Addis Ababa University
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The influence of land use dynamics and climate change on woody species and underutilized wild edible plants conservation in agroforestry and adjacent landscapes of Midakegn District, West Shewa, Ethiopia

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GRADUATE PROGRAMMES

DECLARATION

This is to certify a thesis organized by Sheleme Guzo Diro, entitled: **The influence of land use dynamics and climate change on woody and underutilized wild edible plants conservation in agroforestry and adjacent landscapes of Midakegn District, West Shewa, Centeral Ethiopia** and submitted for the partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Plant Biology and Biodiversity Management (PhD) that complies with the regulations of the university and meets the accepted standard with respect to originality and quality.

Signed by the Examining Board:

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Chair of the Department or Graduate Program Coordinator

DEDICATION

This thesis is dedicated to Mrs. Lelise Dirirsa (my mother), Mrs. Dame Lechisa (my wife), and Mr. Belay Guzo (my brother), who shared their endless love, support, and encouragement throughout every circumstance for my pursuit of this research.

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ACRONYMS

AAU	Addis Ababa University
ACW	Acacia-Commiphora Woodland and Wooded Grassland
ANOVA	Analysis of Variance
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
AUC	Area under Curve
BA	Basal area
CMIP 5	Coupled Model Inter-comparison Project Phase 5
CTW	Combretum-Terminalia Woodland and Wooded Grassland
DAF	Dry Afromontane Forest
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
ETH	National Herbarium
ETM	Enhanced Thematic Mapper
FGD	Focus Group Discussion
GBIF	Global Biodiversity Information Facility
GCM	General Circulation Model
GCP	Ground Control Points
GHG	Greenhouse Gases
GI	General Informants
GPS	Global Positioning System
IPCC	Inter-governmental panel on climate change
IVI	Important Value Index
KI	Key Informants
KII	Key Informant Interviews
LU	Land Use
LULCC	Land use land covers change
MAF	Moist Afromontane Forest
MARDO	Midakegn District Agricultural and Rural Development Office
OLI-TIR	Operational Land Imager and Thermal Infrared Sensor

RCP	Representative Concentration Pathway
ROC	Receiver Operator Characteristic
SPSS	Statistical Package for the Social Science
TM	Thematic Mapper
USGS	United States Geological Survey
UWEP	Underutilized Wild Edible Plant

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SUMMARY

*Pressures from nature and anthropogenic activities are affecting biodiversity conservation, and thus, understanding the impacts of these pressures is very important with regard to ensuring the long-term persistence of biodiversity at local and global levels. The main goal of this study was to examine the effect of climate change on the distribution range of selected species and land use dynamics on the diversity of woody species and the wild edible plants in West Shewa, central Ethiopia through (1) analyzing and quantifying the spatiotemporal land use dynamics along with identifying the major driving pressures (***Paper I***); 2) assessing the influence of altitudinal variation, land use types, and wealth class on the woody species diversity potential in terms of species richness, diversity, and structural composition in the agroforestry systems of the study area (***Paper II***); 3) identifying and documenting underutilized wild edible plants used by the local people of Midakegn (***Paper III***); and 4) predicting the distribution of suitable habitats of S. afromontanum under climate change (***Paper IV***). In Paper I, a study on land use change covering 34 years, i.e., from 1986 to 2020 was conducted. Landsat images of 1986, 2003 and 2020 were acquired from Earth Explorer to quantify land use changes in ArcGIS 10.7. Field observations, interviews, and group discussions were held to identify the drivers of these changes. The change detection was done by post-classification comparisons of land cover statistics for each remote sensing dataset and with respect to the complexity of gradients. For assessment of woody species status, a simple random sampling and a systematic random sampling technique for representative village selection and data collection from 114 land plots in different agroforestry were employed following transect lines, respectively. DBH $\geq$ 2.5 cm and height $\geq$ 1.5 m were measured and recorded. Pairwise mean comparisons of species diversity and structural composition were computed per study sites, land use types, and economic status of households by employing one-way ANOVA, and vegetation structure bar charts in different distribution classes were drawn using R statistical package version 6.3.1. In paper III, key and general informants were selected by snowball and stratified random sampling methods respectively to collect underutilized wild edible species data. A one-way ANOVA was used for the comparison of ethnobotanical knowledge distribution* *between different informant classes. Different ranking exercises were used to measure popularity, multiple functionalities, and threats to those plants in the study district. In Paper IV, potential distribution of S. afromontanum was modeled using the MaxEnt software. For future prediction, RCP 4.5 and RCP 8.5 emission scenarios for 2050 and 2070 years were used. A total of 47 occurrences and 22 environmental variables were considered in the modeling process. The outcome indicated six land use classes, with a substantial decrease in grazing, shrub, and forest lands, while farmland and built-up area indicated intensive increases. The findings also identified both ultimate and indirect causes of land use change in the study district. The expansion of the land use category, mainly farmland, was found to be due to the loss of shrubland, grazing land, and forest-covered areas to afford the ever-increasing population in the study area. A total of 77 woody plant species belonging to 68 genera and 45 families were recorded. Woody species diversity and vegetation structural composition were dissimilar among land use types ($P < 0.05$). The highest mean species richness and diversity per land plot was computed in homegarden and grazing land, while the lowest species richness and diversity were recorded in cropland woodlots, respectively. A total of 50 UWEPs belonging to 39 genera and 30 families were recorded. The highest numbers of these plants were shrubs and followed by trees. Though there were many reservoir areas, the majority were recorded in highly disturbed natural forests. When viewed in terms of the agro-ecology, the highest number of UWEPs were recorded for midland and followed by lowland. This caused heterogeneity in indigenous knowledge between the local communities. Noteworthy is that edible fruits were the dominant and consumed raw outdoors without further processing. Fresh or dried raw mode of consumption accounted for the majority of consumption, while cooking, fermentation, backing, and boiling are also recorded in the study areas. The computed ranking exercise for factors threatening the long-term persistence of UWEPs revealed that human-induced factors, particularly, habitat destruction at the expense of farm land expansion, overgrazing, fuel wood harvesting, and selective logging for different purposes, were identified as principal factors that caused destructive effects on plant resources. The modeling result indicates that solar radiation, followed by precipitation in the driest quarter, significantly* *influences the future potential habitats of the species. The model predicts range reduction trends under both future scenarios. Overall, for sustainable use and conservation of plant* biodiversity *in various landscapes, integrated investigations from different aspects should be considered to alleviate impacts caused by uncontrolled land use, land conversion, and climate change, which definitely impose negative impacts on woody species and wild edible plants and in turn affect the livelihood of people, particularly farmers.*

Keywords/phrases: *Agroforestery, Climate Change, Diversity, Land use dynamics, Wild edible plants, Woody species*

CHAPTER ONE

1. GENERAL INTRODUCTION

1.1. Bacground of the Study

1.1.1. Land use dynamics

Since the industrialization period, global environmental problems have become increasingly prominent due to different human activities, mainly fossil fuel combustion and land surface modifications (Gitay *et al*., 2002). Human intervention in agriculture, settlement, transportation, infrastructure and manufacturing, park recreation uses, mining, and fisheries has caused land cover change (Oumer, 2009; Gashaw *et al*., 2014). For instance, in the last 5 decades, around 83% of the terrestrial ecosystem change has been linked to human footprints (Nkonya *et al*., 2012) and therefore the spatio-temporal modification of the terrestrial land surface as a result of human activities is commonly caused by land use cover changes (Hassan *et al*., 2016), and this causes a quantitative change in the extent (increase or decrease) of land use types (Roy and Roy, 2010). To understand its implications, at the beginning, scientists have focused on the physical aspect of the land changes, but later on, they expanded their investigation into global environmental change and realized that land surface processes influence climate change because of land surface modification (Parveen *et al*., 2018) and hence study on, the land use land cover dynamics is very important for understanding a wide variety of global change phenomena (Rajan and Shibasaki, 2000). On the other hand, modeling spatio-temporal patterns of land surface conversion is an important way of understanding the causes, impacts, and consequences of the land surface process (Verburg *et al*., 1999).

The force of the drivers as well as the changes in driver composition led to changes in the prevalent land use dynamics of a region (Roy and Roy, 2010). The most important factors influencing land cover change around the globe today, e.g., include the fast development and expansion of urban centers, the increased population demography, the scarcity of land, the need to produce more yield, and evolving technologies (Reid *et al*., 2000). This is directly linked with the demands of an ever-growing population to adapt to changing socioeconomic and technological conditions (Reid *et al*., 2000), human interactions with the environment (Lambin *et al*., 2003; Shiferaw and Singh, 2011), and institutional interactions with individual decision makers for political, economic, traditional, and cultural values (Gudesho and Woldu, 2021). The modification of land surface that is caused by the drivers is measured by change evaluation in the land cover category, as is the case in farmland expansion, deforestation, heavy livestock grazing, and changes in urban extent (Lambin *et al.*, 2003).

The consequence of land use dynamics is unprecedented landscape modifications that pose grave danger to terrestrial ecosystems and environmental processes (FAO, 2016; Parveen *et al*., 2018). For instance, changes in land surface temperature are related to many factors, including changes in land use and land surface parameters, seasonal variation, climatic conditions, and economic development (Jiang and Tian, 2010). The land surface temperature change in turn causes an unstable surface energy budget, which affects the comfort of many lives (Imran *et al*., 2021). Fragmentation of ecosystems, disruption of their services, increasing pressure on biodiversity, disruption of socio-cultural practices, soil erosion, soil, water, and air pollution, and increased natural disasters, such as flooding, landslides, and storming, are also the impacts due to LULC change (IPCC, 2000; Gitay *et al*., 2002). These changes lead to biodiversity loss, air and water pollution, and climate change (Jiang and Tian, 2010; Parveen *et al*., 2018) and cause land degradation, degraded ecosystem services, declined water resources, extended aridity, and drought (Maitima *et al*., 2009; Takala *et al*., 2020), which are the top global environmental problems today (Haile *et al*., 2017).

For a series of years in Ethiopia, the main drivers of LULC change have been associated with forest area conversion to cultivated land due to massive deforestation (Dinka and Chaka, 2019) and land degradation due to overgrazing (Lemenih and Teketay, 2004). Godebo *et al.* (2018) related the seriousness of the changes to the intensively increasing farmland expansion and settlements in the country, which are affecting ecosystem functioning and services. For many years, people have been changing the land cover, especially in rural areas of the country where most people either directly or indirectly rely on the land to support their lives and acquire necessities (Bishaw, 2001; Hassan *et al*., 2016). But the extent, intensity, and rate of the change are significantly higher today than ever in the past (Hassan *et al*., 2016). Mainly, forests and woodlands converted to other land forms significantly contributed to habitat loss and natural resource depletion (Lemenih and Teketay, 2004). In some areas exposed to severe changes, there would be the loss of nearly all species and increased fragmentation of the remaining ecosystems (EBI, 2015).

LULC change synergetic effects evaluation has been most commonly focused on the northern highlands of Ethiopia, where they are comparatively exposed to high levels of disruption, mainly from human-induced pressure. Contrastingly, a few studies were conducted in other parts of the country, even in areas that are similarly exposed to high human-induced pressure (e.g., the central part of Ethiopia). The present study is conducted in Midakegn District of West Shewa, central plateau of the country, which is clearly characterized by different ecosystems with different gradients such as grasslands, shrublands, and forests (Woldu and Ingvar 1991). The area has been known for its very ancient sustenance farming system and has a long history of large human settlements. It is highly exposed to land cover modification, mainly due to intensive agricultural land expansion and animal husbandry for years (EBI, 2015; Woldu and Ingvar, 1991). Continued and intensified utilization of natural resources for different purposes causes various fragmented agroforestry systems that are used for different agricultural activities to increase yield production, which could balance the need for increasing population growth. Due to this, some land features are over-modified and are left with no vegetation cover in areas with few vegetation covers, such as small and patchy remnants. However, there are land portions exposed to less intensive utilization and relatively more complex remnants of vegetation cover.

In this circumstance, driver-influenced continuous landscape modification is definitely going to have serious impacts on the study area in the long run. Inappropriate and intensive resources utilization might lead to severe land surface changes that might result in increased biodiversity disturbance and have more negative consequence on livelihood of the local people. Therefore, a systematic examination of LULC change is essential in the study area where no prior research of this kind (**Paper I**) has been done and to precisely understanding the amount of the land cover conversion that may give insight for land managers and policy makers to develop better management and conservation strategies for the natural resources.

Hence, based on temporal land cover data obtained from Landsat images at a seventeen-year interval, the spatio-temporal patterns of LULC change for more than thirteen years (34 years) were evaluated. This included three-year points back (1986, 2003, and 2020) to investigate the changing patterns of past land uses in relation to the contemporary rates of LULC conversions as a result of different drivers. Time-based land modification status was examined from a classified satellite image for each respective year point, and these land complexity conditions were justified by relating to major drivers of the study district.

1.1.2. The consequence of land use intensification on biodiversity

The expansion of agricultural land uses on natural vegetation from time to time has been worsening biodiversity at all levels in ecosystems. Particularly, challenges due to rapid population growth, such as habitat degradation and loss, fragmentation, unification, overexploitation and overreliance on natural resources, pollution, and the introduction of invasive species, are among the primary and most significant pressures that cause climate change, which in turn affect both the structural and functional integrity of biodiversity in ecosystems (Adhikari *et al*., 2012; Gitay *et al*., 2002). The consequence eventually causes natural resource depletion and environmental degradation, including soil erosion, biodiversity loss, and ecosystem impoverishment, which have been accelerated by these pressures (McMichael *et al*., 2003; Berhan and Bekele, 2006; Wakjira, 2006). However, the degree of the influence depends on the system's original characteristics and complexity, its geographical location, and the existence of variables that could control the modifications made (Chapungu and Nhamo 2016). In Ethiopia, for instance, mainly agricultural land expansion and other anthropogenic activities approximately has caused the reduction of 40% forest cover at the beginning of the 20th century, by 24% at the mid-century (1950s), and by 37% at the end of the century (EFAP, 1994; Bishaw, 2001; Lemenih and Teketay, 2004). The biodiversity loss associated with such vegetation clearing leads to a long-term transition to land use types relatively characterized with less density of species and lower carbon contents (Gitay *et al*., 2002). Because of several state-led pledges and initiatives measures for forest landscape reforestation and restoration taken in Ethiopia, recently the coverage has estimated at 11.4–15.5% (FAO, 2015; MEFCC, 2017). But certainly, the modification of forest lands, grazing lands, woodlands, and wetlands into farmlands, settlements, and other agroforestry land uses are some of the threats to biodiversity in the country (EBI, 2015). The factors associated with the continued forest conversion are the high deforestation rate related to a fast-growing population, overgrazing, movement for political centers, and overdependence on forests for construction and energy sources, which has resulted in a loss of biodiversity (Senbeta and Denich, 2006). As a consequence, indigenous people have attained a variety of agroforestry systems by utilizing and modifying natural forests (Wiersum, 2004).

1.1.3. Agroforestry system and its biodiversity importance

Agroforestry is a sustainable land use and management system used by farmers on the same pieces of agricultural landscapes for intensification of land product, which includes the production of a variety of perennial and annual crops, forest plants, and animals at the same time or sequentially (Bene *et al*., 1977; King and Chandler, 1978). Woody species are purposely used in the system for different functions along with crops and/or livestock (FAO, 2013; Dobo *et al*., 2016). While scattered trees are promoted and integrated into the agricultural landscape, people are provided with a number of economic and ecological services (FAO, 2013). Such practices in a traditional agroforestry system by subsistence farmers are almost everywhere in the world (Zomer *et al*., 2014).

Biodiversity in agricultural landscape contributes to a variety of socioeconomic and cultural aspects (Hainzelin, 2013) and offers a mutually beneficial opportunity for farmers in Sub-Saharan Africa (Henry *et al*., 2009). For instance, planting, conserving, managing, and promoting plant growth and development in different agroforestry systems contributes a lot of paybacks, such as medicines, foods, fodder, materials for construction and energy supply, equipment for households and farms, and materials for income generation gained in the agroforestry practice (Altieri, 2014; EBI, 2015; Molla, 2019). Beyond these, it provides essential environmental regulatory services, including microclimate regulation, nutrient recycling, hydrological processes, harmful chemical detoxification, and undesirable organism suppression (Alkemade, 2009; Altieri, 1999). Minimizing risk through pest and disease control, providing long-term resilience to environmental changes and disturbances (Hooper, 2005), providing important ecological services and functions in agricultural production at genetic, species, and ecosystem levels (Thrupp, 2000), and creating habitats for disturbance-tolerant species in the agroforestry system (Udawatta *et al*., 2019) are other contributions of agricultural lands to biodiversity. The majority of plant species retained and managed in different agroforestry systems benefit the rehabilitation of degraded lands (Giday *et al*., 2019). Household income, regulation of soil conservation, watershed protection, sinks for carbon, and mitigation of global climate change are some of the values of plant species in the agroforestry system (FAO, 2013; Giday *et al*., 2019; Molla, 2019). In some areas where subsistence agriculture activities predominate, an intensification of integrated agroforestry systems may create an unconventional approach to increasing biodiversity (Henry *et al*., 2008).

Particularly in Ethiopia, traditional agroforestry practice commonly includes a variety of systems, including tree plantation and growth in and around homesteads, tree retention in croplands, tree management and conservation in grazing land, in woodlots and tree plantation on farmland boundary, and coffee and coffee shade tree plantation, retention, and management (Abebe, 2005). Alley cropping, fodder tree plantations, trees as life fences, roadside tree plantations, trees on gully, and contour bunds plantations are some of the other agroforestry practices that existed in various parts of the country (Agemas, 2019), and they have been playing an important role in the conservation of a large diversity of plant species and minimizing the damage that the local community imposes on the natural forest (Mengistu and Asfaw, 2016). Multiple woody plants are intentionally grown and managed in close association with a variety of crops and/or livestock in an agroforestry land use system created through land use dynamics (Dobo *et al.*, 2016).

Global population increase, industrialization, eating habits, agricultural intensification, and climate change are the main factors contributing to the exponential decline in biodiversity and ecological services (Udawatta *et al.*, 2019). The increased deforestation rate, overgrazing, and overexploitation of forest products for building materials and fuel wood, have put Ethiopia's forest biodiversity gravely at risk (Senbeta and Denich, 2006). On the other hand, intensification brought about by the use of pesticides, artificial fertilizers, and improved seeds, the country's agro-ecosystems along with its biodiversity have also been similarly subjected to significant human pressure (Haile et al., 2017). Using different chemicals such as pesticides, herbicides, and fertilizers for pest and weed control and for yield improvement strongly affects biodiversity in the agroforestry system (Kleijn *et al*., 2008).

To support forest-based ecosystem services and environmental incentive programs that minimize deforestation and forest degradation, agricultural biodiversity protection must always rank among Ethiopia's top conservation priorities (Tadesse *et al*., 2014). This is due to the creative role of the local people in contributing to the conservation of forests through the diversification of agroforestry practices in the agricultural landscape (Wiersum, 2004). The system, along with its biodiversity, provides the three main services, which include ecological, conservational, and livelihood functional groups (Huang *et al*., 2002). Many plants and animal species harbored in the remnant forests and tree covers of different agroforestry land units provides connectivity by creating corridors between fragmented habitat remnants (Udawatta *et al*., 2019) and therefor, have a potential role in biodiversity conservation (Harvey and Haber, 1998; Udawatta *et al*., 2019), act as stepping stones for normal gene flow among fragmented habitats (Crane *et al*., 2014), increase forest regeneration and restoration possibilities (Harvey *et al*., 2008) and helps to reduce the rates of natural habitat conversion by providing a more productive and sustainable alternative to traditional agroforestry systems that may involve natural habitat clearing (Udawatta *et al*., 2019). However, compared to natural forest ecosystems, the biodiversity conservation role of agro-ecosystems receives little scientific attention (Boffa *et al.*, 2008). Hence, increased attention to agroforestry practices for conservation should extend beyond protected areas to maintain biodiversity, ecological processes, and more production of goods and services (Boffa *et al.*, 2008). This is used to fully comprehend the function of agroforestry systems in the maintenance of woody plant diversity and the factors that influence it; more research is required in a variety of ecological and socioeconomic contexts (Haile *et al*., 2017).

To this end, **Paper II** was conducted in Midakegn district, West Shewa Zone, Ethiopia, in the area where an intensive small-scale agroforestry practice that highly caused fragmented and degraded agricultural landscapes due to high human pressure in the modification process. Therefore, woody species diversity's in the different land use systems managed by different wealth class farmers was assessed. This would make it possible to identify how indigenous people manage, conserve, and intensify woody species within the complex agroforestry systems of smallholder farmers and show how land use for different purposes, altitudinal variation, and the economic status of the farmers may impact species diversity in the study area.

1.1.4. Wild edible plants importance and its harvesting status

Plant biodiversity in natural forests and other different land use types are an essential source of edible resources. They provide social security goods such as vegetables, medications, fruits, firewood, wood and timber, and materials for handicrafts and clothes at wider ranges (Cunningham, 2001; Aryal *et al.*, 2009). The world community acknowledges the value of these wild edible plants and other agro-biodiversity in risk management, resilience building, and sustainable food systems (Boedecker, 2014). Similarly, in western Himalaya, people supplement with food and other multiple products from these edible plants under different circumstances, most commonly during food shortages (Aryal *et al*., 2018). Particularly for these people who are vulnerable to malnutrition, the consumption of wild edibles contributes essential nutrients such as fats, proteins, vitamins, and minerals they need (Bell *et al*., 1995). Guaranteeing food security is not only important but also provides materials for medicinal, construction, fuel wood, foraging, income generation, honey production, and detergent values (Tebkew *et al*., 2014). Beyond the production of goods and services, wild edible plants also possess and preserve biological information, cultural heritages, and indigenous knowledge associated with the plants (Balemie and Kebebew, 2006). Rural people have non-similar but deep indigenous knowledge about their multiple functions, which are an integral part of various cultures and are different from place to place throughout the country (Guinand and Lemessa, 2000). However, many of these plants are underutilized among indigenous farming communities for specific socioeconomic reasons and certain environmental conditions (Ajayi and Mafongoya, 2017).

Globally, the term underutilized stands for plant species that are traditionally used for different purposes but still have undeveloped use potentials (Arora, 2014), and yet their use potential is not fully realized (Padulosi *et al*., 2002). Underutlized wild edible plants (UWEPs) are less preserved in *ex-situ* germplasm gatherings (IPGRI, 2002), are currently conserved in their natural homelands (Ajayi and Mafongoya, 2017), and are not often cultivated in the official farming system (Debela *et al*., 2011). Programs related to agriculture and the environments have also neglected the potential importance of these plants for the local population's nutrition and food security (Gari, 2002; Ogle *et al*., 2003). However, people still occasionally use the resources for the improvement of their nutrition, health, and livelihoods, as well as for different socio-cultural preferences and the ecological sustainability of the environment (Arora, 2014; Jaenicke Höschle-Zeledon, 2006). As Ajayi and Mafongoya (2017) and El-Solh (2016) mentioned, when the globe faced serious difficulties related to climate change, UWEPs would be used as another alternative food that balances food insecurity and human nutrition and replaces the food shortages that arise from the insufficient availability of main crops. In the near future, they could serve as risky reduction crops and have greater potential to cope with the shocks induced by global climate change than conventional crops (Mayes *et al.*, 2012; Ajayi and Mafongoya, 2017). Particularly in developing countries, their genetic resources might have more potential for ensuring food security, and they may evolve into significant crops (Ajayi and Mafongoya, 2017; Baldermann *et al*., 2016) and become more attractive (Ajayi and Mafongoya, 2017) under future climatic changes. However, the less management intervention taken for such plants may reduce their adaptive capacity to the adverse effects caused by changing climatic conditions (Muluneh, 2021). Hence, there is an urgent need to broaden these species effectively and sustainably to protect and enhance the use of such regionally significant species that are also more globally applicable in agriculture and environmental management.

