Research Article

Vulnerability of Agrobiodiversity and Agroforestry Settings to Climate Change in Gedeo Zone, Ethiopia

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The study was carried out at the Gedeo zone aiming to investigate the vulnerability of agrobiodiversity and agroforestry settings to climate change in the district. Thus, the study was focused on evaluating crop diversity under different crop management practices and its distribution at the household level among different wealth classes and land use land cover change impact on agrobiodiversity and agroecosystems areas. Therefore, crop survey both from the home garden and crop field, the last 30 years' data from five meteorological stations located in the district and the past 30 years' Landsat satellite images at a 10-year interval within the same season was used. A total of 65 crop plant species with eleven major use categories have been recorded in the studied home gardens and crop fields. The crop plant species collected from both the home garden and crop field account for 57% and 38%, while the rest 5% were from the adjacent field. The land use and land cover map of the study area indicate that the largest part of the study area (108548.01 hectares) was covered by agroforestry, whereas the smallest portion of the district, about 975.15, 6457.41 and 12501.27 hectares of the area, was covered by bare land, cropland, and grassland, respectively. The remaining 20537.73 hectares (13.8%) of the district were covered with settlements. Crop species diversity is higher almost in the entire study site. However, crop species compositions were significantly variable among these study sites. The climatic data results indicated a reduction in average rainfall pattern in most of the stations and an increase in temperature within the employed time range.

1. Introduction

Agrobiodiversity can be defined as the diversity within and among species found in an agroecosystem that contribute to food and agriculture, including planned (domesticated) biodiversity (i.e., the diversity of crops and livestock genetic resources) and all other plant and animal genetic resources (i.e., crop wild relatives) [1–3]. In general, it refers to the diversity of plant and animal genetic resources (PAGR) relevant for food and agriculture.

Agrobiodiversity is being threatened by climate change as rapid shifts in local environmental conditions may drive species number reduction and further to extinction. According to [4], a livelihood system is built upon different productive livelihood resources or assets (natural, human, social, physical, and financial capital) that enable people to engage in different livelihood strategies, which in turn determine livelihood outcomes, such as the degree of vulnerability to climatic shocks.

Agroforestry is the integration of trees into crop and animal production areas and includes a diverse range of systems, such as silvopastoral systems, shade-grown perennial crops (e.g., coffee, cocoa, and rubber), windbreaks, alley cropping, and improved fallows. Including trees within agricultural systems leads to increased soil conservation, microclimatic buffering, and more efficient water use, thereby helping reduce the impacts of climate change. It is a promising option for increasing the resilience of rural communities in the face of climate change. At the same time, agroforestry systems provide a wide array of products to smallholder farmers, diversifying their production and livelihood options. Agroforestry systems that are floristically

and structurally diverse can also provide important biodiversity benefits to smallholder farmers. They can also serve an important role in climate change mitigation by enhancing carbon stocks within the agricultural landscape and, in some cases, reducing pressure on nearby forests, thereby reducing emissions from deforestation [5, 6].

1.1. The Gedeo Agroforestry Systems.

The Gedeo indigenous agroforestry system "home gardens" is characterized as one of the oldest traditional farming systems in Ethiopia. It is composed of highly diversified and closely growing indigenous tree plants, shrubs, and annuals that form apparently unbroken vegetation cover. As indicated by [5], in a home garden of a $100 \, m^2$ plot, a total of 50 plant species with 35 plant families were recorded. Crops typically grown in the Gedeo agroforestry system include *Coffee arabica, Ensete ventricosum, Dioscorea alata, Catha edulis*, and *Ipomoea batatas* and numerous other kinds of vegetables. Fruit trees such as *Persea americana, Mangifera indica, Musa paradisiaca*, and *Ananas comosus* are also integral parts of the system, especially at lower elevations. Trees such as *Cordia africana, Millettia ferruginea, Albizia gummifera, Ficus* spp., and *Acacia* spp. form the upper stories of home gardens [7]. In this case, most of the trees specifically composed in Gedeo agroforestry are indigenous plants and production exclusively relays on indigenous knowledge [6]. It is a long-time practice and is known for supporting large numbers of populations estimated at over 900 person/km^2 [6]. This higher carrying capacity of the system is mainly attributed to the existence of the annual and perennial agroforestry growing all forms of crops and supplementary together and managed as a home garden for over five thousand years by farmers [8].

The Gedeo agroforestry systems are divided into three agroforestry settings based on their altitudinal ranges and dominant component of plant species [5]. These are enset-tree-based, enset-coffee-tree-based, and coffee-fruit-based agroforests with a corresponding altitudinal range of above 2000 m asl (meters above sea level), 1600 to 2000 m asl, and below 1600 m asl. The agroforestry benefits are providing ecosystem services such as improved nutrient cycling, soil protection and enhanced soil water recharge, decreased crop canopy temperatures, and enhanced biodiversity and its potential to diversify rural economies through the generation of relatively high-value food, animal fodder, and medicinal and fuelwood products [5, 9]. It also houses many genera of the invertebrate soil macrofauna and has a high level of carbon stock compared to monoculture agriculture, where the level of soil carbon stock is dependent on the availability of soil organisms in the soil and the difference in vegetation cover [10].

In the Gedeo zone, the intensification of market-based agricultural production and expansions of monocropping have led to the erosion of indigenous knowledge and the wrong perception of agroforestry production, as a whole, challenges the survival of the home garden agroforestry system [6]. Currently, market-based agricultural production, such as the cultivation of khat and sugarcane, monocropping

expansions, like beryl at highland and teff and maize at lowland, and climate change have challenged the agrobiodiversity and socioecological benefits of the Gedeo agroforestry system [5, 6, 11]). Therefore, this study was carried out to evaluate crop diversity under different crop management practices and identify and map climate change vulnerable agroforestry settings in the Gedeo zone.

2. Materials and Methods

2.1. Description of the Study Area.

The Gedeo zone is situated on the western escarpment of the eastern branch of the Rift Valley, in the humid southeastern Ethiopian highlands, approximately between 5 degrees and 7 degrees N latitude and between 38 degrees and 40 degrees W longitude, 365 km southeast of Addis Ababa. The zone is bordered on the north by the Sidama zone and on the east, west, and south by the Borena and Guji zones. Dilla is the main town of the zone, located 365 km and 90 km south of Addis Ababa and Hawassa town, respectively (Figure 1). With an approximate surface area of 1,329 km^2, the Gedeo lands are one of the most densely populated regions in the country. The population number of Gedeo is 847,434 (424,742 males and 422,692 females) [12]) at a density of 1433.3 individuals/km^2 of land. The major economic activities of the zone were farming and small businesses, accounting for 87% and 13%, respectively [10].

2.1.1. Climatic Conditions.

The analysis of the metrological data of monthly maximum and minimum temperature and monthly rainfall was taken from the Addis Ababa National Meteorological Agency for the 1986–2018 period. It showed that the mean annual temperature of the study area ranges from a mean minimum of 9.4°C to a mean maximum of 24.7°C. Generally, the area received a total mean annual rainfall of 1253 mm and has a total mean annual temperature of 16°C during these years. The region indicates that the concentration of rain is of a bimodal pattern type in the zone with long rain in mid-February to mid-may, short rain in September to November, and tiny and fine rain showers in June (Figure 2). The lowest mean temperature over 30 years was 9.4°c recorded in the metrological data of the Fiseha Genet station.

