegetation data and defined a gradient from areas with shrubs density and woody species diversity to areas with a higher density of trees and saplings. Accordingly, SBLD, SBLWD, SBLK, CLD, CLWD, and CLK correlated negatively with axis 1, whereas FLD, SLD, and SLWD positively correlated with Axis 1. Moreover, Axis 2 explained 11% of the vegetation data and defined a gradient from areas characterized with diversity of woody plants, taller trees and shrubs to areas with higher densities of trees and shrubs. CLD, CLWD, CLK, SLD, and SLWD had a negative correlation with Axis 2, whereas mostly SBLD, SBLWD, and SBLK, to a lesser extent, FLD and SLD were positively correlated with Axis 2.

The number of species and families common to all agroecological zones were only two. *Acacia saligna* and *Rhamnus prinoides* were recorded in all the agroecological zones. However, the number of common species and families increased as the land use and land cover types were stratified in agroecology. LULC types located in Dega and Weyna Dega shared 8 species and 5 families while those located in Kolla and Weyna Dega agroecological zones shared 34 species and 25 families in common.

Most communal areas in Ethiopian highlands are associated with human population increase, encroachments in protected areas, and increased dependency on natural

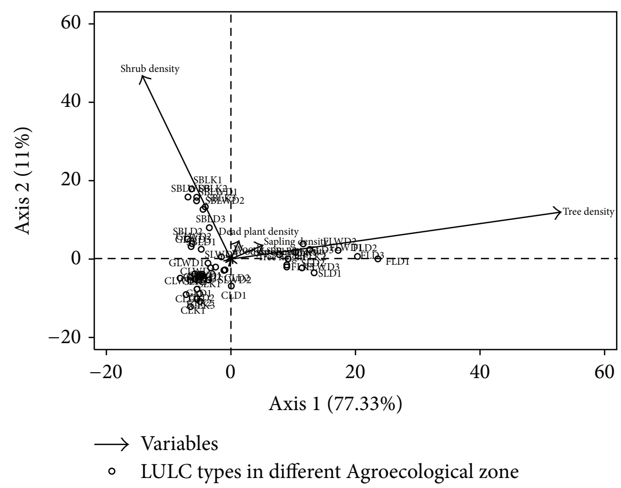


Figure 3: Principal component analysis biplot of measured vegetation variables from the 135 Sample plots in Gilgel Tekeze catchment of LULC types across three agroecological zones (see Table 4).

resources for livelihood, which often result in habitat loss and degradation, thus influencing woody vegetation abundances and their distribution [4, 6]. Besides the environmental variables that influence species composition and distribution along the gradient, anthropogenic activities are key factors that influenced the observed pattern of species distribution, composition and diversity in all sample plots as shown in Table 4 and Figure 3. Most of the areas in the Dega agroecological zone were under population pressure. Dega zone served for settlements and agricultural activities for the local people. In this zone, major parts of protected forests are plantation with one or two exotic plants like *Eucalyptus globulus* and *Cupressus lusitanica*, whereas in Weyna Dega and Kolla agroecological zones which have lower population and livestock pressure covered higher species diversity. The highly diverse community of these zones partly indicates less human impact, compared to that of Dega agroecology zone which had less species evenness and appeared monocrops in most parts of the zone down to plantation and enrichment. It can be argued that the relationship between high species diversity and the drivers of change is largely dependent on the type of vegetation community, the degree of human impact and other natural factors as well as its location on the landscape. Although species diversity was high in Weyna Dega and Kolla zones, it was not evenly distributed across the LULC types, indicating that plant species were evenly distributed only in forest land and shrub-bush land in these agroecological zones where the degree of impact was relatively less severe. The uneven distribution of species typically in grazing land, settlement land, and cultivated land in most parts of the catchment suggests a gradual deterioration of the natural functioning state of the area. This is largely attributed to the loss of species through anthropogenic impacts.

4. Conclusions

The present research work on the long-term dynamics in LULC types and the impacts on woody vegetation diversity in the Gilgel Tekeze catchment has revealed that there were substantial LULC changes in the area during 1976–2008 periods. The proportional changes in area were determined for the total LULC types in three different periods. The multi-temporal analysis of satellite image data clearly indicated that shrub-bush and grazing lands have decreased; in contrary cultivated land and settlement have showed a subsequent expansion in 1976, 1986, and 2008 years. Forest land, bare land, and flood plain have shown little change. Though the forest lands have shown a slight change, the natural vegetation cover had been extensively cleared and most of the cleared areas were gradually replaced with plantations. Generally the first period, between 1976 and 1986 years, has shown rapid changes as compared with the period between years 1986 and 2008. This might have been aggravated by the occurrence of 1985/86 drought. Based on field observation and discussion with local people, the major underlying causes for the changes of this LULC types are through settlements, deforestation, overgrazing, edaphic (topographic, erosion), and biotic factors (planting one or two exotic species) with allelopathic effects in the study area.

This LULC changes have resulted in the observed variations in woody vegetation diversity and pattern in the different LULC types and agroecological zones. Our study provides evidence that vegetation structure and composition significantly differed across LULC in different agroecological zones, particularly in the following variables, namely, tree density, sapling density, dead tree, and woody species diversity. It also shows that tree species diversity was higher in shrub-bush land which is not as much protected like the forested area, that is, natural forest and plantation. However, improving diversity of trees inside forested areas and understanding the causes for less diversity of trees in these forested areas call for further investigation. The introduction of conservation measures in the catchment, through construction of soil and water conservation structures and planting seedlings have helped in the gradual restoration of the catchment. This should be supported by a carefully selected restoration measure(s) such as reintroduction of diversified species to enhance more sustainable ecosystem which will ultimately address and protect vegetations.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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