In Ethiopia, different ecosystems have faced common challenges, mainly due to climate change and land use intensification (MoARD, 2007; Sabates-Wheeler, 2012). Such challenges are more prevalent in densely populated areas such as the northern highlands and central parts of the country. Under such circumstances, UWEPs and the associated indigenous knowledge might face a risk of loss due to natural and human-induced pressure. Neglecting them could cause the gene pools that are available in their diverse and cultivated areas to erode. Consequently, focusing on UWEP species is a good approach to maintaining healthy diets, and integrating them into food systems may aid in the fight against malnutrition, which is especially risky for social groups who are more vulnerable and live in rural areas with low incomes (Baldermann *et al*., 2016). Therefore, ethnobotanical research on these plants at the local and national levels in Ethiopia could provide information for more production in the future and promote the broad use of the resources, thereby improving socioeconomic and nutritional security locally, regionally, and worldwide. Concerning this, only two related works were reported in the northern part of Ethiopia by Tebkew *et al*. (2014) and Aregay *et al*. (2017) when compared to the ecological and cultural diversity that exists in the country. In the study area (Midakegn District), there hasn't been any prior research conducted on UWEPs or the related indigenous knowledge. Thus, **Paper III** emphasized on gathering and documenting the UWEPs along with the associated ethnobotanical information and exploring threat factors to these natural resources. Such types of investigations definitely help in the promotion of ethnobotanical knowledge, the potential utilization of plants, and their contribution to future socio-economic importance under changing climate conditions. This is because giving focus to such species is an effective way to maintain a diverse and healthy diet and combat malnutrition, the so-called ‘hidden hunger’ (IPGRI, 2002).

1.1.5. Climate change impacts on species persistence and distribution

Climate change and various other stresses linked to intensified land use pose serious dangers to ecological systems. Climate change is not as such a new phenomonnen, i.e., it has occurred over the past periods in Earth’s history (e.g., Raup and Sepkoski, 1982). For example, the recent Pleistocene period has been marked with cylces of cold and warm cycles leading to expansion and contraction of species ranges (e.g., Pacifici *et al*., 2020; Manda *et al*., 2022). The mass extinctions of species were also driven by natural forcing climate change (Raup and Sepkoski, 1982; Crowley and North, 1988; McElwain *et al*., 1999). Therefore, the interfaces of climate change and biodiversity had manifested itself at different times across the geological time scale of the Earth. Among the multitude of factors affecting biodiversity, climate change has been viewed as a near future threat (Pörtner *et al*., 2021). There are now mounting evidences showing the redistribution of species at a global scale (e.g., Parmesan, 2006; Chen *et al*., 2011). As the climate shifts, so are the species towards their suitable habitats, a phenomenon often called climate tracking (Urban, 2015; Chaudhary *et al*., 2021; Manes *et al*., 2021). But the current climate change is mainly driven by the activities of humans that led to industrialization (e.g., Abram *et al*., 2016; Ahmed *et al*., 2022). Reported species responses to the current climate change entailed range shifts in altitude (e.g., Chala *et al*., 2016; Enkossa *et al*., 2022; Daba *et al*., 2023; Tadesse *et al*., 2023) and latitude (Chen *et al*., 2011; Zhang *et al*., 2023); range limits of species moves by 6.1 km (±2.4 km) per decade northwards and shifts in phenology (Parmesan and Yohe, 2003). As species adapt to climate change through tracking their microclimates, others could exhibit *in situ* adaptation because of adaptive evolutionary process such as genetic modification or phenotypic plasticity (King *et al*., 2018; Valladares *et al*., 2014). Species extinction occurs if three of these climate change adaptation mechanisms, i.e., range shift, *in situ* adaptation or phenotypic plasticity are absent (Urban, 2015). There are unprecedented shifts in the distribution of species due to climate change, i.e., 2.5 times more than originally reported (Parmesan, 2006;

Taheri *et al*., 2021). Althoguh most species exhibit nonrandom latitudinal or altitudinal range shifts which is consistent with the hypothesis that climate change induces directional range shift, others lag behind the tempo of climate change (Pounds *et al*., 1999; Devictor et al., 2008; Forero-Medina *et al*., 2011). Furthermore, range shifts could be nonlinear and may not be directional due to several factors, e.g., complex interactions between temperature and precipitation (Tingley *et al*., 2012), biotic interactions (Araújo *et al*., 2013), species climate tolerances (Warren *et al*., 2001) and land use change (Crimmins *et al*., 2011).

Climate change, including warming trends and increased rainfall variability, is contributing to changes in species distribution, ecosystem composition and functions, phenology, and other diversity-connected characteristics (Hughes, 2000; Hannah *et al*., 2002; McMichael *et al*., 2003) – Figure 1.1. The challenges from climate change happen either directly through an increase in temperature and a change in precipitation or indirectly through intensifying and increasing the frequency of other disturbances such as wildfires (Gitay *et al*., 2002). The physiological processes (e.g., photosynthesis, growth, development, and behavior), phenological processes (e.g., advance in life cycle events), species distribution patterns, and adaptive capacity of species are directly affected by climate change (Hughes, 2000; Lepetz *et al*., 2009). These phenomena cause functional and structural modifications at all levels of biodiversity, intensifying interaction between and among species (Lepetz *et al*., 2009). Such a response to climate change and other pressures at ecosystem and landscape levels by itself will definitely cause local and global climate change (Gitay et *al*., 2002).

Changes in species richness and diversity can be a result of changes in temperatures (Chapungu and Nhamo, 2016). It is also considered one of the major factors limiting individual species distribution and abundance (Parmesan, 2006; Sinclair *et al*., 2010) and is expected to intensify the distributional pattern with future global warming (Walther *et al*., 2002). In most cases, the changes can be attributed to habitat loss, modification, alteration, fragmentation, and the introduction of new non-native species (Hughes, 2000; Gitay *et al*., 2002). On the other hand, the influence of climate change, such as shifts in geographical distribution or extinctions, is explained more in correlation to recent change trends (Parmesan, 2006; Massot *et al.*, 2008). Those species could face absolute reductions in distribution range size and suffer a greater risk of extinction with the coming global warming (Thomas *et al*. 2004; Parmesan 2006). For many terrestrial species, the circumstances are highly correlated with the pressure due to natural processes and human-induced activities that cause climate change (Gitay *et al*., 2002). For instance, climate change often affects life stages such as seedling setup while not directly causing rapid mortality among mature plants (Gitay et al. 2002). On the other hand, many species responses to climatic change are expected to be either moving at different rates towards the pole or higher elevations from their current distributions (Hughes, 2000; Gitay et al., 2002; Muluneh, 2021). But still, some species can cope with the warming conditions of the environmental patterns through physiological alteration, which lets them adapt to the newly created conditions (Massot *et al.*, 2008; Chapungu and Nhamo, 2016).

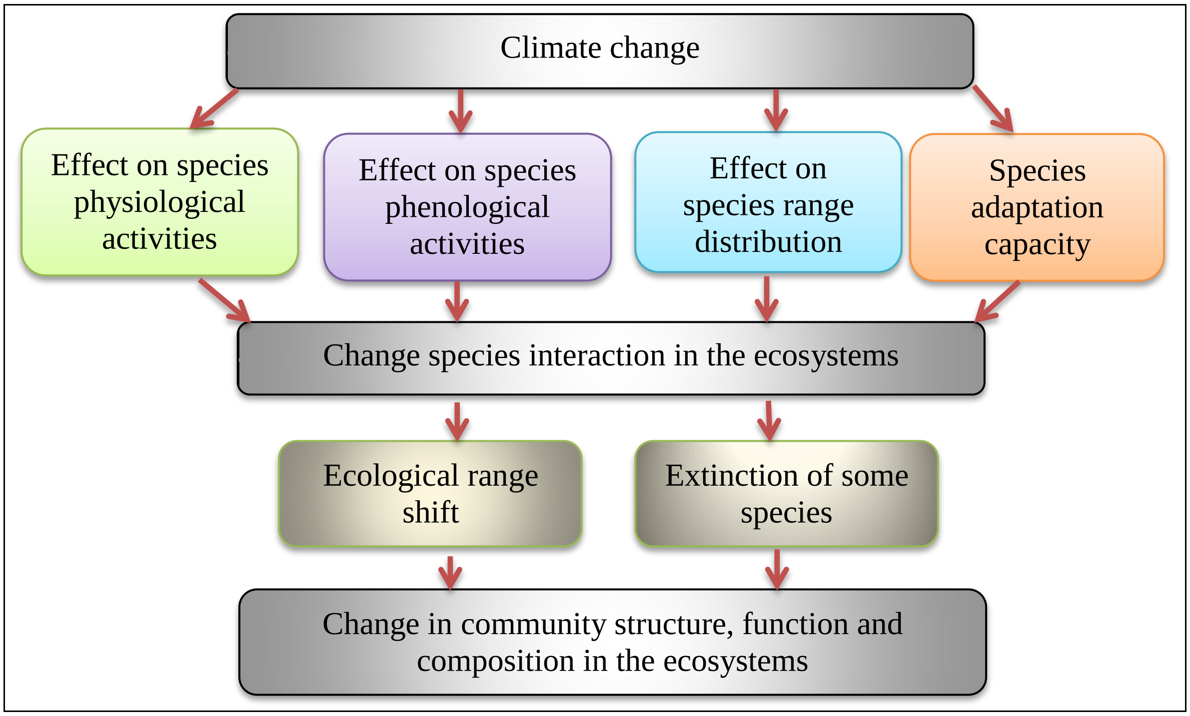


Figure 1.1 Climate change interactions cause the community structural, functional and compositional change in the natural ecosystem

1.1.6. Species distribution model and approaches

A realistic projection of the future state of the terrestrial ecosystem needs to be considered because human-induced activities are significantly affecting organisms' ability to respond to climate change, and hence there is worldwide growing interest in assessing the impacts of climate change (Gitay *et al*., 2002). Thus, it is necessary to adopt climate change-integrated conservation strategies that protect species from being impacted by the continuous warming of the environment through prospective habitat modeling (Hannah *et al*., 2002). This is because knowing the magnitude and direction of expected habitat changes through modeling is an essential element in conservation and management interventions for species under climate change. For modeling processes, various bioclimatic modeling tools (e.g., Maximum Entropy model, community model, BIOCLIM model, etc.) have been driven by a logical desire to get findings that are important for developing biodiversity management and conservation strategy (Thomas *et al*., 2004). MaxEnt uses presence data and background samples to produce species distribution models under current and future climate change. Out of more modeling methods, MaxEnt (Maximum Entropy) is best performance and has been popularly used in the prediction model (Araújo and Rahbek, 2006; Elith *et al*., 2006; Phillips *et al*., 2006). In this regard, the MaxEnt species distribution model is being utilized frequently in species distribution modeling to understand their distribution patterns through space and time under ongoing climate change and other human-induced environmental changes (Phillips et al., 2006; Brown, 2014; Zhuo et al., 2020). The software takes a set of species presence-only occurrences and environmental predictors such as precipitation and temperature as input data across a landscape in the process of modeling (Merow *et al*., 2013) and making predictions about range shift, range contraction, range expansion, suitability of habitats, and the extinction risk of species in response to climate changes and human-related disturbances (Fordham *et al*., 2012).

There is evidence of widespread environmental alterations related to ongoing anthropogenic climate change, and these changes are predicted to have an increasing influence on species distribution in the near future (Parmesan, 2006; Field and Barros, 2014). More specifically, because of their limited distribution ranges and persistence in areas of climatic constancy over evolutionary time scales, endemic species and those with narrow ecological ranges (Hallstan, 2011; Mbatudde *et al*., 2012; Trew and Maclean, 2021) and species in biodiversity hotspots (Trew and Maclean, 2021), are particularly vulnerable to climate change. Put differently, species with restricted habitat requirements, limited climatic range, and small populations are most likely vulnerable to extinction risk under climatic change (Gitay *et al*., 2002). This is why climate is often related to the distribution of plants on a local, regional, and global scale. Because it reflects the availability of moisture and energy for plant growth and development (Ngarega *et al*., 2021), it is more important than ever to comprehend how species distribution is impacted by climate change and how range shifts may be caused by future climate change (Santini *et al*., 2020). Such circumstances need timely interventions in order to maintain population connectivity, protect biodiversity structural compositions and functions, address the potential extinction risk to species, and conserve the hotspots of biodiversity under this changing climate (Pereira *et al*., 2013; Jetz *et al*., 2019). More importantly, for conservationists and ecologists, it serves as a tool for the employment of conservation and mitigating measures and to develop adaptive strategies under changing climatic conditions.

Sub-Saharan Africa has been characterized as the region most vulnerable to climate change (Ibe and Amikuzuno, 2019). This is because of its dependence on agricultural activities for sustenance of livelihood, which is highly sensitive to climatic variables like rainfall intensity, temperature variation, humidity patterns, and other extreme weather events. Overexploitation and overdependence on natural resources in this tropical ecosystem made the region the most likely affected by climate change (Adeyemi, 2020). Similarly, the forest ecosystems of Ethiopia, which are included in this tropical area, have been seriously declining and face an uncertain future due to climate change and human activities such as extreme farmland expansion, settlement, illegal timber logging, agricultural investment, and road construction (FDRE, 2020). Particularly, the Moist Afromontane Forest and Transitional Rainforest of the country, which are known as coffee forests, together with their many edible, medicinal, spices, endemic plants, and other biodiversity components, have been facing extreme damage due to different human activities (Daksa and Kotu, 2015; FDRE, 2020). Climate change can affect the geographical range of each species independently (Thomas *et al*., 2004), and as a result, the wild edible species *Syzygium guineense* subsp. *afromontanum* F. White, known for its very narrow geographical distribution range, is considered for prediction under climate change in the seriously deteriorating vegetation types of the country due to human pressure. This is because species with narrow distribution ranges receive non-management interventions that support them in adapting to the changing climate (Muluneh, 2021) and could be more vulnerable to human-induced climate change.

Currently, the taxonomic rank of this subspecies is *Syzygium afromontanum* (F. White) Byng. (Christenhusz *et al*., 2018). The online assessment from the POWO data base at https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:77184165-1 indicates that the plant species is native to many African countries. The occurrence data assessment from Global Biodiversity Information Facilities (GBIF), many ecological and ethnobotanical study reports (e.g., Kebede et al., 2014; Legesse, 2017; Raga and Seid, 2017; Tegene, 2018; Fekadu *et al*., 2019; Demise and Asfaw, 2020; Kassa *et al*., 2020), and the National Herbarium of Ethiopia (ETH) specimens indicated that the species is also native to Ethiopia. *S. afromontanum* is protected on coffee farmlands with other coffee shade trees in the moist evergreen Afromontane Forest of the country (FDRE, 2020). The species is known for its narrow distribution range in the altitudinal range between 1400 and 2600 m above sea level, is ecologically restricted to Moist and Dry Afromontane forests, and is occasionally retained as a single tree in croplands (Edwards *et al*., 1995). The species has been used for diverse socioeconomic purposes in the local community's traditional practices, including food, medicine, fuel wood, fodder, construction, fencing, etc. For those community members earning low income, it contributes palatable fruits, which are used as timely food supplements, particularly during food scarcity. Its edible fruit is endowed with essential nutrients (Aragaw *et al*., 2021), the leaf is enriched with plant secondary metabolites, which are used for medication purposes (Tadesse and Wubneh, 2017), and the plant serves as a shade tree in the coffee production systems (FDRE, 2020). Based on the socio-economic values the species contributes and the degree of threat as criteria, a priority setting for 136 woody species was carried out by the IBC (2012), which revealed that *S. guineense* varieties were included in the top list as priority species for conservation.

To reduce the negative effects of climate change, the right adaptive and mitigation measures are needed for the conservation of such plants with a narrow ecological range and outstanding socioeconomic and cultural importance, which should gain top priority for conservation that is currently affected by serious human-induced activities and climate change. This is used for improving favorable environmental conditions for the species in the climate refugia in order to persist more (Vos *et al*., 2008). On the other hand, integration of indigenous knowledge into climate change mitigation and adaptation processes has a mutual effect (Mafongoya and Ajayi, 2017) and therefore ensures poverty reduction and supports sustainable development (Ajani *et al*., 2013). For the improvement of ecological and socio-economic values associated with the species, predicting species distribution is an important mechanism for investigating various aspects used in management, restoration, and conservation activities (Piri Sahragard *et al*., 2021). Additionally, the distribution model is used to examine habitat determinant variables, inform conservationists and ecologists of the possible range shift or contraction in an uncertain future, and, furthermore, examine the possible pressure species face due to climate change under future climatic circumstances. To this end, prediction model analysis was conducted for the highly valuable but with narrow distribution range of the edible plant *S. afromontanum* under current and future climatic change in Ethiopia.

1.2. Research Hypotheses

Hypothesis I: Significant proportion of primary forest habitats has been lost due to continuous state of land use land cover transformation in the study area.

Hypothesis II: Woody species richness, diversity and structural composition show a significant difference among study sites, land use types and wealth classes in the small-scale agroforestry systems in the study area.

Hypothesis III: There is a significant difference in indigenous knowledge on underutilized wild edible plants between different informant groups of the study area.

Hypothesis IV: The significant change in potential distribution area of *S. afromontanum* (F. White) Byng. species would be caused under the mid and end century scenarios (2050s and 2070s) of Representative CO_2 Concentration Pathway (RCP) scenarios (RCP 4.5 and RCP 8.5).

1.3. Research Questions

Answer for the following questions were expected.

- What is the temporal and special pattern of land use/land cover change in study area for three decades?
- Which land use types contribute more for land use/land cover change in the study area?
- What is the diversity of woody plant species in traditional agro-ecosystem of the study area?
- Are woody species richness and diversity are different among house location (altitude), land uses type, and wealth class in variouse agro-ecosystem of the study area?
- What is the current status of the underutlized wild edible plants of the study area?
- Which wealth class has more indigenous knowledge over underutilized wild edible plants in the study area?
- Which parts of the underutlized wild edible plants do the local people rely on?
- What method of preparation do local people use for consumption of underutilized wild edible plants?
- When the local people of the study area use underutilized wild edible plants in the study area?

- What are the existing threats to underutlized wild edible plant species?
- How do local communities manage and conserve underutilized wild edible plants?
- Which plant species are locally threatened and need priority for conservation actions?
- Which bioclimatic variables are significantly influencing species current distribution model?
- Does the potential distribution area of *S. afromontanum* would be affected under climate change in the major biomes of Ethiopia?

1.4. Objectives

1.4.1 General objective

- To examine the pattern of land use dynamics, diversity of woody species, and ethnobotany of underutilized wild edible plants in Midkagn District, and to model the current and predict the possible sustainable habitat of *S. afromontanum* under changing climate conditions in Ethiopia.

1.4.2. Specific objectives

- To assess the effect of the spatio-temporal LULC dynamics from 1986 to 2020 with the associated major driving forces behind land use land cover change in the central plateau of Shewa, Ethiopia.
- To investigate the influence of study site location, land use types, and wealth class on the status of woody species in terms of species richness, diversity, and structural composition in various agroforestry systems of the study area.
- To document underutilized wild edible plants with the associated indigenouse and knowledge in the local people of Midakegn District.
- To predict the potential distribution area of the wild edible *S. afromontanum* under climate change in Ethiopia.

1.5. Description of the Study Area

1.5.1. Geographical location

All the sub-projects contained within this PhD study except sub-project IV were conducted in Midakegn (Figure 1.2 A), which is one of the administrative districts of West Shewa Zone, Oromia Region, Central Ethiopia (Figure 1.2 B). The District stretches from 09^0 02′ 57″ to 09^0 23′ 45″ N latitude and 037^0 22′ 22″to 037^0 45′ 54″ E longitudes. It is characterized by Dry Afromontane Forest and grassland complexes that have been significantly exposed to extensive agricultural expansion through a subsistence mixed (both crop and livestock) farming system (Bekele, 1994). One of the studies (the species distribution model, Paper IV) was carried out within geographical range of Ethiopia by using the recently adopted major vegetation types of the country by EFCCC (2017), which is located at the Horn of Africa and stretches from 3.30–15^oN latitudes and 33–48^oE longitudes (Figure 1.2 C) with area coverage of 1.13 x 10^6 km^2.

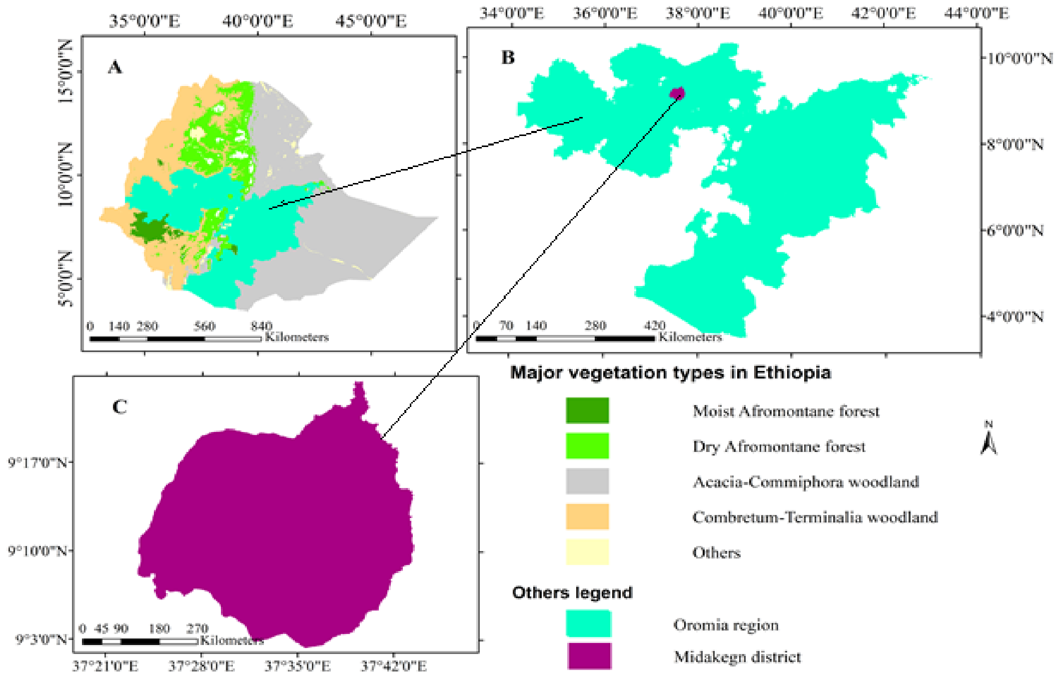


Figure 1.2 General map of Ethiopia showing, Major Vegetation types, Oromia region and the study area

1.5.2. Climate

Ethiopia experiences extensive changes in its tropical monsoon climate due to a wider range of topography (Shekuru *et al.*, 2022) and those altitudinal variations cause climate extremes greatly differ across diverse agro-ecological environments throughout the country (Zeleke, 2014). Shewa plateau which includes the study area in its western part, contains various agro-ecological zones of which tepid moist mid highlands, sub-moist mid highlands, and sub-humid mid highland accounts about 72% of its landmass (Elias, 2016).The western plateau of Shewa (including the study district) faces humid air currents coming from the Atlantic Ocean, which is characterized by a mono-modal distribution pattern and receives maximum rainfall from June to August (Elias, 2016). According to 10 years of weather station data from Cheliya District obtained from the Ethiopian meteorological services agency, the mean maximum and minimum monthly temperatures of the study area were 24.6°C and 8.7°C, respectively, with a mean annual temperature of 16.3°C (Figure 1.3). The study district also received a mean annual precipitation of 1004 mm, and June to August are the main rain seasons, while the peak between March and April indicates the slight rain season.