2.2. Sampling Methods.

Data were collected purposefully from 180 sample households (12 randomly selected sites (kebeles) x 5 subsites in each site x 3 households of different economic status, i.e., poor, average, and wealthy in the society) following [13]. The records of *Kebele* offices were used to determine the wealth status of farmers. The selection of the *Kebeles* was based on their distance to highways and to market and differences in altitude. Distances to market and highway were considered because of their effect on farmer's choice of crop to grow and altitudes due to crop agroclimatic adaptability. The individual household heads were selected from the sampling sites using simple random sampling techniques, whereas an average of 15 key informants were intentionally selected. They were selected from household
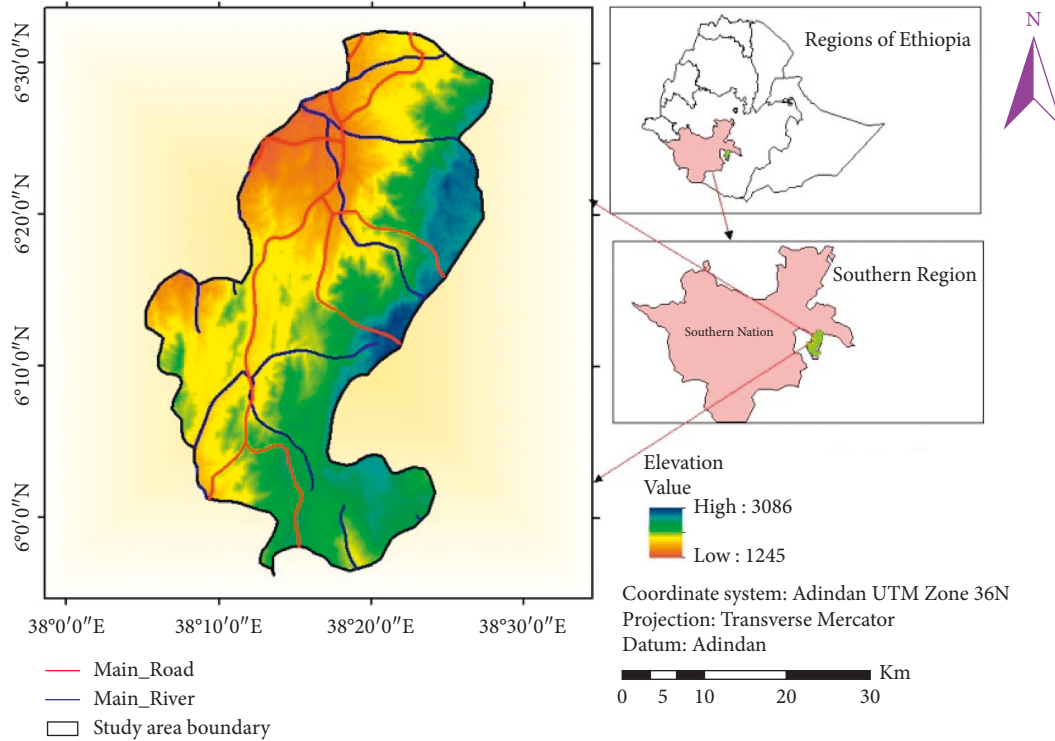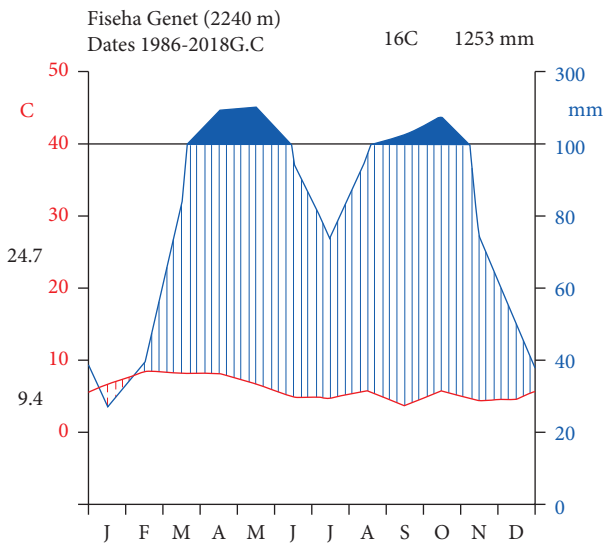
FIGURE 1: Location map of the study area.

FIGURE 2: Map of climatic diagram of the district at the main station of Fiseha Genet. Source (National Meteorological Agency AA).

heads of both sexes and different age groups based on their availability, willingness, and practical knowledge of crop species compositions of the area.

Individual households were interviewed using semistructured questionnaires intended to capture relevant information related to study sites, crop biodiversity and cropping system, farmers' knowledge of varieties, seed selection and storage, farmers' reasons for the maintenance of landraces, and gender role in the management of crop genetic resources. Species and local varieties were identified by their local names in the field with the assistance of knowledgeable farmers. Crops that are lost/endangered at both study sites and district level were recorded.

Regarding indigenous knowledge and crop management system in the area, five key informants from each study site were interviewed on the issues related to the effects of traditional farmers' knowledge in agricultural practices and the management of crop species diversity. Finally, two focus group discussions, agricultural experts and the key informants, were used to strengthen the individual interviews have been done.

2.3. Data Collection. Data on crop plants were collected from both household gardens (home gardens) and any other additional farmland/s owned by each household (crop field). The home gardens often display a mosaic of patches or farm units that are distinct from one another because of the dominant crop grown on them [14]. The area allotted to the different unit types (plant associations) and their degree of intercropping vary considerably. Enset, banana, or coffee units, which are integrated with different crops and trees, form a multistorey structure and cover a very large proportion of these gardens. The perennial crop population was counted using a 20 m × 20 m quadrat in each of the sampled households, and additionally, the pests and diseases infected crop species were identified and counted independently within the plot. The aspect, slope, and elevation of each plot were recorded using Suunto Compass, Clino Master Clinometers, and Garmin 12 channel GPS, respectively.

At the farmland level, the total crop area was measured and the different crop units were identified. For each crop unit, the area was measured, and the different species of crops were recorded. The population of annual crops and other widely grown small plants were estimated by making sample counts. Annual crops were assessed by sampling a 50 m^2 quadrat (subdividing it into 10 m × 5 m adjacent plots and extrapolating it to the area it covers) following the methodology used [15]. For each type of crop, the number of sample quadrants per plot accounts for about 10% of the total size of the plot. For most perennial crops like enset, the total population was counted. The areas allocated for each crop in the integrated units were calculated by considering the number of individuals of a particular crop in relation to its spacing and area of the crop unit. Each species on the field was classified into a functional group in the form of a set of species with similar roles in the livelihoods of the local people. Finally, the numbers of crop species from each of the five subsites were summed, and the average of species abundance was considered. Further, data on the average annual yields of the different crops were also collected [14].

2.4. Data Analysis. Crop species richness (S), Shannon index (H), and evenness (E) were computed across the sites and land use categories. The diversity of functional groups of crops was also calculated using the Shannon index [16] and Evenness measure (E), which are commonly used tools for these purposes [17, 18]. The Bray-Curtis similarity analysis (Cluster analysis) was used to evaluate the similarity in crop species composition of the study agroforestry. Nonmetric multidimensional scales (NMDS) ordination was also employed to identify the variation of crop species distribution along the crop management with crop species treating pests and diseases. Ranking abundance curves were constructed to establish the most abundant crop species in the study sites. Additionally, the monthly maximum temperature and annual precipitation anomaly data were analyzed using R software. Moreover, the climate change stressors and the threatened ecosystem areas were determined using the ArcMap version 10.5 and ERDAS IMAGINE 2014 software. Furthermore, the relationship between different variables such as household head age, family size, and education status of household heads at each sampling site with the crop species distributions was computed. All analyses were conducted using R program version 3.6.1 software of stats and vegan packages.

3. Results and Discussion

3.1. Composition and Diversity of Plant Species in Different Farming Practices. In the present study, a total of 65 crop plant species belonging to 56 genera and 32 families have been recorded in the studied zone. The major families were Poaceae, followed by Lamiaceae, Solanaceae, Fabaceae, and Alliaceae. The identified crop species were also categorized into eleven functional groups: spices, 26.23%; fruits, 19.67%; vegetables, 16.40%; root and tuber crops, 9.83%; cereal crop, 8.20%; other species, 15.06%. The crop species collected from

home gardens and field crops account for 57% and 38% respectively, while the rest 5% were collected from the adjacent field. The average plant diversity per home garden was 21 plant species, ranging from 11 to 37 throughout the home garden. The majority of crop plant species were collected from home garden.