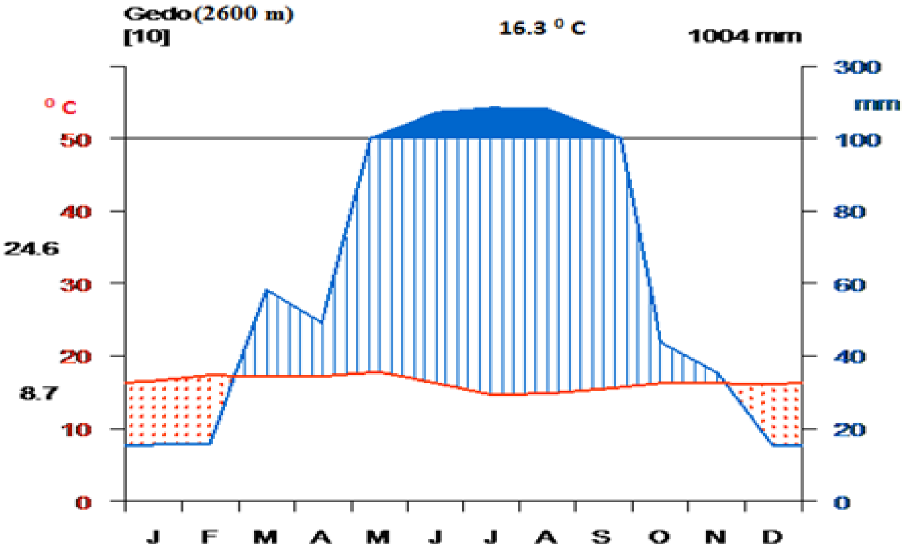


Figure 1.3 Climatic diagram of the study area from 2011-2020

1.5.3. Vegetation types and land use system

Ethiopia is characterized by heterogeneous floral diversity and rich endemism. The classification of vegetation types and its extreme complexity in different ecosystems of the country have been made by different researchers (Woldu and Ingvar, 1999; Friis and Demissew, 2001; Friis *et al*., 2010). Of those, Friis *et al*. (2010) recently classified them into twelve potential vegetation types, including: Desert and Semi-desert scrubland; Acacia-Commiphora woodland and bushland; Wooded grassland of the western Gambela region; Combretum-Terminalia woodland and wooded grassland; Moist evergreen Afromontane forest; Dry evergreen Afromontane forest and Grassland complex; Ericaceous belt; Afroalpine belt; Riverine vegetation; Fresh-water lakes, lakeshores, marsh and floodplain vegetation; and Salt lakes, salt-lakeshores, marsh and pan vegetation. Among those, the central plateau of Shewa which includes the study area commonly falls in the Dry evergreen Afromontane forest and grassland complex vegetation types (Bekele, 1994). The economic activity of Ethiopia is mainly dependent on subsistence agriculture activities (Bishaw, 2001). Various land uses for agricultural purposes are characterized by a mixed system in which forests and trees are on agricultural land and agriculture practices are on forest lands (FAO, 2016). Similarly, the study district is highly dominated by intensive agricultural activities, in which crop cultivation and livestock farming are the principal practices of the area. Such practices had modified the existing natural ecosystem in the study area. An intensive mixed farming system is one of the major human activities that influence ecosystems (Kindu *et al*., 2016).

1.5.4 Geology and soils

The fundamental geology of the Shewa plateau is formed by two Trap series volcanic eruptions that occurred during the Oligocene-Miocene age and the Miocene-Pleistocene age and is dominated by flood basalts that separated in the denudation period (Mohr, 1971). In its northwestern parts, the alkaline basalts and sub-horizontal flood basalts are important formations of parental materials for nitisol and leptosol most commonly found in the area, while the southeastern parts are covered by the series volcanoes for the formation of parent materials for vertisols that dominate the landscape (Elias, 2016). The degraded plateau and hilly landscape currently observed in this area are due to the lavas formation that has been exposed to erosion and dissection (Elias, 2016). Another study by Dinssa and Elias (2021) discovered more major soil types, including nitisols, alisols, luvisols, and cambisols, specifically in west Shewa landscapes. The area is commonly characterized by sandy loam, clay loam, sandy clay loam, and loam in soil textures (Bibiso, 2017).

1.5.5. Conceptual framework

The study's framework revolved around the relationship between drivers, climate change and land use dynamics as the threats to biodiversity, related ecosystem services and environmental processes. It indicates how drivers cause contemporary land use conversions, landscape modification, and climate change. Consequently, within various agroforestery system and other land use types created through land use dynamics, the study intentionally looks at to what extent the land use types in different agroforestery system affects the species diversity, abundance, and structural composition of woody plant species and underutlized wild edible plants in the study area. On the other side, based on the theoretical aspects of climate change, our study peridicts the impact of climate change on potential distribution area of *S. afromontanum* under the current and future climate change scennarios. Overall, the impact and implications of land use land cover change and climate change caused due to different driving factors is considered towards plant biodiversity, ecosystem services and environmental processes (Figure 1.4).

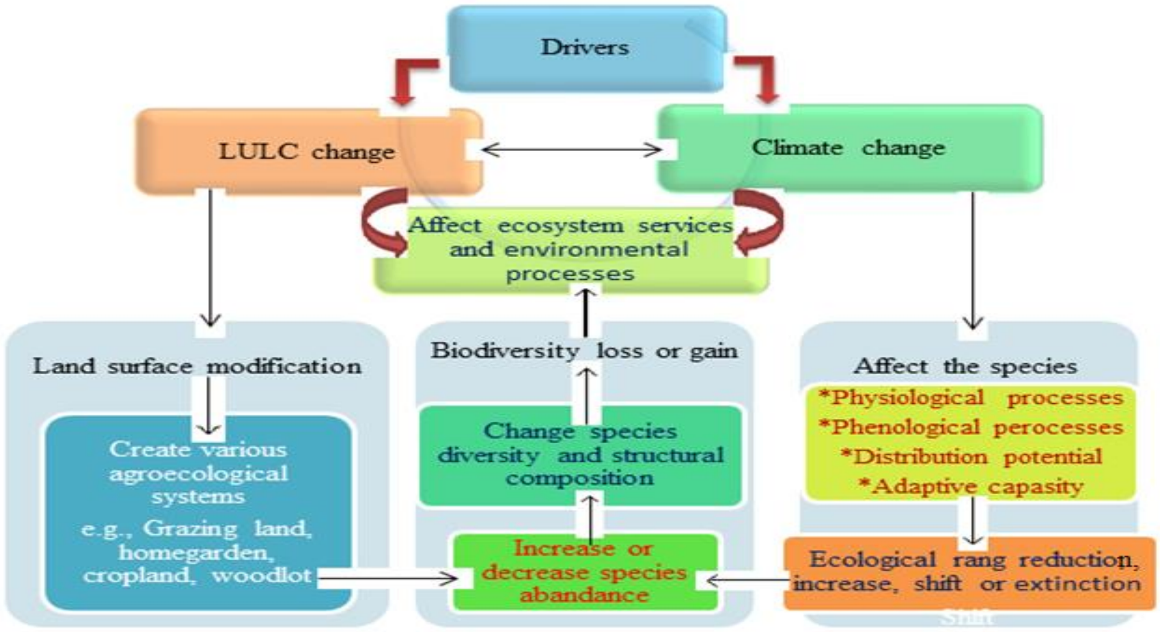


Figure 1.4 Conceptual fremework of the study

1.6. Methods

To quantify LULC changes and visualize changes in spatiotemporal patterns in the time series of land use consequences, different types of aerial satellite images originating from different types of sensors along with multi-temporal records were used (**Paper I**). Hence, Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM$^+$), and Operational Land Imager and Thermal Infrared Sensor (OLI-TIRs) Landsat raster images of the three Epochs (1986, 2003, and 2020) were acquired from the Earth Explorer website (http://earthexplorer.usgs.gov/). The overall land use change detection over two-time intervals (1986–2003 and 2003–2020) was conducted to indicate the absolute change. For better identification of land use cover categories in the pre-processing images, aerial satellite images with maximum resolution and minimum cloud cover were sourced from January to February. Ground control points (GCP), which were recorded by GPS from identified land use types (another primary data) and reference points from Google Earth, previous reports, and maps (secondary data), were used in this investigation. Additionally, socio-economic data were collected and used to understand the trend of LULCC in the study area. A maximum likelihood supervised classification system was used by ArcGIS version 10.7. For accuracy assessment and change detection, the consequent statistical process was carried out using ArcGIS and the Spread Sheet program.

A study on woody species diversity potential analysis in various agroforestry systems (**Paper II**) was conducted in land-managed units of sample households in the intensively cultivated area of Midakagn district. Representative village selection was done through simple random sampling methods in the highly modified landscape areas of the district (midland and highland agro-ecological zones). A systematic sampling design for lying down parallel transect lines at a 200-meter interval in representative sample units was used. At a 150-meter interval, plot size of 50 m x 50 m for croplands, 30 m x 30 m for grazing lands, and at a 30 m interval, a plot size of 10 m x 10 m for woodlots along each transect line were systematically laid down for sample collection. But to collect sample data in the representative households, homesteads were systematically selected, and complete enumeration techniques for sample collection were employed. To observe the impact of economic status of households on woody species diversity and structural composition, sampled land unit owners were classified into different wealth classes.

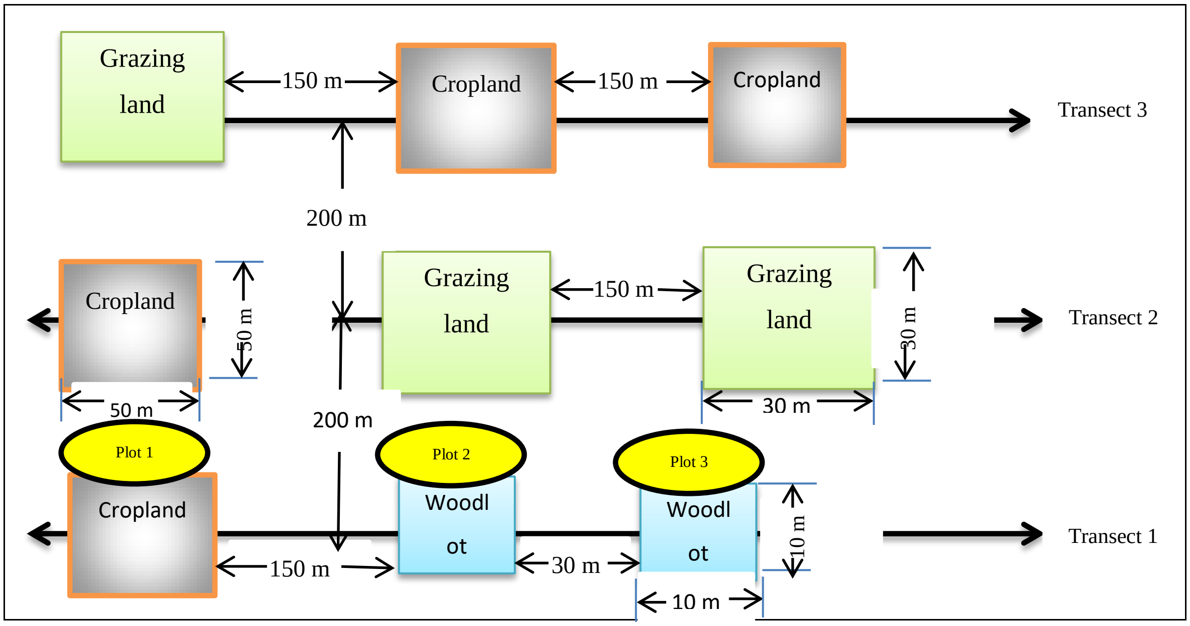


Figure 1.5 Sample collection design for woody plants in different agroforestry practices in the study area

According to the above data collection design (Figure 1.5), a total of 86 plots along 16 transect lines and 28 homegarden land plots at three study villages were inventoried to assess the impact of altitudinal differences, land use types, and wealth classes on woody species richness, diversity, evenness, and structural diversity in the study area. For all woody species with DBH ≥ 2.5 cm and height ≥ 1.5 m, their DBH, height, number of species per land plot, number of stems per plot, and altitudinal location of each land unit were recorded on spot.

A study on the utilization potential and assessing indigenous and local knowledge associated with underutilized wild plants was conducted in three agroecological zones of the study area (**Paper III**). Key informants (KI) and general informants (GI) were selected to collect the ethnobotanical data. A total of 25 KI and 333 GI that include both age and wealth classes were selected by snowball methods and simple stratification methods from the members of the community living in the study area, respectively. A one-way ANOVA was used for the comparisons of ethnobotanical knowledge distribution between different informant classes. Preference, direct matrix, and priority ranking exercises were used to measure popularity, multiple functionality, and threats to those plants in the study district.

For paper II, diversity indices, including species richness, Shannon diversity, and Shannon evenness index, was used to statistically measure woody plant diversity. To test the existence of statistical variation both in diversity and population structure, the computed statistical values for different parameters were done using one-way ANOVA and pairwise mean separation, and comparisons were held by Tukey's post-hoc multiple comparisons analysis that exists in similar statistical packages. Additionally, bar charts of population structures which exist in different distribution classes of LU types were drawn by R statistical package version 6.3.1.

For predicting the potential distribution area of *Syzygium afromontanum* under different climatic change scenarios in Ethiopia (**Paper IV**), predictor variables including presence-only coordinate point data, 19 bioclimatic variables, and three others including the solar radiation index from the World Climate Database and topographic layers (topographic position index and altitude) from Aster DEM were used. For future projection, RCP 4.5 and RCP 8.5 of the mid-century (2050s) and end-century (2070s) scenarios were used to indicate the impact of climate change on the potential distribution area of the species. The recently modified major biomes of the country were used to map the distribution range of the species under all scenarios (EFCCC, 2017). MaxEnt and ArcGIS software were used for spatial and temporal extrapolation of the model over countries' whole geographical boundaries.

CHAPTER TWO

Time series land use land cover change analysis and its drivers in Midakegn District, Central Plateau of West Shewa, Ethiopia

Sheleme Guzo, Sileshi Nemomissa, Ermias Lulekal

A paper submitted to the Arabian Journal of Geoscience, Springer, and is in the review process.

2. Time series land use land cover change analysis and its drivers in Midakegn District, Central Plateau of West Shewa, Ethiopia

Abstract

Land use land cover (LULC) change is a significant process tightly attached to human activities for different needs and its analysis is very important to understand the types of changes on the land and the drivers, and the impacts behind the change. This study seeks to evaluate LULC changes and what drivers are behind the change in the Midakegn district. Satellite images of Landsat 5 Thermal Mapper 1986, Landsat 7 Enhanced Thematic Mapper Plus 2003 and Landsat 8 Operational Land Imager and Thermal Infrared Sensor 2020 were used for the change analysis. Focus group discussions and key informant interviews were used to assess the drivers. Aeronautical reconnaissance coverage Geographic Information System (ArcGIS) 10.7 techniques were used for image processing and map production. Maximum likelihood supervised classification was carried out for image classification. The proportion of area covered by forest, grazing land, shrubland, and water body decreased in hectare by 3145 (-38.5%), 7993 (-22.5%), 5331 (-17.2%), and 2.7 (-1.3%), respectively while farmland and build-up area have expanded in hectare by 13881 and 2590.4, respectively over 34 years. Multiple main factors such as population growth, economic status of the local community, regime change followed by political instability as indirect drivers, and farmland expansion and illegal wood harvesting as direct drivers were indicated as the major cause of LULC change in the study area. Therefore, this study recommends the need for exerting enough attention to balance farmland expansion against the sustainable use of natural resources to maintain a safe and stable ecosystem.

Keywords Drivers, GIS, Landsat, Image analysis, Land use land cover change, Midakegn.

2.1. Introduction

Historically, human societies have been tightly attached to the land for the sake of economic, social, political, and other human activities (Lambin *et al*., 2003). Since the industrial revolution, environmental problems have become increasingly prominent at local, regional, and global scales due to human substantial modification of land use and land cover classes (Chang *et al*., 2018). The term land cover refers to the attributes of the earth's land surface and immediate surfaces, including biota, water, soil, other physical features of the land, and those created solely by human activities such as settlements, farmlands, etc. (Rawat and Kumar, 2015), whereas land use refers to the intended service of land use management systems placed on the land cover by human interference or/and land managers to exploit the land cover for economic activities (Nanda *et al*., 2014). These two composite patterns of a region are the outcomes of natural and socio-economic factors and their utilization by man in time and space (Rawat and Kumar, 2015).

LULC change is the major driver of biodiversity loss, ecosystem service degradation, declining water resources, extended aridity, and drought (Maitima *et al*., 2009; Dibaba *et al*., 2020). In some cases, there is an opportunity to lose nearly all species of fauna and flora on-site, which leads to increasing fragmentation of the remaining ecosystems (Maitima *et al*., 2009). Such modification is caused by land cover conversion, which is measured by a shift from one land cover category to another, as is the case in agricultural expansion, deforestation, changes in urban extent, and heavy livestock grazing (Lambin *et al*., 2003). For instance, forest area conversion to cultivated land by massive deforestation (Dinka and Chaka, 2019) and land degradation due to heavy livestock grazing (Lemenih and Teketay, 2004) are some of the main causes of LULC change.

The force of the drivers as well as the changes in driving factor composition lead to changes in the prevalence of LULC and environmental conditions of a region (Roy and Roy, 2010). Natural disasters and human-related activities are two categorical drivers that cause LULC change (Shiferaw and Singh, 2011). Change in population demography (Dale, 1997), natural environmental change and variability interaction with humans

(Lambin *et al*., 2003), individual and social responses to changing economic and technological conditions (Reid *et al*., 2000), and institutional interaction with the individual decision maker for political, economic, traditional, and cultural value (Gudesho and Woldu, 2021) in combination are the main driving factors that cause LULC change. Population growth leads to urbanization and a decline in the natural land cover types of the region (Dale, 1997). Rapid growth and expansion of urban centers, scarcity of land, the need for economic growth, and changing technologies are other drivers of LULC change in the world in the past and today (Reid *et al*., 2000). The consequence of the change due to multiple interacting factors causes unprecedented and dramatic changes to ecosystems and environmental processes at global, regional, and local scales (Rajan and Shibasaki, 2000; FAO, 2016). Ecosystem modification by different land uses causes climate change, water and air pollution, and biodiversity loss as well (Jiang and Tian, 2010; Tolessa *et al*., 2017; Fasika *et al*., 2019). For instance, soil erosion, alteration of ecosystem services, disruption of socio-cultural practices, and an increase in natural disasters such as flooding and landslides are some consequences of LULC change (Watson *et al*., 2000; Godebo *et al*., 2018). LULC change can also cause an unbalanced surface energy budget, which can affect human life comfort by changing land surface temperature (Imran *et al*., 2021).

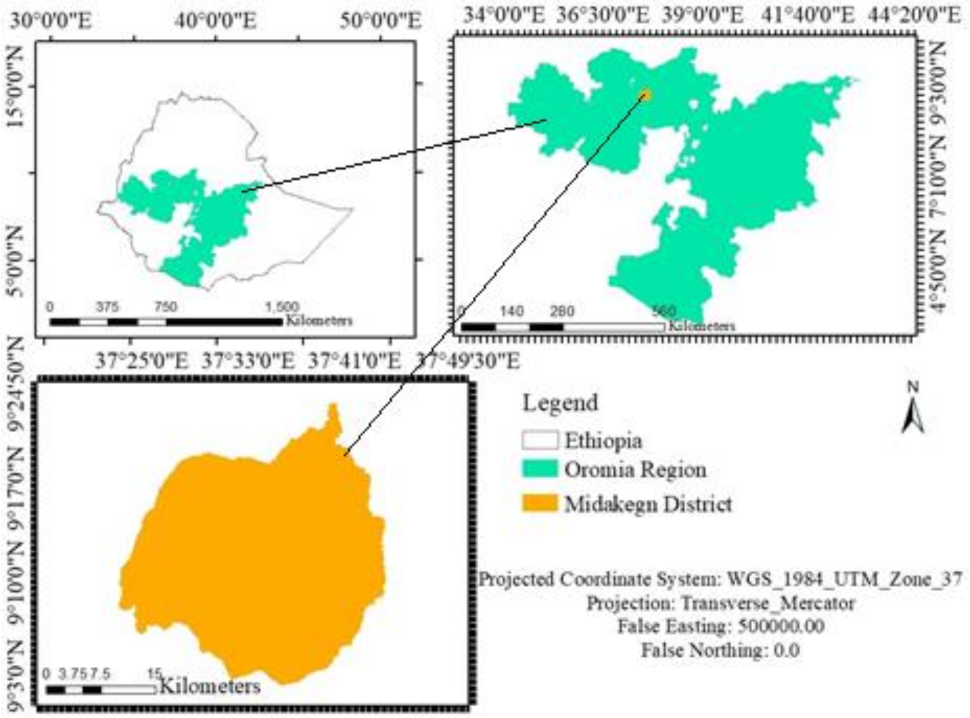
LULC change is a very common occurrence in rural landscapes in Ethiopia (Godebo *et al*., 2018). This is because the majority of the human population lives in rural parts of the country and depends directly on the land for their livelihood (Bishaw, 2001). Such dependence has caused the modification of land by humans to improve livelihoods and obtain essentials for thousands of years, and hence the extent, intensity, and rate of LULC change are far greater now than they were in the past (Hassan *et al*., 2016). The change of vegetation cover areas to other land categories from time to time, especially in highly populated parts of the country, had contributed much modification on the land through worsening areas covered with vegetation (EBI, 2015). Especially the conversion of forests and woodlands in the country into other land use categories (agriculture, settlement, mining, infrastructure, etc.) has significantly contributed to habitat loss and the decline and degradation of natural resources (Lemenih and Teketay, 2004), and this in turn has negatively impacted the production and productivity of the agricultural sector (EBI, 2015). This indicates that inappropriate human activities might lead to severe land cover changes. Determining the effects of LULC changes on the ecosystem requires knowledge of past land use practices, current LULC patterns, and future projections (Bewket, 2002).