3.2. Species Richness and Diversity in Home Gardens

3.2.1. Crop Plant Community Classification. The study identified three crop community types (clusters) in the Gedeo zone (Figure 3), and the three communities and distributions of the sample plots in the communities were identified (Table 1). These clustered woredas into three communities were formed from the clustering based on their similarity in crop plant composition (Figure 3).

Sorensen's similarity index measures the degree to which the species composition of samples is alike, whereas the dissimilarity coefficient assesses which two samples differ in composition. Based on this, similarity in species composition slightly varied among the formed communities. The highest similarity was observed between communities II and III (33.7%). The least similarity was observed between communities I and III (18.1%). Overall similarity coefficient ranges from 18 to 28% among all the communities. Thus, species composition dissimilarities account for 72% of the most similar communities and 82% of those that share the least similarity (communities II and III). The clustered community is also represented by the plot numbers and the collected crop species from each plot (Figure 4).

3.3. Species Diversity. The three communities have almost the same species distribution (equitability or evenness), but comparatively, community I (Bule and Gadeb) has the least species evenness (Table 1).

The Shannon–Weaver index shows a higher diversity of plant species in community III home garden (H′ = 3.88) as compared to the home gardens of community II (H′ = 3.85) and community I (H′ = 3.77).

3.4. Plant Health Status. The health status of crop plant species at the study home garden was identified in different farming practices and wealth statuses of farmers. There are higher numbers of threatened plant species in Dilla Zuria and Chefe sites, particularly in home gardens, whereas lower numbers of threatened crop species were recorded in Bule and Gadeb than those in other study sites. Insect was the more highly treating crop pest than fungi and bacteria in the adjacent and field crop area (Figure 5).

According to farmers' rank, the threatened crop species that are highly susceptible to diseases at their farm are *Brassica carinata, Ensete ventricosum, Lycopersicon esculentum, Mangifera indica, Vicia faba,* and *Musa paradisiaca* ranked from high to low susceptible. Thus, those crop species will need special care for their sustainable use.

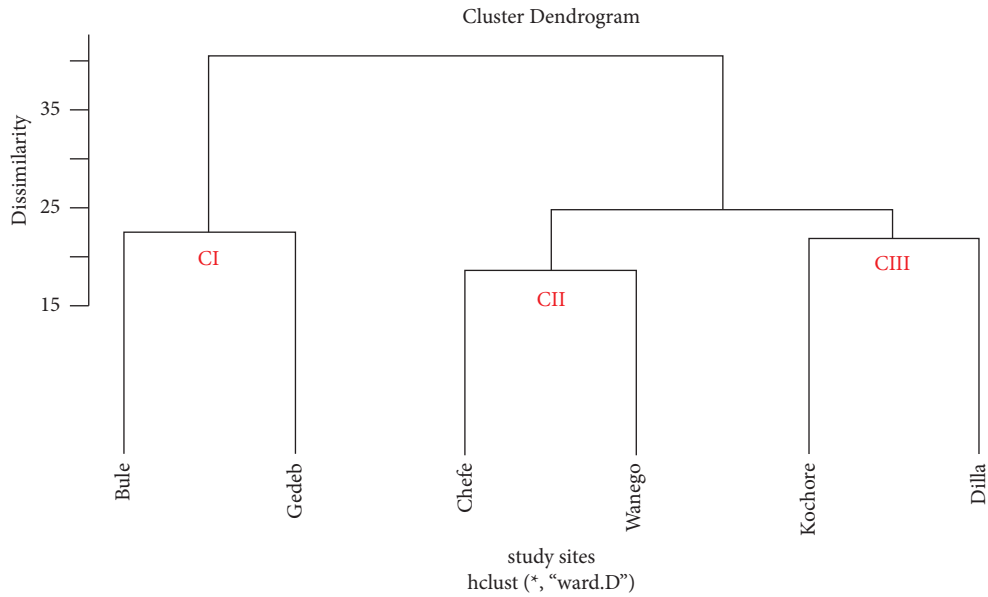From group discussion, the farmers list out a few landrace crops that were being cultivated by farmers and

FIGURE 3: Cluster dendrogram of the major study woredas.

TABLE 1: Species richness, evenness, and Shannon–Wiener diversity index of the plant community types.

Community	Species richness (S)	Diversity index (H′)	Species evenness (J)
I	321	3.77	0.94
II	478	3.85	0.94
III	372	3.88	0.95
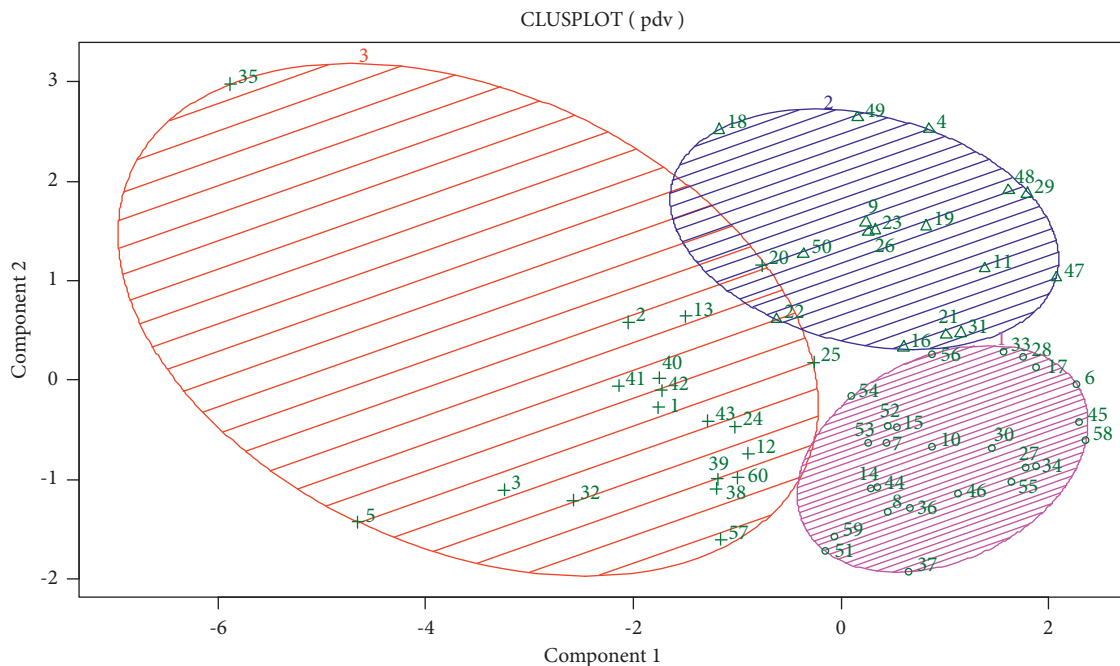
These two components explain 68.91 % of the point variability.