The majority of investigations pertinent to LULC changes in Ethiopia so far have emphasized the northern highlands, where they are relatively encountered with high population pressure (Tegene, 2002). Still, very limited studies related to such an area were done in other parts of the country, even in areas facing relatively high anthropogenic activity. The present study district is part of West Shewa (part of the central plateau of Ethiopia), and this locality is characterized by a clear gradient from grassland through shrubland to forest ecosystems (Zerihun and Backéus, 1991). The ecosystems of the area have been highly affected by human activities such as crop cultivation and animal husbandry for years (Zerihun and Backéus, 1991; EBI, 2015). Here, mainly agricultural expansion, overgrazing, and harvesting of selected species have been considered threats to the ecosystem and cause visible land degradation in the area (EBI, 2015). Land cover changes in areas with high drivers need to be better taken into account in land cover change studies. Accordingly, to exactly understand the extent of the change brought by land cover modifications, systematic analysis of LULC change is crucial in the present study area, where no similar research was conducted earlier. The findings of the present study will have fundamental contributions for land managers and land policymakers to have implementable plans and policies at the local, regional, and country levels for sustainable use and management of natural resources. Therefore, this current study is about the evaluation of the spatial-temporal pattern of land use and land cover change for more than three decades in the study area and seeks to understand what driving forces are behind the changes in the study area.

2.2. Materials and Methods

2.2.1. Description of the study area

The study was conducted at Midakegn District, which is one of the administrative districts forming the West Shewa Zone of Oromia Regional State, in the central plateau of Ethiopia (Figure 2.1). The district extends from 09^{o} 02′ 57″ to 09^{o} 23′ 45″ N latitudes and 037^{0} 23′36″ to 037^{o}45′ 54″ E longitudes, with an elevation range of 1290–3058 m a.s.l. It is bordered by districts: Toke Kutaye to the southeast, Ambo to the northeast, Gindeberet to the north, Guduru to the North, Jimma Rare to the West, and Chelia to the southwest. It is composed of twenty-five kebeles (the smallest community-based administrative units in Ethiopia), among which Balemi (the administrative town) is an urban kebele. The town is located 221 km west of Addis Ababa (capital city of Ethiopia) and 107 km northwest of Ambo (the administrative capital of the West Shewa Zone). The district is known for having three agro-climatic zones. According to the Midakegn District Agricultural Office (MDAO) 2020 annual report (unpublished), the highland agro-climatic zone covers 12.5% of the western part of the Balemi; the midland covers 50% by extending eastward to the northwestern through the central part of the district; and the lowland agro-climatic zone covers the remaining 37.5% in the northern part. The district has different landforms and features: flat plains, undulating plains, mountains, and rocky and valley areas. Red soil, acidic soil, and sandy soil are the dominant soil types in the midland, highland, and lowland agroecological zones of the district, respectively (MARDO, 2020). The study area faces a humid air current coming from the Atlantic Ocean and receives heavy rainfall during the main rainy season (June to September). Currently, the district has 106,438 total residents, of whom 52,148 (49%) are males and 54,290 (51%) are females. Subsistence mixed agriculture is the economic mainstay for the population of the study area. The total land coverage of the study area is about 91,051 hectares (ha) and includes different land use cover classes such as cultivated area, the area covered with forest, shrubs, and grasses, and land coverage used for other purposes.



Figurer 2.1 Map of Ethiopia showing the Oromia region and the study district

2.2.2. Field survey and data collection

The present study used both primary and secondary data sources. Primary data, such as actual current LULC types available in the study area and ground control points (GCPs), were collected on the spot during the reconnaissance survey (2020–2021). The ultimate purpose of the reconnaissance survey was to collect qualitative and quantitative information that would help in better understanding, explaining, and interpreting the LULC change. Hence, during the survey, ground information was collected to identify the current LULC types available and to give a description of the nature of ground covers such as forest, shrubland, farmland, grazing land, water bodies, and built-up available in the study area. GCPs from each identified land use type were taken using a GPS receiver and used for the preparation of signatures for supervised classification, which is important in change detection and aiding different steps of image processing. Knowledge of the study area and information collected during fieldwork were important inputs used by the software to classify the pixels into similar groups based on the sample signatures specified (Oumer, 2009).

2.2.3. Satellite image data acquisition

The high-quality aerial satellite image was sourced, analyzed, and used as another primary source of data. Thus, different types of satellites or aerial images originating from three types of sensors, namely, Thermal Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager and Thermal Infrared Sensor (OLI-TIRS), respectively, for the years 1986, 2003, and 2020, were downloaded from the United States Geological Survey (USGS) Earth Explorer website http://earthexplorer.usgs.gov/ at a seventeen-year interval and were used to quantify LULC changes and visualize changes in spatiotemporal LULC patterns of the study area. The selection of the three years was based on the population demography of the study area and the change of regime followed by political instability in the country. For quality images and easy differentiation of land use types, a satellite image with minimum land cloud cover and the maximum resolution was acquired and downloaded for each year. The year and date of acquisition, Landsat and sensor type, spatial resolution, path and row, cloud cover, bands used, and source of the satellite images are given in Table 2.1 below.

Secondary data including shapefiles and topographic maps were obtained from the Ethiopian Mapping Agency (EMA).

Table 2.1 Satellite data specifications in this study

Year and date of acquisition	**Landsat and sensor type**	**Spatial resolution**	**Path/raw**	**Cloud Cover**	**Used bands**	**Source**
3 January 1986	L5 TM imagery	30*30 m	169/054	4	1-5,7	USGS
4 February 2003	L7 ETM$^+$ imagery	30*30 m	169/054	1	1-5,7	USGS
27 February 2020	L8 OLI-TIRS imagery	15*15m	169/054	0.06	1-7	USGS

2.2.4. Socio-economic data collection

The district is known for having three agroecological zones. The assessment of socioeconomic data collection was made in consideration of these agroecological zones. The intention was to get sufficient information about the past and current trends of LULC change at each agroecology. It is also important for the identification of driving factors that cause the changes and the implications of LULC change on the socio-economic activity of the community and the environment. Thus, detailed focus group discussions (FGDs) with old enough farmers (65–85 years old), key informant interviews (KIIs) with purposively selected individuals who were believed to have a good understanding of the data needed to collect, and on-sit observation were made based on the consultation of development agents housed in the study areas. By following Garbarino and Holland (2009), two FGDs with 6–12 group members were made at each agroecological zone. This is because group member behavior within this range can easily be controlled. Additionally, 32 KIIs from agricultural experts, natural resource management, and land use administration at the district level, agricultural experts at the kebele level, and kebele leaders were selected for interviews to collect the intended quantitative information. Open-ended questions concerning socio-economic activities, change of regime and its consequences, land use policy, and major shifts in LULC classes were prepared in English and translated to the local language '*Afan Oromo*' for data assessment. Other issues related to anthropological activities and natural consequences that could influence land management in the study area were included to get the management perspectives of the indigenous people of the study area. Population demography data within the specified time interval for LULC change analysis was assessed from the central statistical agency office report of the country and Midakegn district. On the other hand, impacts caused by socio-economic activities, population growth, regime government change followed by political instability, natural disasters, institutional and technological development, and the economic status of the local community were all assessed through discussions and interviews.

2.2.5. Image classification

An intensive image pre-processing and supervised classification were performed to extract information from satellite imageries. To combine different bands into a single layer (multispectral bands), the downloaded satellite image data of each year (1986, 2003, and 2020) were imported to ArcGIS version 10.7 for image composite (layer stacking). All the satellite images were already orthorectified by GCPs to have a coordinate reference system of Universal Transverse Mercator (UTM) zone 37N with WGS84 datum. Image enhancement (clipping and mosaicking) into new raster was carried out to have clearer and distinct features for clear classification and interpretation of potential land use classes in the analysis process and subsequently sub-setting was done to have extracted images with study area shape file.

In this study, the maximum likelihood supervised classification system was used in ArcGIS version 10.7. The software was trained to recognize that certain types of pixels represent specific land cover types. Here, information from experts and elders and a review of documents from zonal and district offices were used to define the training site for TM and ETM^+ Landsat image classification. Training sites for OLI-TIRS image classification into different land use classes were defined by information collected during fieldwork and Google Earth imagery of the study area. The manually classified training samples were then used by the classification algorithm to classify all pixels in the image into the chosen land use classes. Training sample selection for each land cover class was dependent on the spectral variability within the class. Later on, six land cover categories were identified and used for LULC change analysis, as shown in Table 2.2 below, after spectral classes and map patterns were visually correlated.

Table 2.2 Land cover class identification and description in the study area

Land cover class	Description
Forests	An area covered with patchy-dense natural forests with thick canopy cover and a woodlot area mainly occupied with *Eucalyptus globulus* Labill.
Shrubland	Areas covered by sparsely distributed trees, bushes, and shrubs, and in some cases mixed with grasses, are included in this class. Wooded grassland and transitional forests (less dense forests) were also included.
Grazing land	These are lands where small grasses are the predominant natural vegetation. It also includes open grasslands with very scattered trees and shrubs and wetlands used for grazing and browsing.
Farmland	The areas are mainly used for both annual and perennial rain-fed crop cultivation of a variety of crops in subsistence farming. Here, fallow land sites and scattered rural settlements included within the cultivated fields were also considered.
Waterbody	Areas that are occupied by water commonly rivers
Built-up	Areas occupied by governmental and public intuitions, residential (cluster of villages), and infrastructures were considered as part of this land cover class. Due to their similar reflectance, the land surface which is mainly covered by bare soil and exposed rock also included in this category.

2.2.6. Accuracy assessment

Accuracy assessment is an evaluation mechanism of the degree of acceptability of the classification process (Oumer, 2009). This is an important indicator of what extent the produced image classification matches well with what exists on the ground. Accordingly, generating a set of points from classified images and comparison with reference points were done through corresponding coordinates on the maps. A set of checkpoints were selected by a random sampling scheme to generate an error matrix for each class. Reference points for 1986 and 2003 were collected from the corresponding Google Earth, previous reports, and spot maps whereas reference points collected during field observation by using GPS and from Goggle earth were used for 2020. Enough samples are very important so that our estimate of the bias is precise (Congalton and Green, 2019).

Accuracy assessment was carried out through pair-wise comparison and weighted overlay (displaying these points on classified image) in the ArcGIS 10.7 by counting the number of points that correctly fit to land use class on the map and the same land use class from which they are recorded. Later on producer's, user's, overall accuracy, and kappa coefficient were computed from each error matrix produced for each period on a spreadsheet program. The method used by Congalton and Green (2019) was used to compute overall accuracy by adding the correctly classified sample units (i.e., the major diagonals) and then dividing it by the total number of sample units in the error matrix. The kappa coefficient was also calculated by following Congalton and Green (2019) as follows:

$$K\hat{} = \frac{\mathrm{Po} - \mathrm{Pe}}{1 - \mathrm{Pe}}$$

Where K^= kappa coefficient, Po is the proportion of correctly classified pixels (i.e., the actual agreement) in the error matrix; Pe is the proportion of agreement that is expected to occur by chance (i.e., the chance agreement).

Even though kappa values can range from -1 to 1, positive values are expected, and this is because of the positive correlation that exists between the remotely sensed classification and the reference data (Congalton and Green, 2019). As a result, the benchmark values used are < 0, 0–0.2, 0.21–0.4, 0.41–0.6, 0.61–0.8, and > 0.8 respectively, indicating a poor, slight, fair, moderate, substantial, and almost perfect degree of agreement (Landis and Koch, 1977).

2.2.7. Land use land cover change conversion matrix and detection

The classification change detection technique was done for LULC change analysis through pair-wise comparison and by carrying out weighted overlaying of two LULC maps at a time in ArcGIS version 10.7. The LULC change transition matrix produced by the software was used as change detection statistics and cross-tabulation analysis, which show quantitative conversions of one LULC category to another with their corresponding area in hectares (ha) over the two time intervals (1986–2003 and 2003–2020). This was used to indicate the absolute change (gained or lost) in the study area after calculating from the matrix.

To analyze the land cover structural changes in the study area, the tables showing the area in hectares and percentage changes between the periods 1986, 2003, and 2020 were quantified for each LULC type. The following three simple formulae were used to show the spatiotemporal distribution change of LULC classes of the same category between two periods. This is to provide information on the trend of conversion in terms of time.

Category area gain/loss (ha) = Category area of the final year - category area of the initial year

$$\text{Percentage category area gain/loss} = \frac{\text{Category area gain or loss in ha}}{\text{Category area of the initial year in ha}} \text{x} 100$$

Finally, the annual rate of change of LULC class between periods 1986-2003, 2003-2020, and 1986-2020) was computed by following the formula stated in Shiferaw and Singh (2011).

$$\text{Rate of change (ha year}^{-1}\text{)} = \frac{A2-A1}{\mathrm{t}}$$

Where, A_2 and A_1 denote the recent year area of the LULC and the previous year area of the LULC in ha, respectively, whereas t indicates the time interval between the recent and initial years. It should be noted that the negative values indicate the magnitude of the decline, and the positive values indicate an increase in that particular land use and land cover type.

2.3. Results and Discussion

2.3.1. Classification accuracy measure

Classification accuracy assessment of LULC products of 1986, 2003, and 2020 through the confusion error matrix and kappa statistics was indicated (Appendex 1). The overall accuracy (OA) of each period map showed 83.6%, 85.0%, and 90.1% accuracy measures, respectively. The kappa coefficient (K^) was 0.802, 0.854, and 0.885, respectively. The overall kappa value of all Landsat imageries revealed the existence of a strong agreement between the remotely sensed classification and the reference data. Relatively, the stronger OA value recorded for the Landsat OLI-TIRS imager indicates the better quality of the image and the better visibility of the land cover on the ground and the classified map.

2.3.2. Land use land cover changes in 1986, 2003 and 2020

The spatiotemporal distribution of the LULC class of the study is presented in Figure 2.2. The six LULC categories indicated in this investigation were forest-covered, shrubland, farmland, grazing land, water bodies, and build-up areas. The figures indicate that farmland, which was the third most predominant land use category in 1986 and 2003, became the most predominant land use category in the study area in 2020, and even if grazing land followed by shrubland were the most predominant LULC categories in 1986 and 2003. Forest, buildup, and water bodies, respectively, occupied the 4th–6th positions in area coverage at all particular time intervals in the study area. The extreme expansion of the farmland, which resulted in the decline of grazing, shrub, and forest land, was mainly observed in the midland and highland areas of the catchment. These grazing and vegetation areas exhibited declining trends currently remaining in lowland agroecology (Figure 2.2).

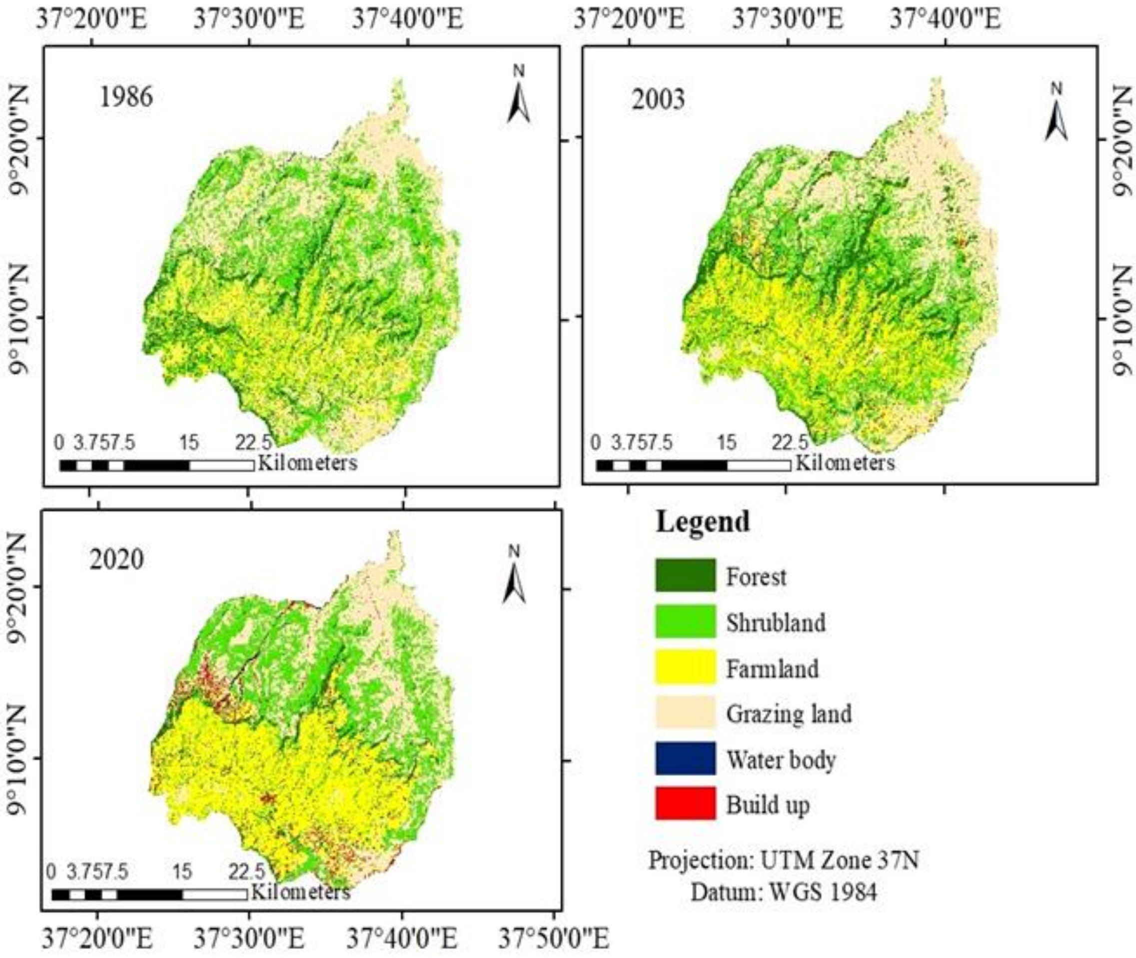


Figure 2.2 Classified LULC maps of 1986, 2003, and 2020 of the study area

The distribution of LULC categories in the study catchment was well prepared, as indicated in Tables 2.3 and 2.4 below. In Table 2.3, proportional distributions of the categories at a particular time are presented, and in Table 2.4, the percentage and rate of LULC change between 1986–2003, 2003–2020, and 1986–2020 are also presented. The decreased and increased percentage change and rate of change per year of the categories were indicated by negative and positive values in the proposed time interval.

As indicated in Table 2.3, the total landmass covered by the six main LULC classes of the study area was 91051 hectares (ha). Of these, grazing land and shrubland, respectively, accounted for 38.9% and 34% in 1986 and 33.9%, 30.9% in 2003, and

30.2% and 28.1% in 2020 in area coverage. Farmland, forest areas, water bodies, and built-up areas had an area coverage of 17.4%, 9%, 0.2%, and 0.5% in 1986; 22.5%, 10.7%, 0.2%, and 1.7% in 2003; and 32.6%, 5.5%, 0.2%, and 3.4% in 2020, respectively.

As the change presented in Table 2.4 indicates, the initial coverage of two dominant land use types, grazing land and shrubland, decreased by 13% and 8.9%, respectively, between 1986 and 2003. On the other hand, the initial coverage of farmland, forest land, and build-up areas showed an increase of 4709 ha, 1591 ha, and 1082 ha, respectively, while no more exaggerated water bodies altered over this time interval of 17 years. During the preceding periods (2003–2020), forest, grazing, and shrubland were reduced by 48.5%, 10.9%, and 9.2%, respectively, while build-up and agricultural land increased by 96.4% and 44.7%, respectively, at the expense of forest, grazing land, and shrubland. An insignificant change was observed in the water body in the study area during this second time interval too. The distribution of LULC change over the two-time intervals for 34 years indicated that grazing and shrublands showed continuous decline, whereas farmland and the built-up area have been in continuous increase. Extreme reductions in forest cover area were observed in the time interval from 2003 to 2020. A small fluctuation, but an insignificant change, has occurred in water body area coverage. The shrinkage of grazing and shrubland could be attributed to the conversion of grassland and the destruction of vegetation areas for farmland expansion. The evidence here is that the expansions of farmland over these periods were at the expense of other LULC classes. The result of the study conducted by Dinka and Ckaka (2019) in the Adei watershed, Central Highlands of Ethiopia; by Tefera and Sterk (2008) in Fincha'a Watershed, Western Ethiopia; and by Tolessa *et al*. (2017) in the Central Highlands of Ethiopia also indicated that the cultivated land was increased mainly at the expense of forest, shrub, and grazing lands. Significant expansion of cropland at the expense of other land use classes was also indicated in the study conducted in a northeastern wetland ecosystem of Bangladesh (Bhattacharjee *et al*., 2021). Such expansion due to the need for economic development to improve people's livelihoods has a negative impact on other LULC categories (Othow *et al*., 2017).

Table 2.3 Proportion of land use land cover distribution in the study area

LULC type	**Area in ha and percentage**					
	1986		2003		2020	
	Ha	%	Ha	%	ha	%
F	8170.9	9	9761.8	10.7	5026.3	5.5
Shl	30917.8	34	28164	30.9	25586.5	28.1
Fl	15817.4	17.4	20526	22.5	29698.1	32.6
Gl	35446.9	38.9	30829	33.9	27454.4	30.2
Wb	214.3	0.2	205.5	0.2	211.6	0.2
Bu	483.7	0.5	1565.4	1.7	3074.1	3.4
Total	91051	100	91051	100	91051	100

Forest, shrub land, farmland, grazing land, water body, and built-up areas are respectively indicated by F, Shl, Fl, Gl, Wb, and Bu

2.3.3. Rate and net of land use land cover change in the study area

The study catchment experienced different LULC dynamics over a series of time intervals over 34 years (1986–2020). Between 1986 and 2003, farmland increased with an annual rate change of 277 ha/year, and nearly two fold increase in the annual rate of change (+539.5 ha/year) occurred in the consecutive years between 2003 and 2020 (Table 2.4). The continuous positive change brought a net gain of 27762 ha of farmland within 34 years. The expansion of this land use category was mainly due to the loss of shrubland, grazing land, and forest-covered areas. This is directly related to the food demand of the ever-increasing population growth at the local and global levels. Increased farmland, mainly from forest, shrub, and grazing lands (Godebo *et al*., 2018) and shrub and grazing lands (Hassen and Assen, 2018), was reported in the Bilate Alaba sub-watershed, southern Ethiopia, and in the Gelda catchment, Lake Tana watershed, Ethiopia. Such LULC change and its management are highly dependent on socioeconomic, environmental, political, and technological forces interactions at local and global levels (Oumer, 2009). The study conducted by Dinka and Chaka (2019) showed similar results, in which farmland expansion had the highest rate of change, followed by grazing land and shrubland. Farmers in the study area were found to commonly use the traditional small-scale farming system. They have used a substantial mixed farming system for the improvement of their livelihood. Quantitative evidence from focus group discussions (FGDs) and key informant interviews (KIIs) indicated that dramatic farmland expansion within the specified period was mainly related to population pressure, the need for economic development (poverty reduction), and poor land administration policy with missed management intervention.