FIGURE 4: Clusplots of bivariate graphical representation of clustering ($K = 3$) partition.

have now totally disappeared from the area and field due to these threats. Mainly the field crops are highly susceptible to total disappearance from the area because their yield was affected by diseases. Farmers did initiate to cultivate it again rather they looked for other new, improved, and disease-resistant varieties. Therefore, the local variety easily disappeared from the area. Currently, the farmers refer to some of the field crops that disappeared from the area; for
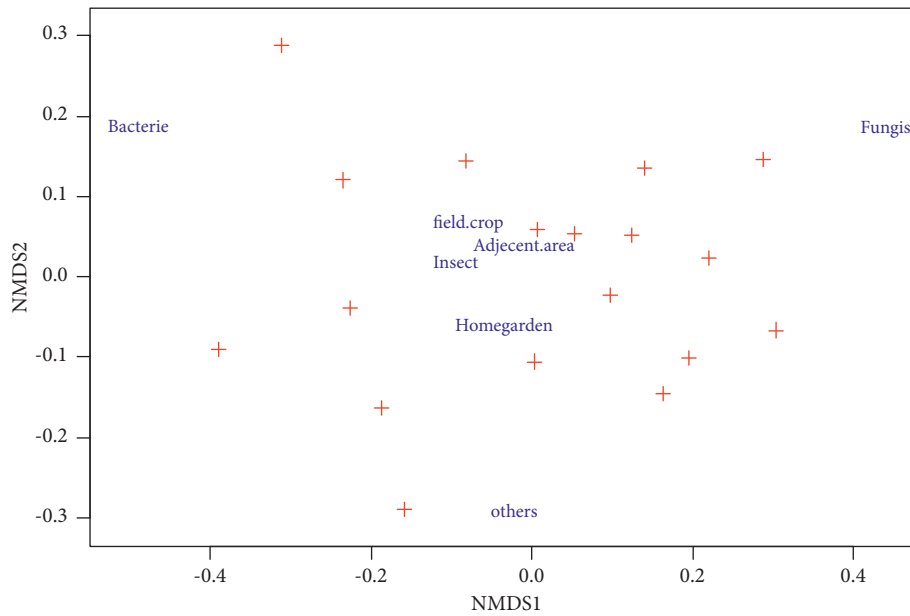
Figure 5: NMDS biplot of Bray-Curtis dissimilarity matrix (stress = 0.122) showing crop health status at the study.

example, those locally called "Burqudu" (barley cultivars) and Jilo balii (maize cultivars) were totally disappeared from the farmers' land and local market in 1985–1990 GC.

3.5. Climatic Variables

3.5.1. Rainfall Data Analysis. In the last 32 years' meteorological data, there was variability in annual rainfall. Boxplot is used to depict central tendency, variation, and presence of outliers and, in general, distribution of the data through the district in just one graph. Boxplot is presented for the weather within the woredas. The total average annual rainfall variation in the studied woreda has a significant average mean variation (Figure 6). Again, during focus group discussions and key informant interviews, the participant reported that the monthly rainfall pattern has fluctuated for the last 20 years. In addition to this variability, a reduction in rainfall amount is also observed in the district during all rainy seasons (Figure 7).

3.5.2. Humidity Data Analysis. Comparatively, the annual average humidity patterns also fluctuated in the study area. The average annual humidity has increased significantly for the last ten years (Figure 7). The total average annual humidity at all stations similarly increased from time to time for the last 20 years especially from 2010 to 2018 GC.

3.5.3. Temperature Data Analysis. The annual maximum, average, and minimum pattern of temperatures from all stations within the study district slightly increased from 1988 to 2018 (Figure 7). However, participants in focus group discussions replied to the changeable behavior of local climate, which is characterized by an increase in temperature, decline in rainfall, and increase in evaporation. In general,

the result of this study showed that there was a fluctuation in local climate change.

3.5.4. Land Use and Land Cover Change Analysis. The Gedeo zone has three major agroclimatic zones: Dega (2400–3086 m asl), Woyna Dega (1800–2400 m asl), and Kola (1245–1800 m asl) agroclimatic zones(Figure 8).

3.5.5. Image Classification. The sample of training sites was evaluated using a contingency matrix in ERDAS IMAGINE 2014. Accordingly, no errors occurred during our signature collection; i.e., no training sites were collected outside of the represented features.

In the analysis of land use and land cover impact on the vulnerability of agrobiodiversity and agroecosystems areas to climate change stresses in the study area, the current study has employed the supervised image classification technique. Supervised image classification with the maximum likelihood statistical approach is selected because it is the most sophisticated and achieves a good separation of classes.

It also requires strong training set to accurately describe mean and covariance structure of classes. Accordingly, with supervised classification techniques, the researchers categorized the land cover of the study area into five categories of land cover features (Table 2). These were agroforestry, grassland, settlement, bare land, and cropland. Finally, we generated a land cover map for 1988, 2002, and 2018, which were very important for the analysis of the current study.

3.5.6. Accuracy Assessment of LULC Map. Land use and land cover maps generated from remote sensing images contain some sort of errors. In order to use such maps for the analysis of ecosystem change, it is vital to quantify errors in terms of classification accuracy. For this purpose, sufficient
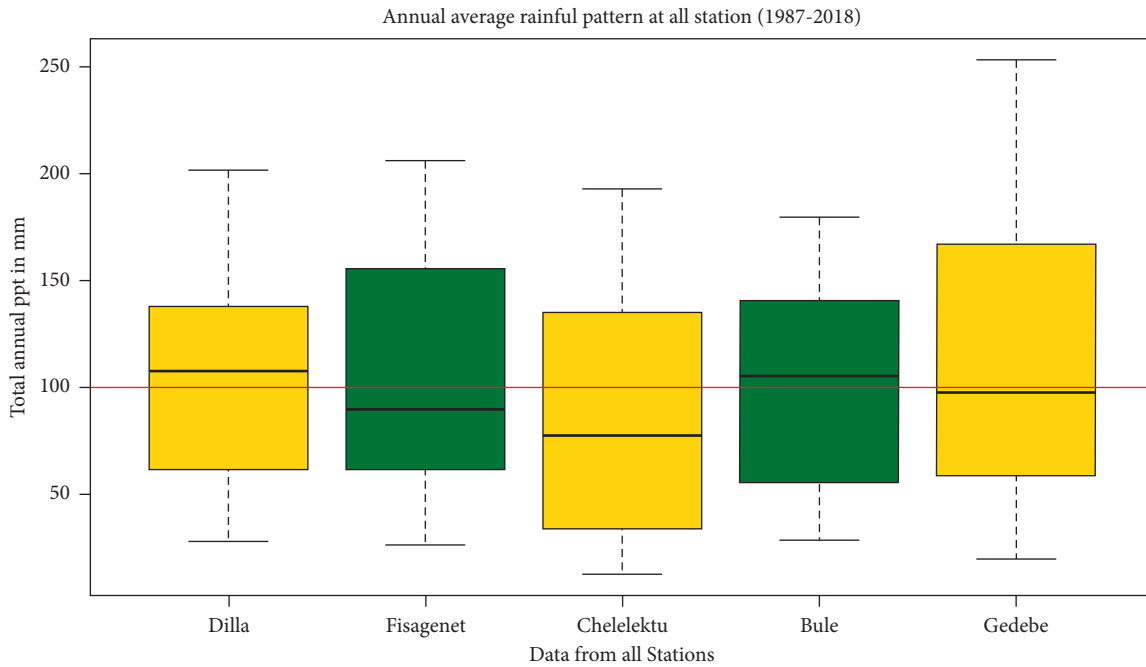
FIGURE 6: Annual boxplots of rainfall data at five local stations within the study zone for the last 30 years. Source (National Meteorological Agency AA).
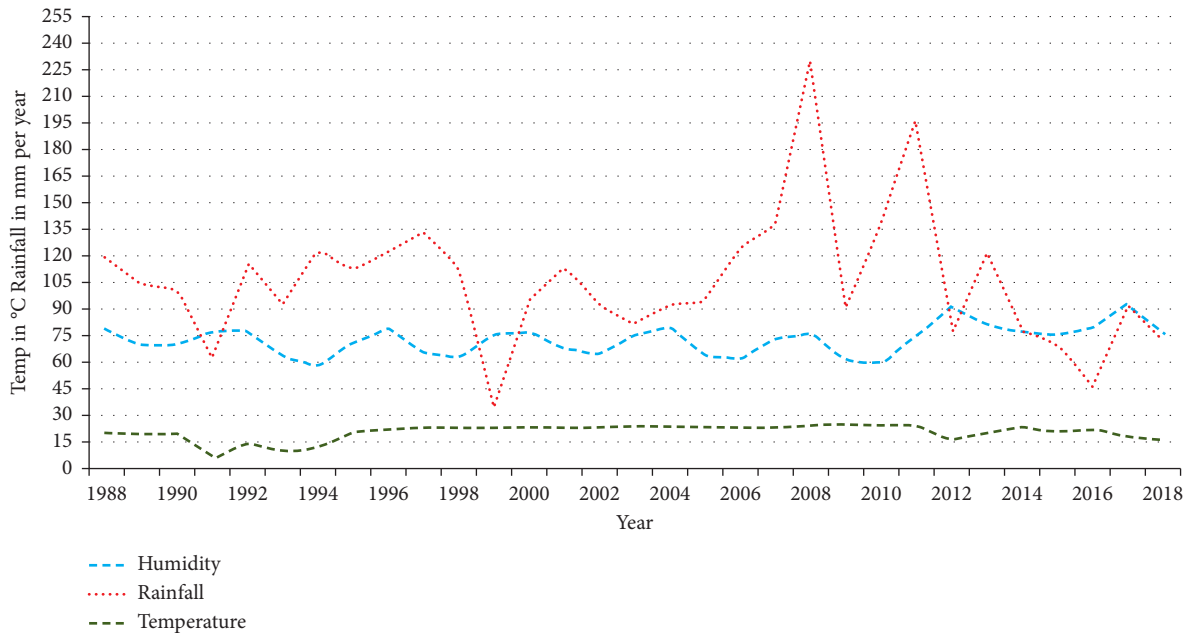

FIGURE 7: Annual average humidity at 12 : 00 local time per month, temperature, and rainfall data per year at all stations. Source (National Meteorological Agency AA).

numbers of ground control points were collected from each land class of the study area. Accordingly, the LULC maps of the study area were classified by 85% of the overall accuracy level with a kappa coefficient of 80.4% indicating the result of classification was best and acceptable. Therefore, result obtained for this study fits the minimum level of accuracy in the classification of land use land cover types of remotely sensed data which should be at least 80% of the kappa coefficient [19].

The above-classified map of the study area raveled that (Figure 9), the largest part of the study area (108548.01 ha) during 1988 was covered by agroforestry, which served as home for different biodiversities that can grab many animals and plant species, whereas the smallest portion of the
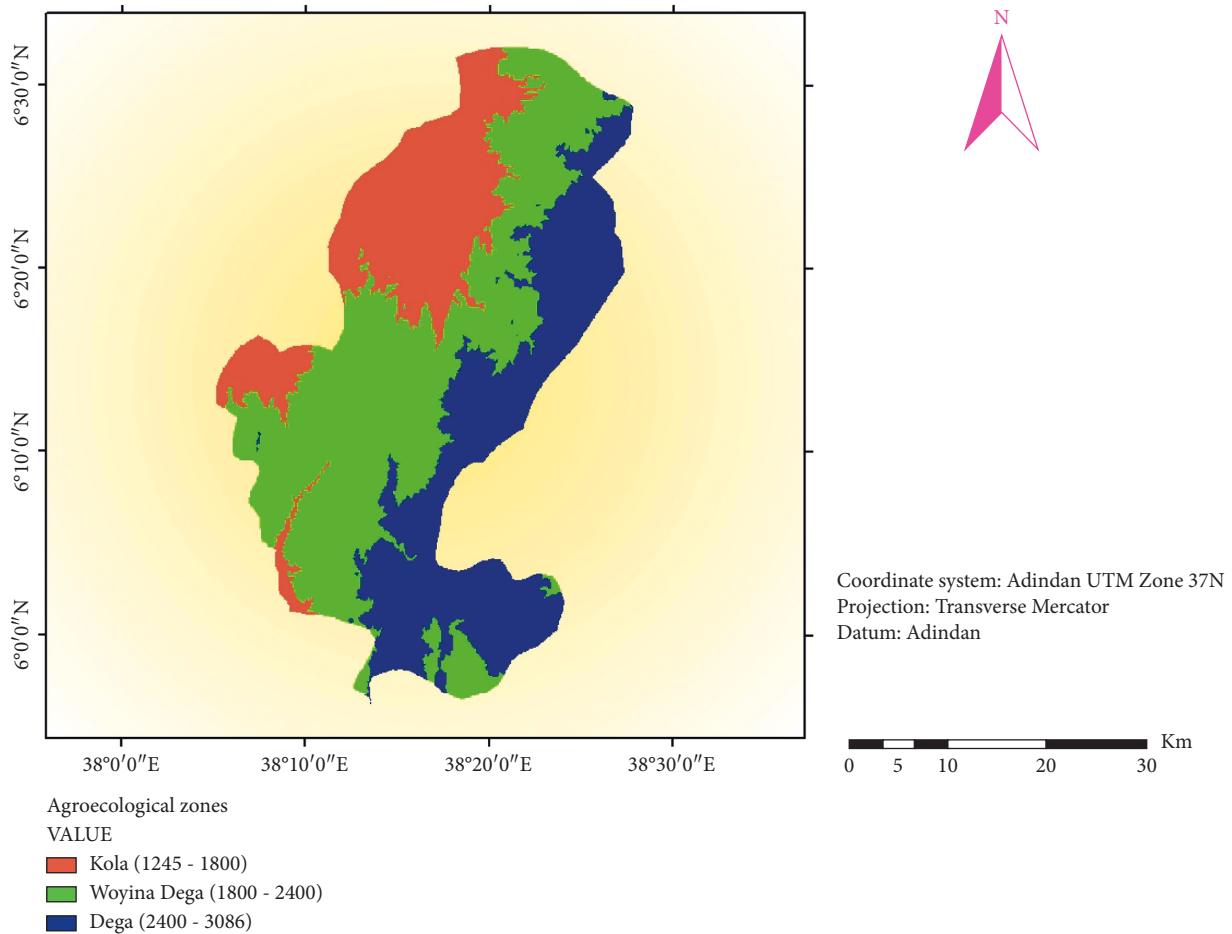
FIGURE 8: Agroecological zone of the study area.

TABLE 2: The description of the land use class in 2018.

No	LULC class	Description
1	Agroforestry	The complex land use pattern includes natural and plantation trees, including trees, ensets, coffee, and other fruits like avocados, bananas, and mango.
2	Grassland	The land is covered with grass, which is used for grazing purposes. In some parts, it is mixed with crops and vegetation.
3	Settlement	It is the area covered by a residential area, towns, institutions, infrastructures like roads.
4	Bare land	Nonvegetated area that included rock outcrops and empty area.
5	Annual crop	It refers to rain-fed crops such as maize, barley, wheat, beans, teff fields that were out of the agroforestry.

district; about 975.15, 6457.41 and 12501.27 hectares of the area, were covered by bare land, cropland, and grassland respectively. The remaining 20537.73 hectares (13.8%) of the district were covered with settlements that have an impact on climate change by removing the forest in the study area.

The above-classified map (Figure 10) of the study area indicates the significant reduction of agroforestry areas by 23.3% during 2002 compared to that of the 1988 LULC class, whereas the cropland, settlement, and grasslands increased by 11.4%, 9%, and 1.2%, respectively.

The above-classified map (Figure 11) of the study area also indicated the significant reduction of grassland agroforestry areas by 7% and 4.8% during 2018 compared to that of the 2002 LULC class, whereas the cropland, settlement, and bare land increased by 6.1%, 5.4%, and 0.3%, respectively.

The agroforestry land use classification of the Gedeo zone has a large area during 1988 compared to the other land use classes (Table 3). However, the agroforestry and grassland area decrease from time to time, whereas settlement, bare land, and cropland increase.