Forest had the second highest annual increasing rate of change (+93.6 ha year^{-1}) from 1986–2003. However, this LULC category had shown an alarming reduction with a decreasing annual rate of change (-278.6 ha year^{-1}). Information obtained through FGD and KII indicated that this dramatic loss in forest cover could be mainly linked to farmland expansion, population dynamics, regime government change followed by political instability, illegal harvesting (selective cutting and fuel wood extraction), and unsustainable natural resource management practices in the study area. Of the widespread anthropogenic activities, farmland expansion due to population pressure had the most significant contribution to the reduction of vegetation cover in the study area. Teshager and Abeje (2021) stated that increasing population growth in Ethiopia caused overexploitation of natural resources such as forest clearing mainly for farming and settlement purposes.

In declining LULC dynamics, grazing land had the highest annual rate of change (-271.6 ha/year), followed by shrubland (-162 ha/year) between 1986 and 2003. As stated by FGDs and KIIs, the high reduction of grazing and shrubland areas occurred during the transitional period following the ending of the Derg regime (1991). It was a period of political instability until the new government was well established. As a result, a large mass of land use categories, especially communal grazing land and shrubland, were converted into privately owned farmlands. But in the following time interval (2003–2020), the forest had the highest decline rate of change (-278.6 ha/year), followed by grazing (-235.1 ha/year), and shrubland (-156.8 ha/year). Again, as stated by FGDs and

KIIs, the continuous conversion of one LULC category into the other was done without any protection, even though land use and management policy was changed by the newly established government. This is the reason why, contrary to the former time interval, the declining trend in forest areas was a widespread phenomenon in subsistence agriculture areas, characterized by an increase in the demand for cultivatable land and illegal logging for fuel wood, charcoal, timber, and other forest products. Tolessa *et al*. (2017) also reported the same reason for the declining trend of forest coverage in the study conducted in the central highlands of Ethiopia. The water body in the study area had a minimum annual rate of change throughout the time intervals. In decreasing net change, grazing land showed the highest (15985.2 ha), followed by shrubland (10662.2 ha) and forest (6289.5 ha) from 1986 to 2020 (Table 2.4).

Table 2.4 Percentage and rate of land use land cover change

LULC type	**Change**								
	1986-2003			**2003-2020**			**1986-2020**		
	ha	%	ha/year	Ha	%	ha/year	ha	%	ha/year
F	1591	19.5	93.6	-4735.5	-48.5	-278.6	-3145	-38.5	-92.5
Shl	-2754	-8.9	-162	-2577.2	-9.2	-151.6	-5331	-17.2	-156.8
Fl	4709	29.8	277	9172	44.7	539.5	13881	87.8	408.3
Gl	-4618	-13	-271.6	-3374.3	-10.9	-198.5	-7993	-22.5	-235.1
Wb	-8.8	-4.1	-0.5	6.1	3	0.4	-2.7	-1.3	-0.1
Bu	1082	223.7	63.6	1508.7	96.4	88.7	2590.4	535.5	76.2

F, forest; Shl, shrubland; Fl, farmland; Gl, grazing land; Wb, water body and Bu, built-up

2.3.4. LULC change inter-category transition matrix

The LULC change detection matrix computed for the two-time intervals of 1986–2003 and 2003–2020 transitions revealed that the study area was subjected to considerable land use changes (Table 2.5). Area gain, loss, and percentage change were indicated in the matrix too. During the study period 1986–2003, the highest gain occurred in shrubland, followed by farmland, grazing, and forest land. The buildup area, followed by the waterbody, revealed the lowest gain. The same is true for the former three land use classes, which showed the highest gain in the study duration of 2003–2020. Buildup area, forest cover area, and water body showed the lowest gains.

The highest loss belongs to shrub land, followed by grazing land, farmland, and forest area between 1986 and 2003. In contrast to this, the build-up area followed by the water body indicated the lowest loss. In the study period 2003–2020, shrubland, followed by grazing land, forest area, and farmland, attained the highest loss, while build-up area and water bodies showed the lowest loss.

Table 2.5 LULC change detection matrix between 1986-2003 and 2003-2020

To	2003	F	Shl	Fl	Gl	Wb	Bu	Total	Loss
From 1986	F	**4696.5**	2015.5	1104.6	274.1	3.9	76.2	8170.9	3474.3
	Shl	3637.1	**13772.1**	4655.5	8369	20.5	463.6	30917.8	17145.7
	Fl	210.2	4247.6	**8049.2**	3071.8	1.8	236.8	15817.4	7768.2
	Gl	1201.1	7954.8	6436.4	**19014.5**	90	750.1	35446.9	16432.4
	Wb	5.5	45.3	23.3	29.7	**87.6**	22.9	214.3	126.7
	Bu	13.9	116	268.1	66.8	1.6	**17.2**	483.7	466.5
	Total	9764.4	28151.3	20537.1	30825.9	205.5	1566.7	91051	
	Gain	5067.9	14379.2	12487.9	11811.4	117.9	1549.5		
	% Change	19.5	-8.9	29.8	-13	-4.1	223.9		
To	2020	F	Shl	Fl	Gl	Wb	Bu	Total	Loss
From 2003	F	**3603.9**	3967	1237.5	524.3	22.3	409.4	9764.4	6160.5
	Shl	1124.3	**12019**	8793.3	5001.7	75.6	1137.4	28151.3	16132.3
	Fl	177.1	840.6	**16891**	2043.8	0.4	584.2	20537.1	3646.1
	Gl	79.7	8620	2118.6	**19376.2**	13.4	618	30825.9	11449.7
	Wb	3	1.9	15.5	23.8	**72.6**	88.7	205.5	132.9
	Bu	38.3	138	642.1	484.6	27.3	**236.4**	1566.7	1330.3
	Total	5026.3	25586.5	29698	27454.4	211.6	3074.1	91050.9	
	Gain	1422.4	13567.5	12807	8078.2	139	2837.7		
	% Change	-48.5	-9.1	44.6	-10.9	3	96.2		

F, forest; Shl, shrubland; Fl, farmland; Gl, grazing land; Wb, water body and Bu, built up

2.3.5. Driving factors and impacts of land use land cover change in the district

Summarized information on FGDs and KIIs on drivers of LULC change in the catchment is indicated in Figure 2.3. The informants classified the driving forces into two categories: the indirect and ultimate causes of LULC change. The main indirect drivers mentioned by the informants were population growth, land use policy, political instability following the regime's governmental change, the need for institutional and technological development, economic status (poverty), and natural phenomena, whereas farmland expansion practice, infrastructure construction, woodlot expansion, overgrazing, illegal wood harvesting, resettlement, and fire were some of the main direct drives of LULC change.

The frequency of citations by informants indicated that population demography, followed by the economic status of the local community (poverty), had an outstanding contribution to LULC change in the study area (Figure 2.3). The 2007 population and housing census report of Ethiopia indicate that the total population demography of Midakeng District was 79,580, of which only 2.6% was urban (CSA, 2007). This population size was estimated to be 101,932 in 2017 by CSA (2013). On the other hand, the estimated population size sourced in March 2021 from the Midakeng District Health Office indicated that it was elevated to 106,438 in 2020. The majority of the population with high density but economically poor people was observed in the midland and highland agroecology of the catchment, where the local community livelihood was completely dependent on agriculture-related human activities. This steady population growth is tightly linked with farmland expansion, which was ranked first according to the frequency of citations given by informants (Figure 2.3). Continuous farmland expansion into various land use categories all over the world to meet the demand for food and fiber is the main driver of LULC change (Lambin *et al*., 2003). Through this predominant socio-economic activity, communal and private natural vegetation and grazing lands were highly reduced, especially at highland and midland agroecology, for supporting the livelihood of the ever-growing population. The reducing trend of grasslands, natural vegetation, and marginal land was mainly due to population pressure; institutional and policy factors were also reported in another part of Ethiopia by Hassen and Assen (2018). Even shifting cultivation systems were not common, and farmers frequently plowed farmlands in traditional cultivation systems for many years. Such practices exposed the land use category to soil erosion more than other land use classes (Obsa *et al*., 2021). In line with this, qualitative evidence from FGDs and KIs indicates that the very common problem in these agro-ecologies is a prominent decrease in land soil quality. On the other hand, the

Eucalyptus globulus plantation, which has been extensively expanded as a separate woodlot, especially in the highlands, was reported as a cause of soil quality reduction and LULC change as well. Lands under cultivation and those covered with *Eucalyptus globulus* were characterized by high acidity saturation, poor macronutrient content, and a loss of soil fertility compared to lands covered by natural vegetation and grasses (Nesru *et al*., 2023). The main indicator suggested for decreased land quality was farmer dependence on nitrogen fertilizer and more and more utilization of fertilizers year after year on the same farmland for the same crops. Such anthropogenic nitrogen fixation can increase greenhouse gas concentrations, produce other oxides of nitrogen, acidify soils, reduce soil nutrients such as calcium and potassium, which are essential for the long-term maintenance of soil fertility, and finally accelerate losses of biological diversity (Vitousek *et al*., 1997). Another anthropogenic activity connected with the livelihood of the community and reported as the second direct driver was illegal logging. In their day-to-day activities, people need more access to illegal harvestings such as charcoal and fuel wood extraction and selective cutting for timber to meet the growing demand for energy, construction, and income generation.

In contrast to the highland and midland, the lowland agroecological zone had open grazing land, shrubland, and forest cover areas. This area was known for having a minimum population density due to recurring natural disasters such as vector-borne and water-borne epidemics, as noted in the past more than three decades. Relatively high temperatures with low humidity, a far distance from health services, and a lack of other infrastructure were other reasons why people didn’t prefer living in this agroecology. The information assessed from the majority of informants reflected that the common driving factors here for LULC change were overgrazing and fire rather than any other ultimate drivers. A large mass of livestock has been moved to the lowland during cropping season for a couple of months (June–September) because of the scarcity of sufficient grazing land in highland and midland agroecology. The fire was the second common driver in this area, which was annually released, deliberately or unintentionally burning many hectares of grassland, wooded grassland, shrubland, and forests.

FGDs and KIIs reported that regime change followed by a lack of quick political stability were additional underlying causes of LULC transformation. When the Derg government came into power, the regime declared the "land for land tillers" policy and later on established a relocation program to transition rural inhabitants into village life before 1991. Land distribution to landless people was made simpler by the "land for land tillers" policy, which also established some regions as communal lands for community service. The regime focused on enhancing community livelihoods through infrastructural development and providing enough food for the populace. However, proper land use management and the sustainable use of natural resources received insufficient attention. As a result, uncontrolled conversion of other LULC classes, especially grazing and shrubland, into farmlands was made. Discussants also noted that following the downfall of the Derg regime and the coming to power of the Federal Democratic Republic of Ethiopian regime, there were periods of governmental transition and political instability that caused continuous expansion of farmlands at the expense of other LULC categories. The attention of people during this period was largely focused on privatizing lands left as communal lands during the Derg regime. Until now, a farmer in the rural community has made changes to his private LULC class without sustainable use measures or a proper land management system.

Quantitative evidence from discussants revealed that infrastructure and technology expansion have been recently increasing in the catchment and had a little share in the LULC change. Constructions of educational, medical, agricultural, and other government institutions at the kebele and district levels, as well as the building of concrete roads connecting the districts, kebeles, and kebeles to districts, as well as the establishment of small urban areas at various locations, were all specifically associated with an increase in the build-up area. In addition, some of these developments were considered to be amplifiers of socio-economic activities for LULC change.

As FGDs and KIIs stated, the main impacts encountered due to LULC change as a result of the drivers in the study area were decreased agricultural productivity (yield), reduction of habitat for living organisms, biodiversity loss, declined water and nutrient cycles, increased soil acidity, increased soil erosion and land degradation, increased CO_2 emission, and natural disasters such as flooding and drought. Some of these adverse impacts of LULC change were also reflected in the study reports of Dinka and Chaka (2019) and Dibaba *et al*. (2020). Rajan and Shibasaki (2000) and Lambin *et al*. (2003) reported that unprecedented and dramatic changes to ecosystems and environmental processes at global, regional, and local levels are the consequence of LULC change due to multiple drivers.

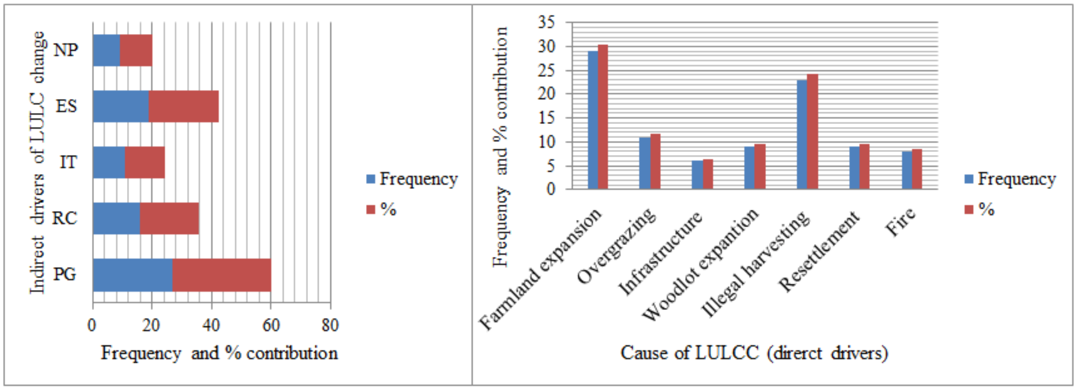


Figure 2.3 LULC change driving factors' frequency and percentage citation in the study area. PG indicates population growth; RC, regime change and political instability; IT, institution and technology development; ES, economic status; NP, natural phenomena

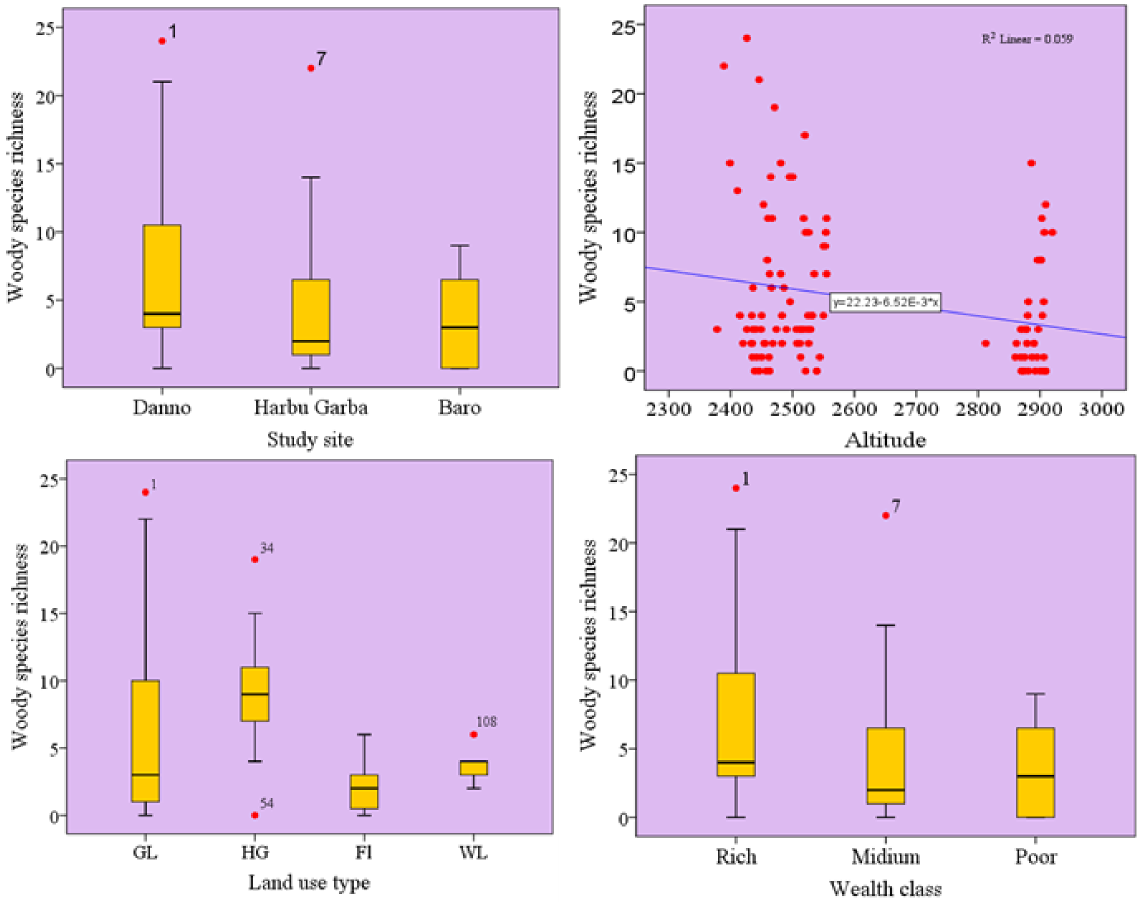
2.4. Conclusion

The three periods (1986, 2003, and 2020) of quantitative spatiotemporal evidence obtained from interpretations of primary and secondary data in the Midakeng District indicate that the study area has been experiencing different LULC changes since 1986 as a result of various driving factors. A significant change from one LULC category to another was detected between the six major LULC classes. Between 1986 and 2020, farmland and built-up areas showed an increasing trend, while grazing and shrubland revealed a decreasing trend. The forest coverage of the study site slightly increased during the first time interval between 1986 and 2003, while it declined at the highest rate in the second time interval between 2003 and 2020. An insignificant change was observed for the water body over the entire time interval.

The summarized quantitative information from FGDs and KIIs indicated that the main cause of LULC change was human-related activities such as increased population dynamics, poor economic status of the community, regime-governmental change followed by political instability, and the need for infrastructure and technology development. Farmland expansion for more yield production to balance the demand of ever-increasing population growth was the predominant direct driver of LULC change. The consequences of the change reflected by informants in the long term include decreased agricultural productivity, reduced soil quality, reduced habitat for living organisms, biodiversity loss, acidification of soils, increased soil erosion and land degradation, increased CO_2 gas immession, and natural disasters such as flooding and drought. Thus this study suggested the prominent and timely need for enough attention to balance farmland expansion against the proper use of natural resources and the sustainability of the ecosystem in the Midakagn district.

CHAPTER 3

Woody species diversity potential and population structure across the small-scale agroforestry farming system of the Midakegn District, West Shewa Zone, Ethiopia



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3. Woody species diversity potential and population structure across the small-scale agroforestry farming system of the Midakegn District, West Shewa Zone, Ethiopia

Abstract

Biodiversity in agroforestry systems contributes to diversified socio-economic and cultural dimensions and to managing biodiversity. Agroforestry is one of Ethiopia's highest conservation priorities to promote forest-based ecosystem services and environmental incentive programs that minimize deforestation. This study was carried out across intensively cultivated areas of Midakegn district to assess the woody species diversity potential of agroforestry systems managed by farmers. Out of 114 plots laid down on transect lines, 33 (30 m×30 m), 44 (50 m×50 m), and 9 (10 m×10m) plots belonged to grazing land, cropland, and woodlots, respectively, and 28 representative homegardens were systematically selected. For each sample of data encountered, the diameter and height of woody species were measured. Species richness, Shannon diversity, and evenness indices were used for diversity analysis and the mean values/land unit were calculated using a one-way ANOVA, and Tukey's pairwise comparison was done through SPSS statistics at ($P < 0.05$). A total of 77 species belonging to 68 genera and 45 families were recorded in all agroforestry systems. Species richness was significantly affected by study site, land use type, and wealth class, and evenness was significantly affected by land use type and wealth class. But species diversity was only affected by land use type. The highest mean density/hectare (8244.44 and 1263.17) and basal area/hectare (85.68 and 19.00) were recorded in the woodlot and rich homesteads, respectively, while the lowest mean density/hectare (9.82 and 48.16) and basal area/hectare (2.27 and 1.40) were computed for the cropland and poor homesteads, respectively ($P < 0.05$). The results confirmed that different agroforestry systems have great potential in conservation woody species, particularly native plant biodiversity. Hence, there is a need to promote and enhance the system through a development and management approach to maintain more biodiversity.

Keywords Agroforestry system; Cropland; Grazing land; Homegarden; Woodlot; Woody species

3.1. Introduction

Biodiversity in agricultural ecosystems contributes diversified socio-economic and cultural dimensions (Hainzelin, 2013). This creates a win-win, beneficial opportunity for smallholder farmers in Sub-Saharan Africa (Henry *et al*., 2009). Farmers plant, manage, and encourage plant growth within and around their homesteads, crop fields, and grazing lands to obtain a range of benefits, including foods, fodder, construction materials, household and farm equipment, fuel wood, and medicines, throughout their agroforestry practice (Giday *et al*., 2019). Beyond production of food, fiber, fuel, and income, its biodiversity performs ecosystem services (Altieri, 1999). In areas where smallholder subsistence-oriented agriculture land predominates, the intensification of integrated agro-forestry systems may create an alternative to increasing biodiversity (Henry *et al*., 2009). Globally, the purposeful retention and management of woody species on smallholder agroforestry is also very important for the rehabilitation of degraded lands (Giday *et al*., 2019).

Agroforestry has been defined as a sustainable land management system that intensifies the overall product of the land and combines the production of agricultural crops, tree crops, forest plants, and/or animals sequentially or simultaneously on the same pieces of land, enhanced by management practices that are well-suited to the cultural patterns of the local community (Bene *et al*., 1977; King and Chandler, 1978). Overall, agroforestry practices have been implemented on the agricultural landscape, which is the dominant landscape and economy sector for 85% of the population living in rural areas in Ethiopia (Bishaw, 2001). Various sorts of agroforestry have been created by the indigenous people while using and manipulating natural forests, which frequently resulted in the conversion of the forests into forest gardens or other kinds of agroforestry system (Wiersum, 2004). Multiple woody species are purposefully grown and managed in intimate association with both perennial and annual crops and/or livestock in the agroforestry systems (Dobo *et al*., 2016).

Depending on their kind, method of use, and management, the agro-ecosystem is mainly grasslands (meadows and pastures) and cultivated fields (including crop fields and homegardens) with their biodiversity (Jaskulski and Jaskulska, 2012). Likewise, the common traditional agroforestry practice in Ethiopia includes a variety of systems, such as homegardens, retaining scattered trees in crop fields, managing trees on grazing land, woodlots and tree plantations on farm boundaries, and coffee and tree shade (Abebe, 2005). These land units have been serving as areas where a diversity of plant species are conserved and play a great role in minimizing the impacts of local communities on the natural forest (Mengistu and Asfaw, 2016).

The country is believed to have had extensive natural vegetation cover and an agroforestry ecosystem, in which it hosts an estimated higher plant species between 6500 and 7000 (Egziabher, 1991; Asfaw and Tadesse, 2001). A more estimated report indicated that there are about 6027 higher plants, of which 10% are endemic species (Kelbessa and Demissew, 2014) and 1000 are woody species (Vivero *et al*., 2003), in the flora of the country. At the beginning of the 20th century, the 40% of vegetation coverage of the country declined to 16% in the 1950s and to less than 3% at the end of the century due to anthropogenic and natural disasters (Bishaw, 2001; Lemenih and Teketay, 2004), and because of forest management, forest conservation, and forest restoration done in the country, the forest coverage is currently increased to an estimated 11.4-15.5% (FAO, 2015; MEFCC, 2017).