4. Discussion

4.1. Crop Diversity and Sustainability. In the present study, at all study sites, only cultivated crop plants are considered. Ornamentals, shade and windbreak trees, and weeds are not included. A total of 65 cultivated crops species and an average of 37 crop species per home garden, 23 at the adjacent field, and 5 at the crop field. However, only 75 plant species, including crops, were recorded. The Gedeo home garden is
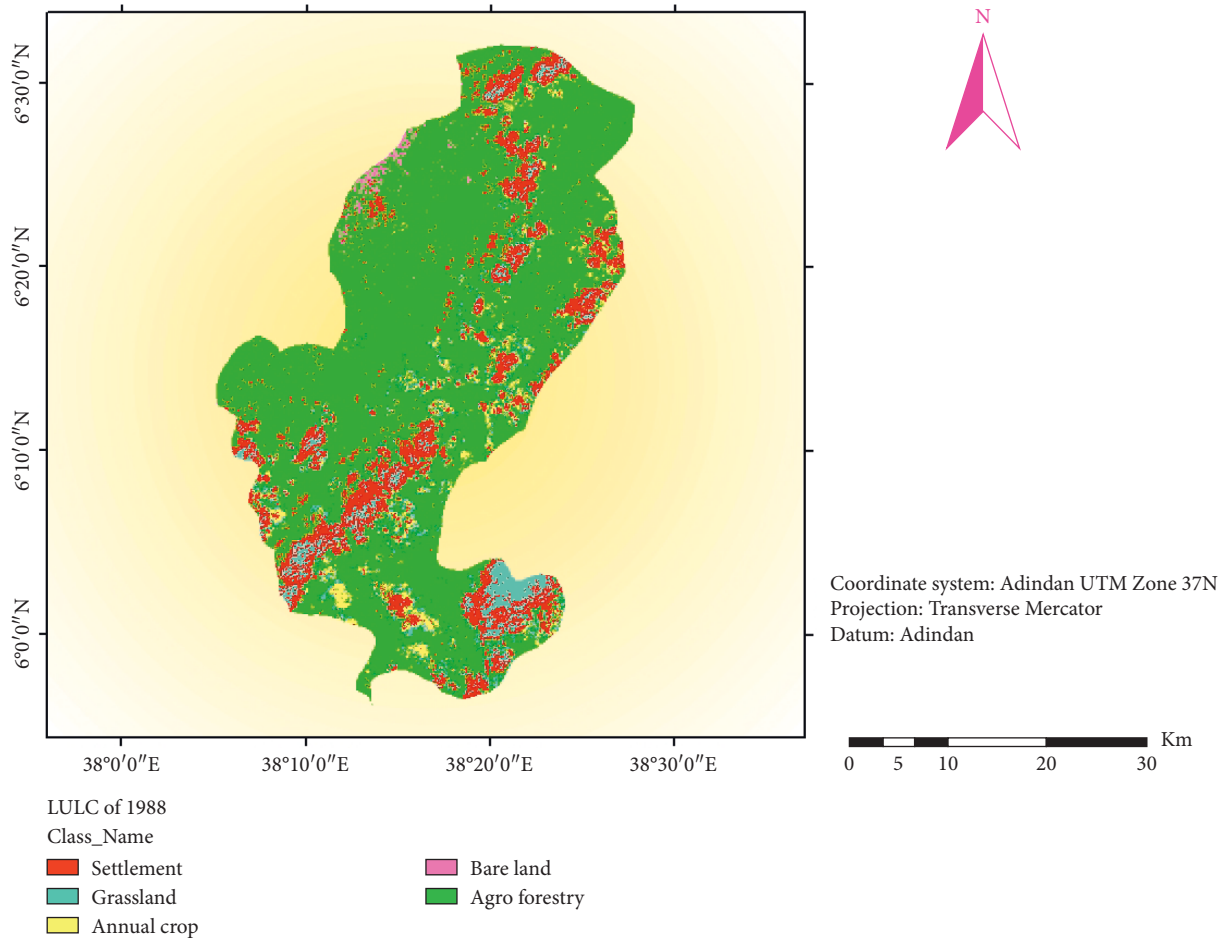
FIGURE 9: Land use land cover of map of 1988.

clearly diverse in holding many crop species. This result agreed with [20], which stated that Gedeo agroforestry practices have a rich potential for production and ecological services. The study indicates that the distinction between these functional groups is not absolute, but species may have a multifunctional role. According to [21], 26 landraces of enset (*Ensete ventricosum* W.) were recorded in the study home gardens, out of which an average of six was grown on each farm. Likewise, 26 cultivars of coffee (*Coffea arabica* L.) were identified, out of which 15 were local landraces and 11 were improved coffee berry disease-resistant varieties. An average of three coffee cultivars is grown on each farm. Nevertheless, even when considering crop species only, our analysis illustrates the importance of not just relating sustainability to species diversity but rather toward more specific features of species diversity. As discussed above, the functioning of the home gardens is highly related to the presence of the two species enset and coffee, which together account for 63% of the crop area. Enset forms major staple food for the households, while coffee is the major cash crop providing income for household expenditures.

4.2. Variation and Dynamics in Crop Diversity. The spatial variation is related to temporal variation in species diversity resulting from dynamics in crop composition. Two main processes of change in home garden composition were observed. On the one hand, there is a tendency toward increased incorporation of cash crops because of adaptation to the expansion of commercial networks offering options for income generation. The advance of cash cropping depends on both ecological factors such as crop suitability and socioeconomic factors such as access to markets. The results of this research revealed that community I is higher in crop species diversity; this is because Dilla and Kochore areas are very accessible to the market and the local people and have started to introduce different commercial important crops and vegetables. At the regional scale, important differences in these factors occur, and consequently, gradually, a geographic variation in home garden type develops. On the other hand, there is a tendency to grow the importance of maize and sweet potato as alternative staple food crops and replace coffee and enset with khat and sugarcane as alternative cash crops. The increased importance of these
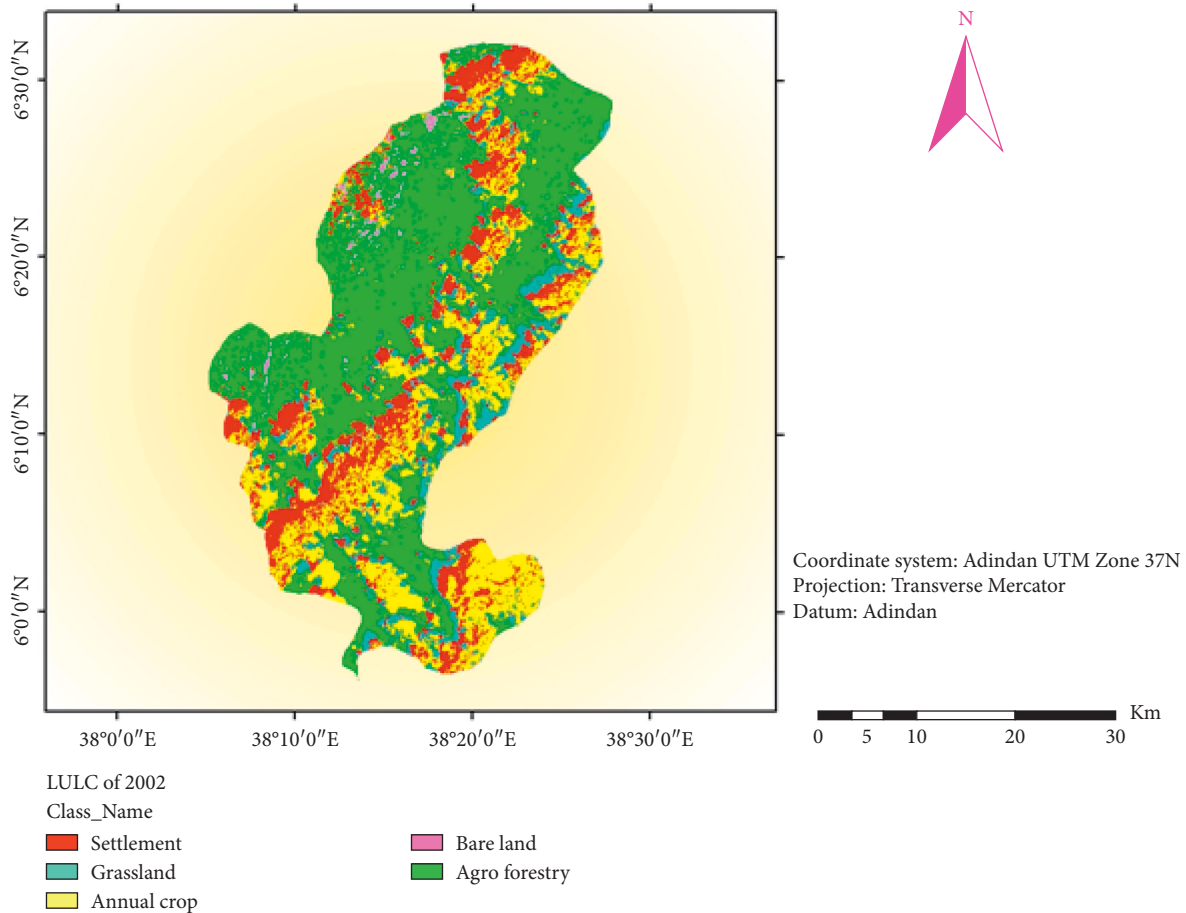
FIGURE 10: Land use land cover of map of 2002.

alternative crops is associated with a decline in the number of associated crops in these plots. This gradual development of monocropping plots within the integrated multistory systems involves a negative overall trend in terms of crop diversity [22, 23]. Small farmers are reducing coffee and enset farm to grow annual crops because they cannot wait for five to six years until enset reaches maturity. All these cases together with the erosion of indigenous knowledge and expansion of monocropping are highly challenging the sustainability of the agroforestry ecosystem [6]. Additionally, in the majority of the district, disease and pests frequently affected enset and coffee plantations. This could also lead farmers to lock another option for their families' food security.

4.3. Temperature and Rainfall Variability.

All the agricultural activities within the district were highly rainfall-dependent. Analysis of rainfall and temperature data for 30 years within the district revealed that there wwereas a reduction in rainfall and an increase in temperature. The result also agreed with that in [24], and the distribution of rainfall varies greatly across Ethiopia, according to season, altitude, and physical features of the landscape. The increase in humidity in the study area is mainly linked to rainfall and temperature. The temperature and rainfall variability within the district are associated with the conversion of indigenous trees, land cover change, and expansion of urbanization. The focus group discussion and key informant interview argued that the conversion of larger indigenous shade trees is responsible for the observed changes/variability in rainfall and temperature. Similarly, studies revealed a reduction of average annual rainfall by 15–20% across the zone especially between 2007 and 2018 [27] These local climatic changes have resulted in the deterioration of livelihood (prevalence of poverty) and further degradation of natural resources.

4.4. Land Use and Land Cover Change.

The proportion of land use and land cover change of agroforestry area account for 72.8% during 1988, which was reduced to 49.5% and 45.1% during 2002 and 2018, respectively. The grassland area accounted for 8.4% in 1988, which also increased to 9.6% in 2002 and rapidly decreased to 2.6% in 2018. This decline of the agroforestry and grassland area, especially in mid-highland and highland ecosystems, is common. These
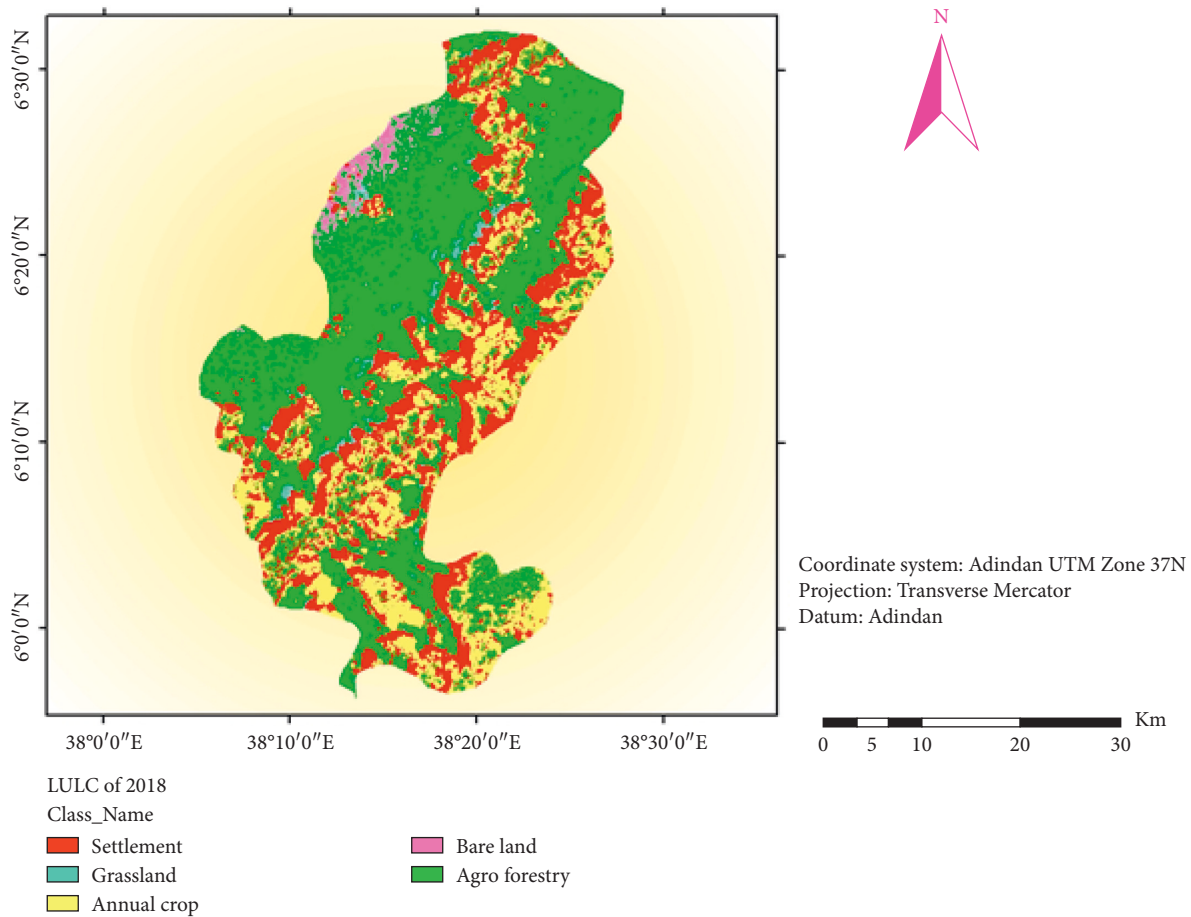
LULC of 2018

Class_Name

- 🟥 Settlement
- 🟦 Grassland
- 🟨 Annual crop
- 🟪 Bare land
- 🟩 Agro forestry

FIGURE 11: Land use land cover of map of 2018.

TABLE 3: Summary of LULC of Gedeo zone during 1988–2018 by 10 years interval.

No	LULC class type	Areas in (ha.)	% of area in 1988	% of area in 2002	% of area in 2018
1	Agroforestry	108548.01	72.8	49.5	44.7
2	Grassland	12501.27	8.4	9.6	2.6
3	Settlement	20537.73	13.8	22.8	28.2
4	Bare land	975.15	0.7	2.4	2.7
5	Crop land	6457.41	4.3	15.7	21.8
Total		**149019.6**	**100**	**100**	**100**

ecosystems were alleged to hold higher crop diversity than other ecosystems within the zone. However, this area reduction would challenge the biodiversity of the ecosystem. The decline of those core ecological components indicates ecological degradation [25, 26].

5. Conclusion and Recommendations

Crop species compositions were significantly variable among the study sites. This is very important for ecosystem stability since the study supposed that the greater the species diversity, the stronger the ecosystem. The fluctuation of rainfall and increase of temperature has adverse impacts on the livelihoods of society and the biophysical environment. Rainfall variability affects major rain-fed agriculture activities and makes particular crops vulnerable in the district.

Additionally, an increased temperature and humidity pattern with the variability of rainfall affect the socioecology of the area by causing resource degradation, food insecurity, and adverse effects on human, plant, and animal health due to the physiological constraints of each species. These observed effects of climate change are products of multiple factors and causes.