The biological and genetic diversity of the country has been seriously threatened by a number of factors. The rapid population growth rate, along with the high deforestation rate, overgrazing, movement of political centers, and exploitation of forests for fuel wood and construction materials without replanting, still threatens the forest area of the country and consequently causes a loss of biodiversity (Senbeta and Denich, 2006). Similarly, the agro-ecosystems of the country have been exposed to a strong anthropogenic impact due to intensification through the adoption of improved seeds, inorganic fertilizers, and pesticides (Haile *et al*., 2017).

Therefore, conservation of agricultural biodiversity must forever remain one of Ethiopia's highest conservation priorities to promote forest-based ecosystem services and environmental incentive programs that prevent deforestation and forest degradation (Tadesse *et al*., 2014). In this case, the existence of various small-scale agroforestry systems demonstrates the creative role of local communities in conserving forest resources (Wiersum, 2004). Ecological, conservational, and livelihood functional groups are the three important serves in the system (Huang *et al*., 2002). It supports native plant and animal species as well as increasing connectivity among populations, communities, and ecological processes in fragmented landscapes, thus aiding in biodiversity conservation (Harvey and Haber, 1998). However, the biodiversity conservation role of the system receives little scientific attention when compared with that of natural forest systems (Boffa *et al.*, 2008).

Plant diversity in agroforestry has played a role in the provision of forest products and services for subsistence farmers and the conservation of genetic resources (Giday *et al.*, 2019). They also provide ecological services such as soil and water conservation, nutrient recycling, and reducing environmental deterioration (Mengistu and Asfaw, 2016). Thus, an increased respect for conservation should extend beyond protected areas and take place at the scale of agricultural landscapes to maintain biodiversity, ecological processes, and the production of goods and services (Boffa *et al*., 2008), and more studies are needed across diverse ecological and socioeconomic settings to comprehensively understand the role of agroforestry practices in woody plant species diversity preservation and its determinant factors (Haile *et al.*, 2017).

In Ethiopia, only a few agro-forestry-related empirical studies were done in particular in the northern, southern, and southwestern regions of Ethiopia (e.g., Tefera *et al*., 2014; Molla and Kewessa, 2015; Giday *et al*., 2019; Wari *et al*., 2019). Of these, the majority are emphasized in the coffee agroforestry practice area of the country. Enough attention has not yet been given to assess the woody species diversity potential and richness in different agricultural land uses in the country, which is definitely important for future agroforestry management and conservation practices (Duguma *et al*., 2009; Duguma and Hager, 2010).

Therefore, this study was conducted in Midakegn district in the area characterized by an extensive small-scale farming system that highly caused fragmented agricultural landscapes and degradation due to large human settlements in the central plate of Shewa, and we assessed woody species diversity potential in different agroforestry land uses managed by farmers. This would permit the identification of woody species intensification and conservation areas within the complexity of the smallholder farmers land use systems and to indicate how land use and management practice could matter the woody species diversity in the study area. To this end, our specific objective was to assess (i) the woody species diversity potential of different smallholder farmers' agricultural land uses and (ii) the similarity or variation in woody species diversity and richness among household location (altitudinal difference), land use type, and wealth class.

3.2. Material and Methods

3.2.1. Description of the study area

The study was conducted at Midakegn District, which is located between 09^{o} 02′ 57″ to 09^{o} 23′ 45″ North latitude 037 ^{o} 23′36″ to 037^{o}45′ 54″ East longitude in the West Shewa Zone, Oromia Regional State, central plateau of Ethiopia (Figure 3.1). Balemi (the administrative town of the district) is located about 221 km west of Addis Ababa and 107km northwest of Ambo (the administrative town of the West Shewa Zone). The Midakegn District Agricultural Office (MDAO) 2020 annual report (unpublished) indicates that the total area of the district is 91,051 hectares (ha) and has an elevation range of 1290–3058 m a.s.l. Three known agroclimatic zones are associated with the district. The highland, midland, and lowland agroecological zones cover 12.5%, 50%, and 37.5% of the land mass of the district, respectively (MDAO, 2020).

The area is characterized by unimodal rainfall and humid air currents coming from the Atlantic Ocean. The mean annual rainfall of the study area was 1004 mm and it receives the maximum rainfall distribution from Jun to Aguest and the minimum from Decenber to February. The highest mean annual temperature was 24.6 °C recorded in December, and the lowest mean annual temperature was 8.7 °C recorded in February (Guzo *et al*., 2023). The topography of the district is characterized by different landforms and features: flat plains, undulating plains, mountains, and rocky and valley areas. The dominant soil types found in the district are acidic soil, red soil, and sandy soil in its highland, midland, and lowland agroecological zones, respectively (MDAO, 2020). The total population of the district is 106,438 (male 52,148 (49%) and female 54,290 (51%)) (MDAO, 2020).

According to MDAO (2020), the major land use types in the district are farmland/cropland, vegetation cover area, and grazing land. The characteristic agro-ecological practice in the study area is a subsistence mixed agriculture (mixed crop-livestock) farming system. The major crops growing in the study area are wheat, barley, teff, maize, sorghum, niger seed, and linseed. The native woody vegetation of the study area includes the most common tree species: *Afrocarpus falcatus* (Thunb.) C.N.Page, *Juniperus procera* Hochst. ex Endl., *Olea europaea subsp. cuspidata* L., *Vachellia abyssinica* (Hochst. ex Benth.) Kyal. & Boatwr, *Ficus sur* Forssk. *Syzygium guineense* (Willd.) DC., *Croton macrostachyus Hochst. ex* Deilel., and *Ficus vasta* Forssk, which were scattered in different agroecologies, and the *Eucalyptus globulus* Labill, mainly planted as a separate woodlot, were the common vegetation of the district.

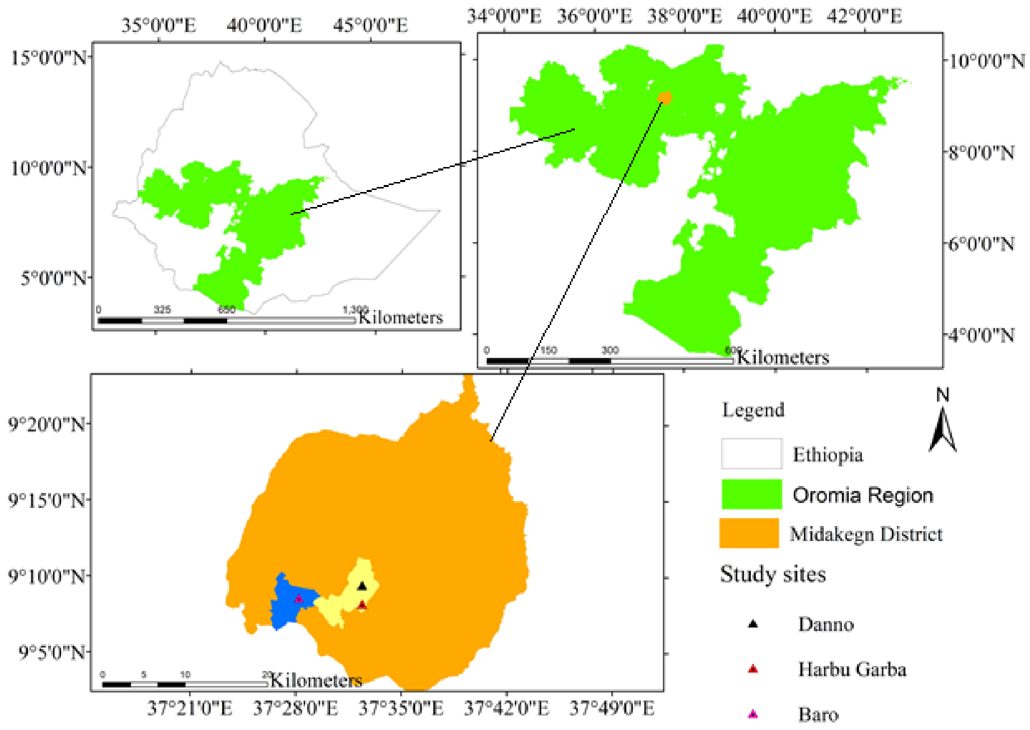


Figure 3.1 Map of Ethiopia showing Oromia region and the district's study sites

3.2.2. Land use types in the agroforestry land use system

After a reconnaissance survey, two agroecological areas (highland and midland) in which extensive agricultural activities take place were considered. Based on agroforestry land visited, the land use (LU) types were categorized according to the dominant land use systems by residents, and they were grazing lands (GL), homegardens (HG), croplands (CL), and woodlots (WL). This was to assess the impact of study sites, LU type, and wealth class on the diversity of woody plant species in the agroforestry system of the study area.

As the study area context, GL was the land plot used for pastures and fallows, mainly including remnant patchy natural vegetation, open wet grassland, open grassland with scattered trees, and riverine vegetation areas that served as grazing and browsing. A land plot around the homestead, which was delineated by a living fence around the homestead and is commonly used for the cultivation of vegetables, maize, trees, shrubs, and sometimes pulses and other cereal crops, was considered HG. Kumar and Nair (2004) defined this agroforestry area as the space that is enclosed around the homestead and has intimate, multi-story arrangements of various trees, vegetables, and crops, occasionally in association with domestic animals. Globally, it is described as economically efficient, biologically sustainable, and ecologically sound in areas (Fernandes and Nair, 1986) and mostly fertilized by organic nutrient resources in the form of composted animal dung. A plot of land commonly used in the subsistent-oriented cultivation of different annual crops, mainly cereal crops such as teff, wheat, and barley, and oil crops such as niger seeds and lin seeds, as well as a variety of pulses, was considered CL, whereas those covered with planted trees, mainly *E. globulus* and *Hesperocyparis lusitanica* (Mill.) Bartel were categorized as woodlots.

3.2.3. Key informant selection

For this study, key informants (KIs) are defined as knowledgeable persons who have more ecological knowledge and local conditions. Thus, purposive sampling technique was used to choose a total of 15 KIs (5 from each community) in order to gather preliminary data in accordance with Martin (1995), and they also participated in the land plot owner citation while data collection, identification of woody plant species, provision of information about the agroforestry system, and household wealth class categorization.

3.2.4 Woody plant species data collection and household selection

A total of three villages—one from the highlands and two from the midlands—were randomly selected from highly cultivated areas of the district. A total of five to six parallel transect lines at a distance of 200 m were systematically laid down on the agricultural landscape of the villagers by considering their land settlement, position, and boundaries. Systematically, different numbers of plots for different LU types were laid down along the transect line. We used the distance between two consecutive plots of 150 m for GL and CL and 30 m for the woodlot. According to Senbeta *et al.* (2002), a sample plot size of 30 m x 30 m for GL, 50 m x 50 m for CL, and 10 m x 10 m for WL was used for sample collection, and the owner of each land plot was recorded on the spot with the help of key informants selected at each study site. This was also used as a method for representative household selection to collect woody species data in their homesteads. Based on the complete lists of households residing in each village which was given by the Kebele administrative office, smallholder farmers who had only homegarden were included by simple random techniques. Accordingly, from a total of 91 residents, woody species data was inventoried from 28 HG through the complete enumeration method.

Finally, smallholder farmers included in the sample collection were classified into three wealth classes (rich, medium, and poor), and this was applied to investigate the impact of the economic status of the villagers on woody species richness, diversity, and structures. Classification was done with the help of the KIs, development agents, and administrative offices by considering local criteria such as housing status, land holding size, and livestock holdings. This is because housing type and the number of cattle are the determinants of the economic status of the people (Kindt *et al*., 2004).

In each sample plot, parameters such as species richness, abundance (individuals), and tree diameter at breast height (cm) were collected. All individual species with a diameter at breast height (DBH) ≥ 2.5 cm and a height ≥ 1.5 m were counted, and their respective DBH was measured by using a caliper and diameter tape. Individual species that were branched, along with the circumference, were measured separately, and the average was taken. Accordingly, all encountered species at each study site were collected, identified, and recorded by their vernacular names with the help of key informants. By using the field guide book prepared by Tesemma and Tengnäs (2007), initial specimen identification was made and confirmed at the National Herbarium (ETH) with the help of specialists from the National Herbarium (ETH), AAU, by comparison with real specimens, illustrations, and taxonomic keys, and by using published volumes of Flora of Ethiopia and Eritrea.

3.2.5. Diversity indices analysis

The recorded woody species were estimated through the species richness, Shannon diversity index (*H'*), and Shannon equitability or evenness index (E) by following (Krebs, 1999; Maihe and Kr'auchi, 2003), and the existence of statistical differences among study sites, LU types, and wealth class was compared using one-way ANOVA in the IBM SPSS statics package version 24 and when ANOVA revealed a significant variation, mean separation was made using Tukey's pairwise comparisons in the same statistical package. Species richness reveals the total number of species in the sample plot or community. Because it takes into account both abundance and species richness, Shannon diversity is the most widely used indicator when comparing diversity among sample plots and community (Maihe and Kr'auchi, 2003). Therefore, it was computed as follows:

$$\mathrm{H}' = -\sum_{i=1}^{s} \mathrm{pilnpi}$$

Where H' = the Shannon diversity index, s = the number of species, pi = the proportion of individuals of the i^{th} species expressed as a proportion of total cover in the sample, and ln = the natural logarithm.

Shannon equitability or evenness index (E) was also calculated to test species evenness, and its value ranges between 0 and 1 (Krebs, 1999). Value 1 indicates maximum equitability (evenness), in which all species in the community are equally abundant (completely even in distribution). Species evenness was considered because it's less sensitive to sample (plot) size and it was computed as follow:

$E = \mathrm{H}'/\mathrm{H}'\max = \mathrm{H}'/\ln S$

Where, E = Shannon equitability or evenness index, H' = Shannon diversity index, $\mathrm{H}'\max$ = the maximum level of diversity possible within a given population; $\mathrm{H}'\max = \ln S$, and S = Total number of species, ln = the natural logarithm of the species richness.

3.2.6. Woody species population structure analysis

Qualitative and quantitative techniques were used for analyzing the recorded data. The population structure of all individual woody species recorded in the land use system was grouped into DBH, height, and frequency distribution classes, as well as density, and the basal area of all species was computed as follows (Mueller-Dombois and Ellenberg, 1974). The program in R statistical package version 6.3.1 was used to draw the bar charts of vegetation structure for the distribution class in the LU types and their mean comparison through one-way ANOVA in the SPSS statics package. Similarly, the density and basal area per hectare (ha) among study sites, LU types, and wealth class was done by using similar statics package.

Frequency is the chance or probability of finding a species in a given sample area or plot (Mata *et al*., 2011). Its value reflects the pattern of population distribution, and it was computed as the proportion of sample plots within which a species was found. Flowers

$$\text{Frequency (F)} = \frac{\text{Frequency of a species}}{\text{Total mumber of sample plot}}$$

According to Kent and Coker (1992), the density of woody species was estimated by adding up all of the stems from all of the sample plots and converting to hectares as follow:

$$\text{Density(D)} = \frac{\text{Number of above ground stems of a species counted}}{\text{Sample area in hectare}}$$

Basal area is the cross-section area of a tree at breast height, and it was computed based on the value of diameter at breast height (DBH), which is in m^2 ha^{-1} as follow:

$$\text{BA} = \pi(\text{DBH}^2)/4$$

Where BA = basal area, $\pi = 3.14$, and DBH = diameter of tree at breast height

The ecological importance of each species in a given LU type was computed by using parameters such as relative frequency, relative abundance, relative dominance, and the importance value index (IVI), which is a composite index that depends on the relative measures of species frequency, dominance, and abundance (Kent and Coker, 1992).

Larger value of the index shows the dominance of the species over individuals of species with relatively lower important value index. The larger value also reveals the plant species that the rural community depends on the most. Thus, IVI was computed as follows:

IVI (%) = Relative frequency (%) + Relative dominance (%) + Relative abundance (%)

The frequency of a species as a percentage of all species' frequencies is known as relative frequency, and relative dominance is the percentage share of the basal area of a given species out of the total measured stem basal areas for all species, whereas relative abundance is the percentage of the abundance of each species out of the total stem numbers for all species.

$$\text{Relative frequency } (\%) = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \text{ x } 100$$

$$\text{Relative dominance } (\%) = \frac{\text{Basal area of a species}}{\text{Total basal area of all species}} \text{ x } 100$$

$$\text{Relative abandance } (\%) = \frac{\text{Number of individuals of a species}}{\text{Total number of all species}} \text{ x } 100$$

3.3. Results

3.3.1. Woody species floristic composition

A total of 77 woody species including 68 genera and 45 families were recorded from the four small-scale agroforestry land uses visited. Out of the total recorded species, 56 were from GL, while 43, 22, and 17 species were recorded from HG, CL, and WL, respectively. The proportion of individual woody plant species recorded at HG, WL, GL, and CL was 1308, 984, 504, and 107, respectively. Growth form analysis indicates that 51.95% of the recorded woody species were shrubs, while 45.45% and 2.6% were trees and climbers, respectively. Native woody species accounted for 87%, whereas 13% were exotic woody species. A comparison of all recorded families indicates that, *Fabaceae* and *Rosaceae* contributed the highest number of woody species (each represented by 7 species), and they were followed by Asteraceae, Celasteraceae, Euphorbiaceae, Myrsinaceae, Myrtaceae, and Rutaceae, which were represented by three species each (Appendex 2). The remaining 8 families (8.9%) and 29 families (64.4%) each contributed two and one woody species, respectively.

3.3.2. Woody species richness, diversity and evenness index

The statistical variation of species richness, diversity, and evenness was computed for the study area, LU type, and wealth parameters as indicated in Table 3.1. The species richness of woody species showed a significant difference among study sites, land use types, and wealth classes at ($P < 0.05$). The Danno study site had the highest number (7.06 ± 1.14) of woody species richness, followed by Harbu Garba (5.11 ± 0.72) and Baro (3.40 ± 0.61) study sites (Table 3.1). This number of species per land plot of households decreased with an increased attitudinal gradient in the study sites (Figure 3.5B). When considering the LU types, HG had the highest number (9.48 ± 3.54) of woody species per land plot, followed by GL, WL, and CL (Table 3.1).

The Shannon diversity index of woody species was significantly affected by LU type but not by study sites or the economic status of the smallholder farmers, whereas woody species evenness was significantly affected by LU type and wealth class but not affected by study sites at ($P < 0.05$) (Table 3.1). The highest diversity mean value was recorded in HG ($H' = 1.80$), while the poorest was recorded in WL ($H' = 0.30$), and the highest evenness index was recorded for CL ($E = 0.96$) while the lowest was recorded in WL ($E = 0.29$).

Table 3.1 Mean (± SE) diversity indices and richness of woody species across study sites, land use type, and wealth class of the study area

Parameters			
Study sites	**Species richness**	**Shannon diversity**	**Species evenness**
Danno	7.06 ± 1.14^{a}	1.38 ± 0.16^{a}	0.85 ± 0.05^{a}
Harbu Garba	5.11 ± 0.72^{ab}	1.21 ± 0.12^{a}	0.84 ± 0.04^{a}
Baro	3.40 ± 0.61^{b}	0.93 ± 0.12^{a}	0.79 ± 0.05^{a}
Overall	5.12 ± 0.50	1.18 ± 0.08	0.83 ± 0.03
Land use type	**Species richness**	**Shannon diversity**	**Species evenness**
GL	6.42 ± 1.27^{a}	1.30 ± 0.20^{a}	0.90 ± 0.02^{ab}
HG	9.14 ± 0.74^{a}	1.80 ± 0.07^{b}	0.82 ± 0.01^{a}
CL	1.86 ± 0.21^{b}	0.80 ± 0.07^{c}	0.96 ± 0.02^{b}
WL	3.78 ± 0.36^{b}	0.30 ± 0.05^{c}	0.27 ± 0.08^{c}
Overall	5.12 ± 0.50	1.18 ± 0.08	0.83 ± 0.03
Wealth class	**Species richness**	**Shannon diversity**	**Species evenness**
Rich	6.44 ± 0.80^{a}	1.23 ± 0.12^{a}	0.78 ± 0.04^{a}
Medium	4.23 ± 0.87^{ab}	1.11 ± 0.15^{a}	0.92 ± 0.02^{b}
Poor	3.42 ± 0.64^{b}	1.14 ± 0.15^{a}	0.82 ± 0.03^{a}
Overall	5.12 ± 0.50	1.18 ± 0.08	0.83 ± 0.03

Within the same column for the same parameters, values with different letters show significant differences at $P < 0.05$, whereas similar letters indicate a non-significant difference.

3.3.3. Important value index (IVI)

The IVI of woody species recorded in the various LU types was calculated to evaluate the relative ecological importance of each species, and the thirteen most important of them are presented in Appendex 3. Out of the recorded species, *A. falcatus*, followed by *J. procera*, and *O. europaea* subsp. *cuspidata*, had the highest IVI (45.1%, 35.1%, and

19.4%) in the GL, respectively. *E. globulus* (39.7%), followed by *H. lusitanica* (26.8%) in HG, *O. europaea* subsp. *cuspidata* (54.9%), *J. procera* (32.9%), and *A. falcatus* (31.0%) in *CL*, and *E. globulus* (184.3%) in the woodlot, were recorded with the highest IVI. The IVI for the whole species was indicated in Appendex 2.

3.3.4. Stand structure

Frequency was the ratio of the number of plots on which a particular species appeared to the total number of plots of land used in the research region. The computed percentage frequency of woody species in each LU type was categorized into four frequency classes: A (0–25%), B (25.1–50%), C (50.1–75%), and D (75.1–100%), and the number of species in each category were presented as indicated in Figure 3.2. There were also 15.2, 4, and 25 percentage frequency of land plots with no species recorded in the GL, HG, and CL, respectively.

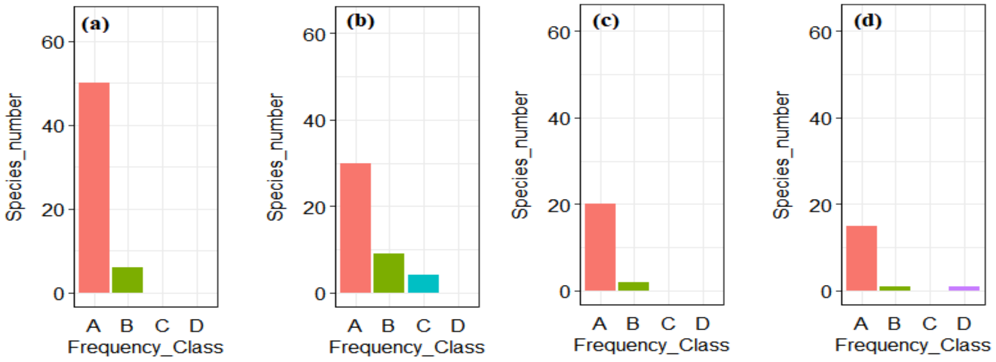


Figure 3.2 Show woody species frequency class of grazing land (a); homegarden (b); cropland (c); and woodlot (d)

The overall DBH class distribution was classified into six categories and converted into percentage classes. These are: 1 (2.5–10 cm), 2 (10.1–20 cm), 3 (20.1–30 cm), 4 (30.1–50 cm), 5 (50.1–60 cm), and 6 (> 60 cm), and the percentage class distribution of all individual trees showed an inverted J-shape in all LU except in CL (Figure 3.3). Out of all, the lowest class distribution in GL, HG, and WL had the highest number of woody species of 61.4%, 65%, and 72.1%, respectively, with a gradual reduction toward high

DBH classes. In the CL, the highest DBH class consisted of 24.1% of woody species, followed by the lowest DBH class, which had 22.2% of the species. The overall recorded heights were grouped into three distribution classes, including the lower (1.5–5 m), medium (5.01–10 m), and upper (≥ 10 m) height classes. This general pattern indicated that the lower height class across all LU types consisted of a higher frequency percentage of woody species (Figure 3.4). The overall mean difference in DBH and height was significantly different at ($P < 0.05$) (Table 3.2)

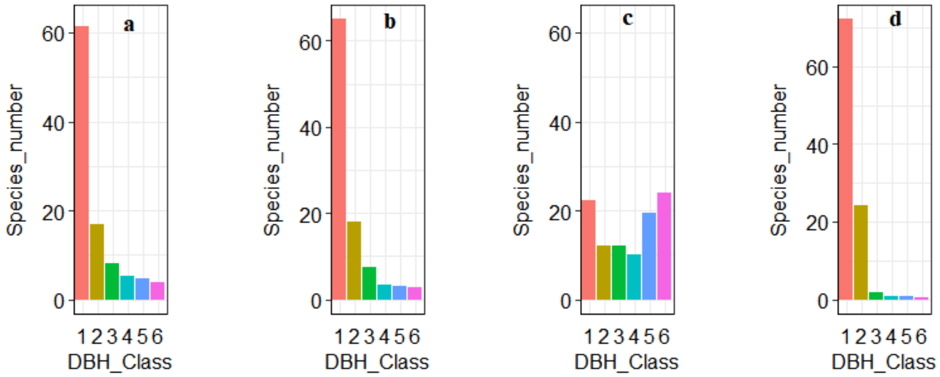


Figure 3.3 DBH percentage class distributions of woody species in grazing land (a), homegarden (b), cropland (c), and woodlot (d)

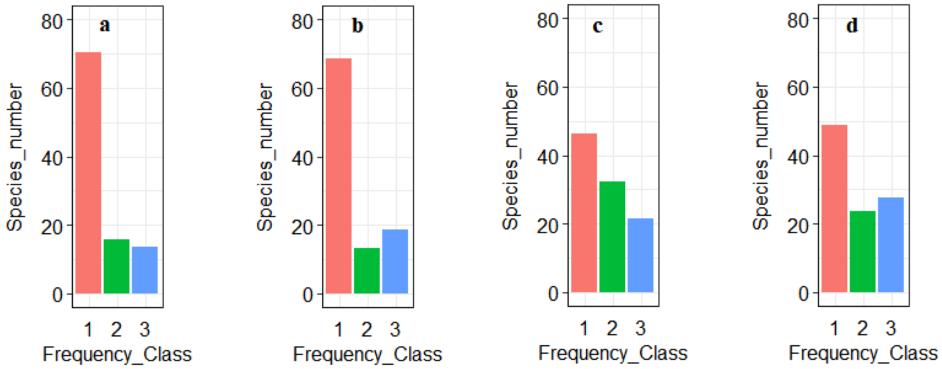


Figure 3.4 The height percentage class distribution of woody species in grazing land (a), homegarden (b), cropland (c), and woodlot (d) of the study area

Table 3.2 Mean DBH and height (± SE) statistical correlation among land use type

Parameters		
Land use type	**DBH**	**Height**
GL	15.00 ± 0.95^{a}	5.22 ± 0.2^{a}
HG	12.63 ± 0.49^{a}	5.66 ± 0.13^{a}
CL	41.77 ± 3.39^{b}	7.31 ± 0.45^{b}
WL	8.27 ± 0.31^{c}	7.23 ± 0.16^{b}
Overall	13.03 ± 0.36	6.07 ± 0.09

No common letters in the vertically ordered mean value for the same parameters reveal a significant difference at $P < 0.05$.

The tested statistical variation of BA and density per ha of woody species along the study areas, LU types, and wealth classes at ($P < 0.05$) is indicated in Table 3.3. BA and density per ha of woody species were significantly affected by LU types and wealth classes. However, an insignificant difference was observed among study sites. The highest mean BA/ha (85.7) and woody steam/ha (8244.4) were recorded in the WL, while the lowest BA/ha (2.3) and density/ha (9.8) were recorded in the CL.

Table 3.3 Mean (± SE) comparison of basal area and density per hectare of land plot

Study area	**Basal area/ha**	**Density/ha**
Danno	12.80 ± 3.78^{a}	754.95 ± 355.76^{a}
Harbu Garba	7.67 ± 2.54^{a}	623.49 ± 300.87^{a}
Baro	12.78 ± 6.27^{a}	801.84 ± 428.77^{a}
Overall	11.08 ± 2.63	727.58 ± 211.13
Land use type	**Basal area/ha**	**Density/ha**
GL	9.06 ± 1.93^{a}	169.03 ± 38.60^{a}
HG	3.34 ± 0.70^{a}	97.66 ± 6.06^{a}
CL	2.27 ± 0.41^{a}	9.82 ± 1.35^{a}
WL	85.68 ± 20.0^{b}	8244.44 ± 527.08^{b}
Overall	11.08 ± 2.63	727.58 ± 211.13
Wealth class	**Basal area/ha**	**Density/ha**
Rich	19.00 ± 5.06^{a}	1263.17 ± 382.26^{a}
Midium	5.30 ± 2.27^{ab}	351.82 ± 301.81^{ab}
Poor	1.40 ± 0.39^{b}	48.16 ± 8.83^{b}
Overall	11.08 ± 2.63	727.58 ± 211.13

No common letters in the column mean value of the same parameters reveal a significant difference at $P < 0.05$, whereas similar letters show a non-significant difference.

3.4. **Discussion**

3.4.1. **Wood species composition and diversity**

The small-scale agroforestry system of the study sites encompasses remarkable woody species diversities, of which a higher proportion were naturally grown species (n = 67). Out of those, 5 species (6.5%), *Erythrina brucei* Schweinf, *Lippia adoensis* Hochst. ex Walp., and *Solanecio gigas* (Vatke.) C.Jeffery. as least concerned, *Rhus glutinosa* (Hochst. ex A.Rich.) Mofett as vulnerable, and *Maytenus addat* Loes. as locally threatened, were indicated in the red list of endemic trees and shrubs in the country

(Vivero *et al*., 2003). This remarkable total record had a greater number of woody species than the previous related study results documented in other parts of Ethiopia. For instance, a total of 70, 27, 55, 55, 48, 39, and 60 woody species were identified from agricultural landscapes in the study conducted by Tolera *et al*. (2008), Duguma and Hager (2010), Tefera *et al*. (2014), Molla and Kewessa (2015), Teshome *et al*. (2019), Giday *et al*. (2019), and Wari *et al*. (2019), respectively. However, a larger number of woody species were recorded by Haile *et al*. (2017) (101 species) in smallholder agricultural land units in central Ethiopia and by Tadesse *et al*. (2014) (155 species) in agroforestry forest mosaic landscapes in southern and southwestern Ethiopia, respectively.

It was observed that woody species richness was significantly affected by study sites, LU types, and wealth classes (Figure 3.5A, C, and D). The highest mean richness was recorded in the Danno (7.06) study site, followed by Harbu Garba (5.11) study site, while the lowest was recorded in Baro study site. This indicates a decreasing trend with an elevating altitudinal gradation in the study area. This is because the former of the two study sites belong to the midland agro-ecological area, which is favorable for plant growth when compared to the upper (Baro) study site, which belong to the highland agro-ecology of the study area (Figure 3.5B). On the other hand, the species richness variation observed among study sites was due to the presence of some remnant patchy forests and marginal lands with scattered woody species that were used for grazing purposes in the Danno and Harbu Garba. Such land units were not common in the Baro, and instead the open and wet grassland was used as grazing land. In agreement with our findings, Negash *et al*. (2012) and Yirdaw *et al*. (2015) reported a decreasing trend of woody species number with increasing altitudinal changes in the study conducted in the multi-strata agroforestry system, Southeastern Ethiopia, and in the Afromontane forest, Bale Mountains, Ethiopia, respectively. Contrary to this, an increasing trend of tree and shrub species richness with increasing altitudinal variation was reported by Haile *et al*. (2017). Such circumstances could be influenced by other variables, such as topography, slop, soil conditions, land use and management systems, and other extra factors (Negash *et al*., 2012).

Concerning LU types, on the overall small-scale agricultural landscape of the study area, 72.7% of the total recorded species were in the GL. The number was relatively higher as compared with the numbers recorded in Hg (55.8%), CL (28.6%), and WL (22.1%). However, the highest mean of species richness was recorded in HG, while the poorest was recorded in WL and CL. Related studies by Duguma and Hager (2010), Tefera *et al*. (2014), Haile *et al*. (2017), Tolera *et al*. (2008), and Henry *et al*. (2009) showed a high correlation of woody species richness with LU units. Relatively, the lower species richness was recorded in the cropland and woodlot. The low species richness in the cropland indicated that the understory of the natural vegetation in the land serving for crop cultivation was being cleared during the conversion of the natural forest to crop fields (Lemenih, 2004; Lemenih and Teketay, 2006; Tolera *et al*., 2008), and the scattered woody species were retained in the field following the consequence of agricultural land expansion (Lemenih, 2004). The poorest species richness in the WL might be due to the inter-computational consequence that causes the removal of native plant species and leads to the dominance of a few exotic species (e.g., *E. globulus*). There was also a significant difference in species richness among the three wealth-class categories. It revealed that households with more agricultural land plots recorded higher species richness. This finding was in agreement with the study results of Haile *et al*. (2017) and Giday *et al*. (2019). Duguma and Hager (2010) also quoted an increased woody species richness with increasing household economic status, but with no significant difference. This could be due to the land size and units managed by the households, and the number of tree species is directly proportional to the household's farm size (Agidie *et al*., 2013).

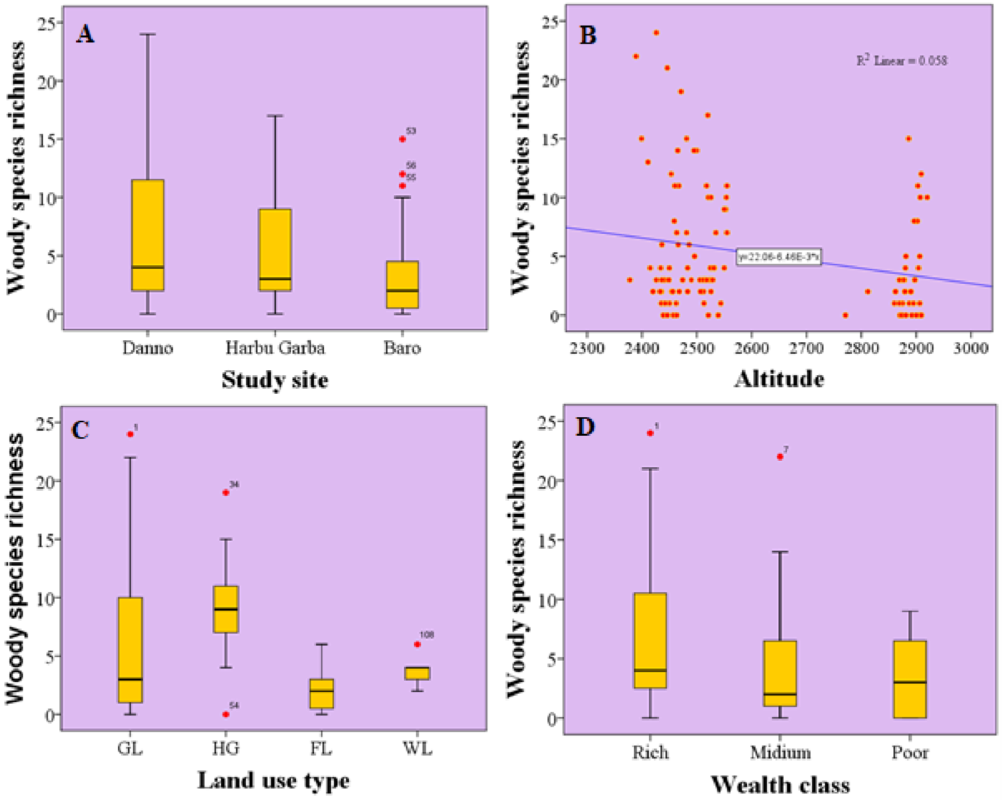


Figure 3.5 Species richness in relation to (A) study sites, (B) attitudinal gradient, (C) land use type, and (D) wealth classes of the selected households

The significantly affected diversity indices by LU types revealed that the highest Shannon diversity mean value belonged to HG and the lowest was recorded for WL, while the highest (*E = 0.96*) and the lowest (*E = 0.29*) evenness were recorded for cropland and woodlot, respectively. The highest diversity index indicated that the homegarden hosted a relatively higher abundance of different woody species per land plot than in the other LU units. In addition to woody species growing and retaining in the homegarden, the life fence, which was considered part of the homestead, was where the high indigenous woody species conservation and more growth of exotic species were observed. On the other hand, the lowest diversity and evenness index in the WL revealed the dominance of a few species, mainly *E. globulus*, in the LU type. The highest mean evenness value (0.96) indicated that more homogeneous species were found in the cropland than in other land use systems. This result was consistent with the research reports of Haile *et al*. (2017) and Mengistu and Asfaw (2016), with a similar $P < 0.05$, showing variation in the woody species diversity among various LU types. But our study result was higher than that of the mean diversity value recorded by Haile *et al*. (2017) and Mengistu and Asfaw (2016) in other parts of Ethiopia. Contrary to this finding, the highest woody species diversity was recorded in the GL than in other LU types in the study conducted in agroforestry practice around Jimma town, Ethiopia (Wari *et al*., 2019). A comparable mean value was recorded in the study conducted on agroforestry systems and plant species diversity in southwest Ethiopia (Seid and Kebebew, 2022).

Eventhough there was no significant difference, a higher woody species mean diversity and evenness was recorded in Danno ($H' = 1.38$, $E = 0.85$), and the lowest was recorded in the Baro study site ($H' = 0.93$, $E = 0.79$), while the highest diversity with the lowest evenness was recorded in the land managed by rich households (Table 3.1). The highest diversity value revealed the most abundance of different woody species, while the lowest diversity value revealed that a few species were more abundant in the sample (Molla and Kewessa, 2015). When compared with the other study sites, the highest species evenness (0.85) indicated that Danno was characterized by the highest homogeneity of species found in the area. Variation in mean diversity values of tree and shrub species among different study sites but lower than our study results was also documented by Haile *et al*. (2017) in central Ethiopia and Henry *et al*. (2009) in western Kenya, and a comparable range of species evenness (0.91–0.99) was reported in the study conducted in different traditional agroforestry areas by Molla and Kewessa (2015).

Shannon diversity was not significantly affected, while evenness was significantly affected by the socioeconomic status of farmers**.** Similar to our findings, Boffa *et al*. (2008) stated that wealth class couldn't affect either the diversity or abundance of on-farm tree species around Mabira Forest Reserve, Uganda. But Giday *et al*. (2019) quoted the slightly higher diversity value recorded in rich homesteads, which might be due to the fact that rich community members had a larger and more varied agroforestry system than people with medium and lower economic status. Contrary to this finding, Duguma and Hager (2010) and Haile *et al*. (2017) indicated a significance difference in woody species diversity on lands managed by different wealth classes, and comparatively, our findings were less than the mean woody species diversity value reported in the related study conducted by Giday *et al*. (2019) and almost comparable to that of Haile *et al*. (2017).

3.4.2. Important value index (IVI)

The highest basal area of *A. falcatus*, *J. procera*, and *O. europaea* subsp. *cuspidata* contributed to the species highest value of relative dominance of 28.3%, 18.3%, and 10.2%, respectively, and hence attained the highest IVI relative to the other species in Gl. In the homesteads, the highest IVI was recorded for *E. globulus* and followed by *H. lusitanica*. This is due to the highest relative dominance and relative abundance of the former species and the highest relative abundance of the later species. Such circumstances could be related to the economic importance and domestic service of the species for construction, life fences, firewood, income generation, and the fast-growing nature of the species as well. The highest relative frequency and relative abundance of three species—*O. europaea* subsp. *cuspidata*, *J. procera*, and *A. falcatus* —also contributed to their highest IVI in the CL of the study area. Farmers in the study area retained those woody species, along with some native species having large basal areas in their croplands. On the other hand, due to its high frequency, dominance, and abundance, *E. globulus* contributed the outstanding IVI in the woodlot. Agidie *et al*. (2013) also suggested a similar effect that frequency, basal area and abundance have on the importance of a species. The highness of IVI in this regard revealed the most dominance of the species, and the circumstances might also be associated with the preference of the species by the households (Wari *et al*., 2019). Mengistu and Asfaw (2016) also stated that the species importance in various agroforestry systems depends on the product value or serves of the species in the agroforestry system.

3.4.3. Population structural diversity

3.4.3.1. Frequency

According to the class categories, the majority of woody species in each LU type belong to the A (0–25%) frequency class. Similarly, Wari *et al*. (2019) found that across all land use classes, the lower frequency class had the highest proportion of woody species. Out of the total species recorded in GL, 50 and 6 species were grouped in A and B frequency class categories, respectively, and no species was recorded with a percentage frequency greater than fifty. More *A. falcatus*, *J. procera* (each 36.4%), and *O. europaea* subsp. *cuspidata* (33.3%) were recorded in GL than other species. The number of species recorded in the A, B, and C frequency classes in the HG was 30, 9, and 4, respectively, whereas no one species was recorded in the D frequency class. The most frequently recorded species in the HG were *Gymnanthemum auriculiferum, H. lusitanica, E. globulus*, *Rhamnus prinoides* L. Herit., and *Justicia ladanoides*. All species inventoried in the CL only belong to the A and B frequency classes, and those recorded in the WL were categorized into the A, B, and D frequency classes. There were none of the species in frequency classes C and D in CL and in C in the woodlot. The most frequently observed species in cropland were *O. europaea* subsp. *cuspidata* (31.8%), J. *procera* (27.3%), and *E. globulus,* the only species recorded in all woodlot sample plots in the study area.

3.4.3.2. Diameter at breast height (DBH) and height class distribution

All individuals with ≥ 2.5 cm DBH and ≥ 1.5 m height of woody species encountered in the inventoried LU system were recorded and categorized into diameter and height classes. Except in CL, there was a gradual decreasing pattern of DBH from the lower to the higher distribution class, and such a distribution pattern indicates the healthier structural population dynamics of the vegetation (Dibaba *et al*., 2014). In line with these findings, similar results were reported by Mengistu and Asfaw (2016) and Wari *et al*. (2019). The DBH mean showed a significant difference among the systems. The highest mean value recorded in the CL was due to the fact that a few old and mature woody species, mainly *A. falcatus*, *O. europaea* subsp. *cuspidata*, *J. procera*, and *V. abyssinica*, were retained in the CL for various socioeconomic purposes. Such woody species are purposely left and conserved by farmers for a longer period of time on their own managed land. Mengistu and Asfaw (2016) stated that selective thinning causes the growth of very few or limited tree species in a larger area without competition. The lowest mean value of DBH in WL in the study areas, specifically in Danno and Harbu Garba, is due to the current conversion of some farmlands by newly planted socio-economically important exotic woody species, mainly *E. globulus*. Even farmers do not let such plants mature enough because they consider their frequent use either for income generation or for construction and other purposes. According to the general pattern of height class distribution, the lower height class across all LU systems encompasses a higher frequency of woody species. Similarly, Wari *et al*. (2019) also revealed that lower-height class categories had the highest number of individuals compared to the middle and higher-height classes. The overall height mean value also showed a significant difference at ($P < 0.05$), and the highest mean value was observed in the CL (7.31) and WL (7.23), while the lowest mean height was observed in the GL (5.22). This was due to very mature woody plants having a higher height being conserved on the farmer's farmland, and the higher mean value of the woodlot was due to the dominance of *E. globulus,* which is characterized by fast-growing woody plants reaching higher heights even at low DBH. Such woody species are purposely required for woody products, and that is why woodlots are dominated by higher-height species (Wari *et al*., 2019), and exotic plants' greater growth potential has resulted in the replacement of indigenous plants by exotic species (Tefera *et al*., 2014). The lowest mean recorded in the study area was due to small shrub remnant patches that were used as grazing land, mainly in the Danno and Harbu Garba study areas.

3.4.3.3. Basal area and density of woody species

The mean density and BA statistical tests revealed a significant difference among LU types and wealth classes at ($P < 0.05$). In this regard, the highest density and BA per ha were recorded in the WL and rich farmer homesteads, while the lowest were computed for the cropland and poor wealth classes. Eventhough their finding was higher than our study result, Abebe (2005) and Wari *et al*. (2019) also recorded the highest density of wood species in the woodlot compared to other LU systems. But this finding was higher than the density/ha recorded in WL by Haile *et al*. (2017) and Duguma and Hager (2010). Similarly, the mean density/ha recorded in GL was higher than the number of woody species individuals/ha recorded in Haile *et al*. (2017), Mengistu and Asfaw (2016), and Fikadu and Argaw (2021). On the other hand, the woody species stem/ha recorded in our study, both in the HG and CL, were relatively less than the average density/ha of woody species recorded in similar LU types by Wari *et al*. (2019). Similarly, Haile *et al*. (2017) also reported a higher number of individual woody stems/ha than our study findings. However, a less measured mean density/ha in the HG by Mengistu and Asfaw (2016) and both in the HG and CL by Duguma and Hager (2010) was noted in their study report. The less scattered multipurpose trees that occur on parklands are mainly related to farmers' practices for reducing tree cover from tree shading and enabling easier ox-ploughing (Syano *et al*., 2023).