The land use land cover map of the study area indicates that the largest part of the study area (108548.01 ha) was covered by agroforestry, which served as the home for different biodiversity that can grab many animals and plant species, whereas the smallest portion of the district about 975.15, 6457.41, and 12501.27 hectares of the area were covered by bare land, cropland, and grassland, respectively. The remaining 20537.73 hectares (13.8%) of the district were covered with settlements.

However, the proportion of land use land cover of agroforestry class and grassland areas during 1988 was decreased in 2000 and 2018. Agroforestry was reduced by 23.3% from 1988 to 2000 and by 28.1% from 2000 to 2018, while settlements and cropland were increased by more than 10% in each time range. These changes have their own impact besides the climate change by removing the forest from the study area.

The presence of higher crop species composition and economically useful indigenous crop species indicates the potentiality for maintaining the agroecology of the Gedeo zone. Currently, it is experiencing a high rate of destruction because of the frequent population growth that results from the settlement increment, farmland expansions, and social and cultural uses of agroforest products besides the climate effects. This has resulted in the depletion of agroforestry, thus causing damage to both plant and animal diversity.

In general, the urbanization activities should be reduced by encouraging vertical urbanization rather than using the horizontal urbanization plan; the established field gene bank in all districts should be strengthened and mainly focus on maintaining all crop collections from the local areas. Finally, further studies on the ecosystem-wide resilience plans, protection of crop healthy, and inventory of pests and diseases are recommended options for sustainable management, restoration, and conservation of the Gedeo agroforestry practice.

Data Availability

All data relating to crop plants and climatic data used, generated, or analyzed during this study are included in this published article. The data that support the findings of this study are available from the author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

FE wrote the original draft, collected plant data, identified crop plants, and analyzed climatic data; AA conducted GIS and LULC data analysis; finally, both authors have read and approved the manuscript.

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References

[1] C. Perrings, L. Jackson, K. Bawa et al., "Biodiversity in agricultural landscapes: saving natural capital without losing interest," *Conservation Biology*, vol. 20, no. 2, pp. 263-264, 2006.

[2] L. Jackson, M. van Noordwijk, J. Bengtsson et al., "Biodiversity and agricultural sustainagility: from assessment to adaptive management," *Current Opinion in Environmental Sustainability*, vol. 2, no. 1-2, pp. 80–87, 2010.

[3] M. Smale and A. G. Drucker, A. InKontoleon, U. Pasual, and T. Swanson, Agricultural development and the diversityof crop and livestock genetic resources: a review of the economics literature," *Biodiversity Economics Principles, Methods and Applications*, pp. 623–648, Cambridge University Press, Cambridge, UK, 2008.

[4] I. Scoones, "Sustainable rural livelihoods: a framework for analysis'," *IDSWorking Paper 72*, Institute for Development Studies, Brighton, UK, 1998.

[5] M. Negash, "Tree management and livelihoods in Gedeo'-sagroforests, Ethiopia'," *Forests, Trees and Livelihoods*, vol. 17, no. 2, pp. 157–168, 2007.

[6] S. Degefa, *Socio-ecological Production Landscapes and Seascapes (SEPLS) in Africa*, United Nations University Institute for the Advanced Study of Sustainability, Tokyo, Japan, 2016pp. 28–36, Home garden agroforestry practices in the Gedeo zone, Ethiopia: a sustainable land management system for socio-ecological benefits.

[7] B. Bishaw, N. Henry, A. Abdu et al., *Farmers' Strategies for Adapting to and Mitigating Climate Variability and Change through Agroforestry in Ethiopia and Kenya*, C. M. Davis, B. Bernart, A. Dmitriev, and Forestry Communications Group, Eds., Oregon State University, Corvallis, Oregon, 2013.

[8] K. Tadesse, *A Case Study OnGedeo Land-Use (Southern Ethiopia)*, Five Thousand Years Of Sustainability?, p. 295, Wageningen Agricultural University, Wageningen, Netherlands, Wageningen Agricultural University, 2002.

[9] S. Talemos and D. Sebsebe, "Diversity and standing carbon stocks of Agroforestry trees in Wenago District, Ethiopia," *International Journal of Agroforestry and Silviculture*, vol. 4, no. 1, pp. 246–256, 2017.

[10] M. Alemayehu, "Assessment of the prevalence of premarital sex and unprotected sexual practice among Gedeo zone high school students, SNNPR, Ethiopia," *A Research Thesis Submitted to the Department of Community Health, Medical Faculty, in Partial Fulfillment of the Requirements for the Degree of Masters in Public Health*, p. 64, Addis Ababa University, Addis Ababa, Ethiopia, 2006.

[11] A. Regassa Debelo, A. Legesse, T. Milstein, and O. O. Orkaydo, "Tree is life": the rising of dualism and the declining of mutualism among the Gedeo of southern Ethiopia," *Frontiers in Communication*, vol. 2, p. 7, 2017.

[12] CSA, *The 2007 Population and Housing Census of Ethiopia: Statistical Report for Southern Nations, Nationalities and Peoples' Region*, p. 1202, CSA, Addis Ababa, Ethiopia, 2007.

[13] A. Tesfaye, F. J. Sterck, K. F. Wiersum, and F. Bongers, "Diversity, composition and density of trees and shrubs in Agroforestry home garden in Southern Ethiopia," *Agroforestry Systems*, vol. 87, pp. 1283–1293, 2013.

[14] A. Tesfaye, *Diversity in Homegarden Agroforestry Systems of Southern Ethiopia*, Wageningen University, Wageningen, Netherlands, 2005.

[15] A. Tesfaye, "Determinants of crop diversity and composition in Enset-coffee Agroforestry home garden of Southern Ethiopia," *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, vol. 114, no. 1, pp. 29–38, 2013.

[16] C. E. Shannon and W. Wiener, *The Mathematical Theory of Communication*, University of Illinois, Chicago, USA, 1949.

[17] E. C. Pielou, *An Introduction to Mathematical Ecology*, Wiley, New York, NY, USA, 1969.

[18] A. E. Magurran, *Measuring Biological Diversity*, BlackWell, Oxford, UK, 2004.

[19] H. Sharifi and Z. Zhang, "Agile manufacturing in practice-Application of a methodology," *International Journal of Operations & Production Management*, vol. 21, no. 5/6, pp. 772–794, 2001.

[20] M. Getachew and A. Mabrate, "Production and ecological potentials of gedeo's indigenous agroforestry practices in southern Ethiopia," *Journal of Resources Development and Management*, vol. 30, 2017.

[21] Z. Yemataw, K. Tesfaye, A. Zeberga, and G. Blomme, "Exploiting indigenous knowledge of subsistence farmers' for the management and conservation of Enset (*Ensete-ventricosum* (Welw.) Cheesman) (Musaceae family) diversity on-farm," *Journal of Ethnobiology and Ethnomedicine*, vol. 12, no. 1, p. 34, 2016.

[22] A. Challinor, T. Wheeler, C. Garforth, P. Craufurd, and A. Kassam, "Assessing the vulnerability of food crop systems in africa to climate change," *Climatic Change*, vol. 83, no. 3, pp. 381–399, 2007.

[23] E. Linger, "Agro-ecosystem and socio-economic role of homegarden agroforestry in Jabithenan District, North-Western Ethiopia: implication for climate change adaptation," *SpringerPlus*, vol. 3, no. 1, p. 154, 2014.

[24] M. R. Jury and C. Funk, "Climatic trends over Ethiopia: regional signals and drivers," *International Journal of Climatology*, vol. 33, no. 8, pp. 1924–1935, 2013.

[25] M. G. Markos, D. U. Mihret, E. J. Getachew, and G. M. Geleto, "Influence of land use and land cover changes on ecosystem services in the Bilate Alaba Sub-watershed, Southern Ethiopia," *Journal of Ecology and The Natural Environment*, vol. 10, no. 9, pp. 228–238, 2018.

[26] L. E. Jackson, U. Pascual, and T. Hodgkin, "Utilizing and conserving agrobiodiversity in agricultural landscapes," *Agriculture, Ecosystems & Environment*, vol. 121, no. 3, pp. 196–210, 2007.