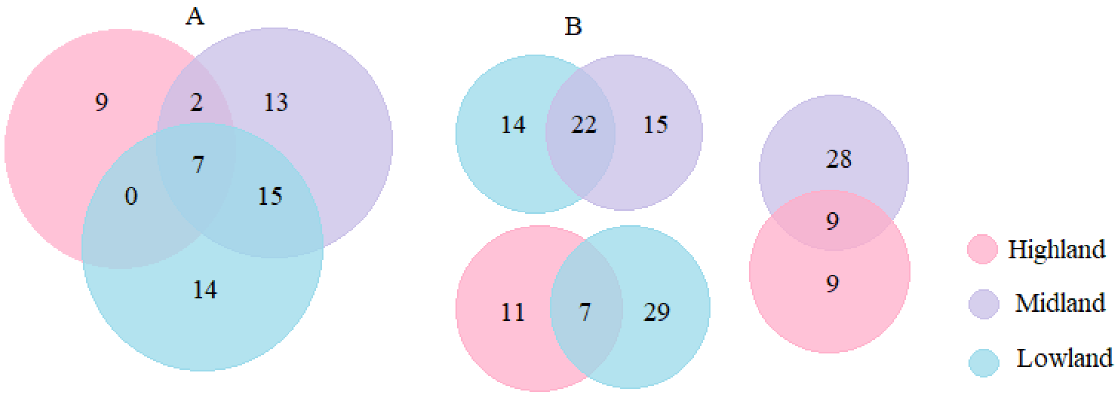
The highest average density of *E. globulus* (7488.9/ha) was recorded in the WL. Similarly, the highest density (10000 stems per ha) of the *Eucalyptus* tree among other woody species was recorded by Abebe (2005). The reason behind the highest density/ha of woody species in the WL was the cultivation of *E. globulus* in a narrowly spaced manner as a separate woodlot on cultivable and uncultivable land plots. Such monoculture practices might threaten indigenous plant biodiversity (Sayer *et al*., 2004). The intensive selection of fast-growing trees and more competitive species might cause the priority removal of other less competitive species (Duguma and Hager, 2010; Agidie *et al*., 2013). Fast-growing species that require low input are highly preferred by households (Agidie *et al*., 2013). Tefera *et al*. (2014) suggested that the high density of *E. globulus* relative to other woody species is due to the special attention farmers pay to its planting and management for their income generation. Other plant species that existed either as life fence for guarding purposes (e.g., *Calpurnia aurea*, *E. brucei*, and *G. auriculifera*) or as purposively conserved species (e.g., *J. procera*, *O. europaea* subsp. *cuspidata*, and *A. falcatus*) or purposively planted along with *E. globulus* (e.g., *Oldeania* *alpina* K.Schum., *Acacia melanoxylon* R. Br., *Grevillea robusta* A.Cunn. ex R.Br.) had a minimum number of average woody steam/ha, which ranges (389–11/ha) in the LU type. The grazing and browthing lands of the agricultural ecosystem of the study area included shrub-patchy natural forests, and *J. procera* and *A. falcatus* dominated remnant natural forests, which were conserved on farmers' own land plots. In this agroforestry system, the average analysis indicates that *J. procera* (18.9 ha), *A. falcatus* (18.6/ha), and *Carissa spinarum* (12.8/ha), *G. auriculifera* (10.8/ha) and *C. aurea* (9.4/ha) were densely populated individuals/ha in the study sites, particularly in Danno and Harbu Garba, whereas the other species had an average density/ha range of 6.7–0.34. The higher density of the former two species might be linked to the small patchy *J. procera* and *A. falcatus*-dominated forests conserved in the study sites. In such land units, the owner minimizes the pressure on the land plots in that farmers do not let other people get direct services from their own managed pieces of land. On the other hand, *H. lusitanica* (12.8/ha), *E. globulus* (12.6/ha), *J. ladanoides* (12.4/ha), *Buddleja polystachya* Fresen. (8.3/ha), *G. auriculifera* (7.3/ha), and *C. aurea* (6.9/ha) with the highest average density/ha were recorded in the HG, while the others were recorded in the range of 5.9 to 0.05 individual/ha. This was due to the farmers selectively growing some exotic plants around their homesteads for several socio-economic reasons, while the others were mostly for their use as life fences. Farmers' woody species planting and growing strategies in various niches such as life fences, front yards, and hedges are the determinant factors for the density of species around homesteads (Duguma and Hager, 2010). In the CL agricultural households land plots, we encountered the highest average density/ha of *O. europaea* (1.6/ha), *E. brucei* (1.5/ha), *J. procera* (1.1/ha), *V. abyssinica* (0.8/ha), and *C. macrostachyus* (0.7/ha), while the others had average density/ha ranging between 0.6 and 0.1. Farmers conserve those woody plant species for a variety of purposes, such as construction materials, food and fodder, household and farm equipment, fuel wood, medicines, soil fertility improvement, etc. The density of any LU type could depend on both the intensity of management and the biophysical situation of the environment (Mengistu and Asfaw, 2016).

3.5. Conclusion

Small-scale farmers' agroforestry systems in the study area serve as complementary habitats for maintaining and conserving large numbers of native and exotic woody species. Farmers' were retaining and cultivating woody species in their grazing land, homegarden, cropland, and woodlots. Parameters such as study sites (latitude), land use type, and the land owner's economic status could determine the composition and diversity of woody species. In line with this, the plant species richness per land plot was significantly affected by the altitudes, land use type, and wealth classes of the farmers. But a significant difference in the Shannon diversity index was only observed among land uses, and the evenness index was affected by both land use types and wealth classes. The highest mean species richness and diversity per land unit were recorded in the homegardens, followed by grazing land, and the poorest were recorded in woodlots, whereas the highest mean evenness was recorded for farmland and the lowest was recorded in woodlots. Eventhough there was no significant difference in woody species diversity observed among study sites, the highest woody species mean diversity and evenness index was recorded in midland and the lowest was recorded in highland study sites. Woody species diversity and evenness for rich households were higher compared to the medium and poor households in the study area. The highest density/ha of woody species was recorded in the woodlot, with *E. globulus* being the most densely populated species in the area. Agroforestry practices play an important role in the conservation of biodiversity, which in turn plays a critical role in the environment and economic development. Therefore, there is a need to promote and enhance the small-scale agroforestry system through the development and management approach to maintain native woody species, and there should be extension practices to convince the farmers and create awareness about planting, managing, and conserving more woody species with socioeconomically and environmentally multipurpose functions.

CHAPTER FOUR

Ethnobotanical study of underutilized wild edible plants and threats to their long-term existence in Midakegn District, West Shewa Zone, Central Ethiopia



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4. Ethnobotanical study of underutilized wild edible plants and threats to their long-term existence in Midakegn District, West Shewa Zone, Central Ethiopia

Abstract

Background*: Ethiopia is endowed with much plant diversity. The insignificant number of studies on wild edible plants with their ethnobotanical perspectives indicated that this plant diversity comprised only hundreds of wild edible plants used to supplement food sources for the local community under different conditions. There still need to be further investigations throughout the country when compared to the total area and cultural diversity of the country. However, they are seriously under pressure due to different natural and human influences. Therefore, the study was conducted to document underutilized wild edible plants along with their associated indigenous knowledge and explore threats to them in Midakegn District.*

Methods: *A questionnaire survey, semi-structured interviews, a market survey, score ranking, and focused group discussions were employed for data collection. Statistical analysis of ethnobotanical knowledge mean variation between different informant groups was computed by using one-way ANOVA in the IBM SPSS Statics version 24 package.*

Results: *A total of fifty underutilized wild edible plants belonging to 39 genera and 30 families were collected, recorded, and documented. The families* Moraceae *(four),* Fabaceae, Flacourtaceae, Myrtaceae, Rosaceae, *and* Tiliaceae *(each three) represented the highest number of species. It comprised shrubs (44%), trees (36%), herbs (18%), and epiphytes (2%). Fruits (62.3%) were found to be the most frequently used and mostly taken raw, fresh, or dried. These edible resources were consumed to supplement staple foods (67.3%), whereas 25% were used as emergency foods. The majority of species (96%) had multiple uses in addition to their edibility. A significantly higher ($P < 0.05$) number of underutilized wild edible plants were cited by males than females, by key informants than generals, elders than youngsters, illiterate than literate, and poorer than other wealth class groups of the community. Priority rankings indicate that agricultural expansion, fuel wood harvest, overgrazing, and selective harvesting are the most threatening factors to underutilized wild edible plants.*

Conclusion: *Fifty underutilized wild edible plants, along with their associated indigenous knowledge, were recorded. Local people utilize them for supplementing staple food, as emergency food, to get relief, trust, and chew during drought. But they are mainly threatened by different human activities in the study area.*

Keywords *Ethnobotany, Ethiopia, Midakegn, Underutilized wild edible plants*

4.1. Introduction

In human history, plant wealth of about 40,000 to 100,000 species has been used by humans for multiple purposes (Padulosi and Frison, 1999; IPGRI, 2002), and this globally accounts for about 5% of the total plant species of the world (Asfaw and Tadesse, 2001). Of these, 30,000 species so far have been identified as edible (Arora, 2014), and about 7,000 species have been cultivated and/or collected for food at one time or another (IPGRI, 2002). As a result of the Green Revolution, many of these local, traditional crop species and varieties have been replaced by high-yielding staple crop cultivars developed by modern breeding programs (Ebert, 2014).

The flora of Ethiopia has been endowed with an estimated 7,000-6500 higher plants (Balemie and Kebebew, 2006). Of these, nearly 3% (203 species) were reported as wild edible plants used to supplement food sources in different parts of the country under different conditions (Asfaw and Tadesse, 2001). After ten years of this report, the review report done on wild edible plants in Ethiopia indicated the country has 413 WEPs with their ethnobotanical information, and this accounts for about 5% of the higher plant species (Lulekal *et al*., 2011). Rural communities in the western Himaliya depend on these edible resources to meet their food needs, mostly during periods of food crises (Aryal *et al*., 2018). During the drought-stricken years of 1966–1969, the Konso people of southern Ethiopia survived by increasing their consumption of wild food plants (Guinand and Lemessa, 2000). In another country, the consumption of foods from the wild also played a significant role in saving lives during times of hunger. For instance, in 1973 and 1984–1985, the Berti people of Sudan relied on tree fruits and wild grass seeds to survive severe food shortages (Bell, 1995). Consumption of such edibles contributes essential nutrients that play a vital role in maintaining food security. Consumption of wild green leafy vegetables as part of supplements or main dishes by the southern population in Ethiopia helps to alleviate malnutrition (Addis *et al*., 2013a). Thus, for community members who are vulnerable to malnutrition, particularly children, consumption of wild edible plants helps them get the essential fats, proteins, vitamins, and minerals they need (Bell, 1995).

Ensuring household food security is not the only importance of those plant diversities; they also contain and provide materials for economic, medicinal, and forage values and also possess and preserve cultural heritages, biological information, and indigenous knowledge about their utility (Balemie and Kebebew, 2006). With such a variety of plants, people offered and used materials for income generation, medical care, foraging, fuel wood, construction, honey production, and detergent (Tebkew *et al*., 2014). In most cases, rural people have deep, non-similar indigenous knowledge of wild edible plants, and their consumption is still an integral part of the different cultures in the different parts of the country under different conditions (Guinand and Lemessa, 2000; Balemie and Kebebew, 2006). However, many of these plants are underutilized and/or neglected by indigenous farming communities for specific socioeconomic reasons (Ajayi and Mafongoya, 2017). For example, 33 underutilized wild edible plants in the local community were reported in the Chilga District, northwestern Ethiopia (Tebkew *et al*., 2014).

Even though there is a lack of consensus on the definition, a wide range of terms are used for underutilized plant species, which include minor, neglected, local, traditional, underexploited, underdeveloped, orphan, lost, new, promising, and alternative plant species (Padulosi and Thompson, 2013; Arora, 2014; Chivenge *et al*., 2015). Of these, the most widely used term is underutilized, which refers to plant species that communities traditionally use for food, fiber, animal fodder, oil, or medicine, but that have further undeveloped potential uses (Arora, 2014). They are less represented in ex-situ germplasm collections (IPGRI, 2002), their potential has not been fully realized (Padulosi *et al*., 2002; Jaenicke and Höschle-Zeledon, 2006), and they are not included in the official farming system (Debela *et al*., 2011). Those plant species are currently maintained through *in-situ* conservation (Ajayi *et al*., 2017), and this is because they are less competitive with other species in the same agricultural environment (El-Solh, 2016). However, UWEPs are still important resources for the subsistence of local communities, socio-cultural preferences, and traditional uses. They could be serving as an alternative food source while the world faced critical challenges due to climatic change, food security, human nutrition, and overdependence on a few staple crops for the world food supply (El-Solh, 2016; Ajayi *et al*., 2017). These species could become important crops to reduce risks and, adapt to shocks caused by climate change in the future (Mayes *et al*., 2012; Ajayi *et al*., 2017). They significantly improve health and nutrition, livelihoods, household food security, and the ecological sustainability of the environment (Balemie and Kebebew, 2006; Jaenicke and Höschle-Zeledon, 2006; Arora, 2014). Especially in the case of nutritional value, wild and semi-wild foods provide a diversity of nutrients in the diets of many households (Debela *et al*., 2011).

There are four major areas where underutilized species can make significant contributions to sustainable agriculture: food security and better nutrition; increased income for the rural poor; ecosystem stability; and cultural diversity associated with local food habits and religious and social rituals (Jaenicke and Höschle-Zeledon, 2006; El-Solh, 2016). Their role has evolved over time, and as it is today, it adds to the quality of life besides meeting the needs of the rural poor in particular (Arora, 2014), and it becomes extremely important to mitigate risks and adapt to shocks caused by climate changes. Thus, the genetic resources of UWEPs might become more attractive to farmers (Ajayi *et al*., 2017). This might be due to their greater potential to cope up with the adverse effects encountered due to extreme climate change than conventional crops (Sina and Degu, 2015). Specifically, in developing countries, there is a wider opportunity to use these species to ensure food security, and they could be important crops in the future (Baldermann *et al*., 2016; Ajayi *et al*., 2017).

Thus, giving attention to UWEP species is an effective way to maintain diverse and healthy diets, and mainstreaming them into local food systems could help to combat malnutrition, particularly among low-income rural households and the more vulnerable social groups in developing countries (IPGRI, 2002; Baldermann *et al*., 2016). Besides multiple use categories, it provides synthesized information on underutilized grains, roots and tubers, leafy vegetables, fruits, spices, condiments, etc. It also brings out several emerging concerns for their further promotion of human welfare in addressing food security, minimizing malnutrition, poverty reduction, and income generation. What is equally important is the need to capture the associated indigenous knowledge base held by the indigenous community. For a wide range of such under-cultivated species, there is an urgent need to broaden this base of species effectively and sustainably to protect and enhance the use of such regionally significant species that are also more globally applicable in agricultural and environmental management. Missing attention might lead to the erosion of the available gene pools in their areas of diversity and cultivation.

Ethiopian farmers face common challenges due to deforestation, drought, land degradation, and climate change, and they experience significant food insecurity (MoARD, 2007; Sabates-Wheeler *et al*., 2012). The situation is also very common in the study area, the central part of Shewa, and the households are similarly facing challenges. Under such circumstances, underutilized and/or neglected plants can offer alternatives to the basic crops to ameliorate the situation and maintain farm productivity. This is due to their natural adaptability and resistance to challenges growing due to various environmental constraints (Rao *et al*., 2014). Future local and global food security could greatly benefit from such species (Mayes *et al*., 2012; Rao *et al*., 2014; Ajayi *et al*., 2017). On the other side, this central part, which includes the study area, is one of the most densely populated areas of the country. The wild edible plants and the associated indigenous knowledge with their usage are in danger due to human and natural impacts. Thus, the study area at the local level and Ethiopia at the country level would benefit from such research to increase the production and value of these resources and promote their widespread cultivation, which would increase food, economic, and nutritional security.

On the other hand, only an insignificant number of investigations on wild edible plants with their ethnobotanical perspectives were reported throughout the country when compared to its total area and cultural diversity (Guinand and Lemessa, 2000; Lulekal *et al*., 2011). This suggests that the ethnobotanical knowledge of UWEPs was inadequately documented and is still held in the collective memory of senior community members. The term "UWEPs" used in this study revealed that all wild edible plants and their potential values got less attention and thus remained underestimated among the indigenous people of the study area. Giving poor attention to such plants meant that indigenous communities missed the opportunity to access rich nutrients and health-promoting compounds with preventive effects against malnutrition and some chronic diseases (Baldermann *et al.*, 2016). The literature survey carried out on the ethnobotanical studies showed that there has been no previous investigation reported on UWEPs and the associated indigenous knowledge of the local people in the Midakeng District. Therefore, the purposes of this study were to: (1) collect UWEPs and document the associated ethnobotanical knowledge of the local people residing in the study area before it is lost forever; and (2) explore the threat of underutilized wild edible plants in the study area. This helps to promote indigenous knowledge on the potential utilization of UWEPs and their importance for present and future socio-economic significance.

4.2. **Material and Methods**

4.2.1. **Description of the study area**

Midakegn district is one of the administrative districts forming the West Shewa Zone of Oromia Regional State, in central Ethiopia (Figure 4.1). The study area lies between $09^{0}02'57''$ to $09^{0}23'45''$N latitudes and $037^{0}23'$ to $037^{0}45'54''$E longitudes, with a total area of about 91,051 hectares (ha) and an elevation range of 1290–3058 m above sea level. According to the Midakegn District Agricultural Office's (MDAO) 2020 annual report (unpublished), the district is known for having three agro-climatic zones. These are namely: "*Baddaa*" (highland) covers 12.5% of the western part of the “*Balemi*” (the capital town of the district); "*Badda Daree*" (middleland) covers 50% by extending eastward to the northwest through the central part of the district; and "*Gammojji*" (lowland) covers the remaining 37.5% in the northern part. The study area faces a humid air current coming from the Atlantic Ocean and receives heavy rainfall during the main rainy season (May to September). The highest mean annual rainfall of the study area within ten years was 186.4 mm, recorded in July, followed by 183.2 mm in August, whereas the lowest mean total was 6.5 mm, recorded in December. The lowest mean temperature over ten years was 8.7 ^{o}C recorded in December, whereas the highest was 24.6 ^{o}C recorded in February. The total population of the district was about 106,438 people, of whom 52,148 (49%) were males and 54,290 (51%) were females. Subsistence mixed agriculture was the economic mainstay for the population of the study area.

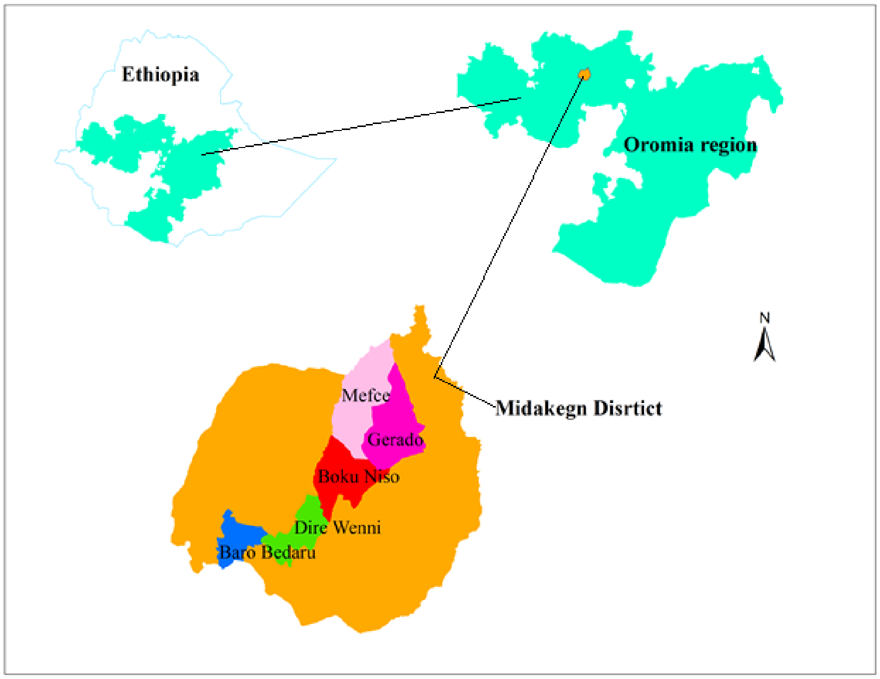


Figure 4.1 A map of Ethiopia shows the Oromia region and the study district with study sites

4.2.2. Site selection

After being informed of the purpose of the field study, the district authorities requested permission and granted it. In order to gather broad information for site selection, a reconnaissance survey and contacts with specialists, including district and kebeles' officials, agricultural workers, and elders, were made between March 1 and 15, 2021. Then, five kebeles (the lowest administrative unit in Ethiopia) from the three agro-ecological zones were chosen for UWEPs data collection: one from the highland, two from the midland, and two from the lowland (Table 4.1). These kebeles were chosen based on criteria including the degree of accessibility for data collection, such as the varied altitudinal location, availability of UWEP, and livelihood of the local people.

4.2.3. Key informant and household selection

The snowball and a simple stratification method were used in this study to choose the informants. This was used to analyze the indigenous knowledge and plant utilization differences among the local communities in the study area. Following Martin (1995), key informants (KIs) were chosen using the snowball method. The approach was used to identify the research area's most knowledgeable individuals. According to this study, KIs are those who are relatively most aware of UWEPs and the regional circumstances in the study area than other residents. Therefore, a total of 25 KIs (five from each kebele) were chosen. In the beginning, individually, ten knowledgeable people in each kebele were called up by three elders who were chosen at random. Then, the five most knowledgeable individuals who were often informed by the three farmers were selected as KIs and took part in preliminary ethnobotanical data collection, a survey questionnaire, a semi-structured interview, a scoring and ranking procedure, and focus group discussions. A stratified random sampling technique was applied to select general informants (GIs) from the households residing at the study sites. The purpose of stratification was also to involve all age and wealth categories during data collection. Therefore, by following Cotton (1996), households were categorized by age (18–40 years and > 40 years) and wealth class (poor, medium, and rich). The Yamane formula, as described in Adam (2020), was used to determine the sample size from the total number of households at the study site at a 95% confidence level, $p = 0.5$, and ± 5% level of precision. Thus, a total of 358 informants (25 KIs and 333 GIs) out of 3478 households belonging to the study sites were selected, and one person from each representative household was involved in survey question activities carried out during data collection.

$$n= \frac{N}{1+N(e^2)}$$

Where n is the sample size representative, **N** is the total households, **e** is the level of area precision, and 1 is the probability of an event occurring.

Table 4.1 Sampled kebeles, number of respondents, and agroecologies of the study area

Study Kebeles	**Key informants**	**General informants**	**Agroecology**
Baro Bidaru	5	68	Highland
Dire wenni	5	66	
Boku Niso	5	66	Midland
Mafce	5	66	
Gerado	5	67	Lowland
Total	**25**	**333**	

4.2.4. Data collection and analysis

To collect ethnobotanical data, questionnaires and semi-structured interviews were prepared, pretested, and administered to households (general) and KIs as stated in (Cotton, 1996). Thus, the same standard open- and closed-ended questions were prepared in English and translated into the local language, "*Afan Oromo*," for the interview. After the objectives of the current study were shared with the interviewee, an interview was administered to each identified respondent by the researcher on a face-to-face and one-on-one basis based on their consent at the place of their choice, which could be at home or in the field. Consequently, field observations were conducted by guided field walks to identify where UWEPs are grown and to collect their specimens. Detailed information targeting UWEPs known to the informants, including the plant species used, vernacular names, part(s) used, method of preparation, ways of consumption, consumption role, other use diversity, threatening factors, and conservation strategies, was collected and recorded. All UWEPs listed in the socio-economic survey were verified, and ideas that deviated from reality were removed from the data. Finally, all encountered plants were collected, pressed, dried, and recorded by their vernacular names along with a voucher number. Preliminary specimen identification was attempted in the field and confirmed at the National Herbarium (ETH) by using published volumes of the Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989; Edwards *et al*., 1995; Hedberg *et al*., 1995; Edwards *et al*., 1997; Edwards *et al*., 2000; Hedberg *et al*., 2003; Tadesse, 2004; Hedberg *et al*., 2006) and comparison with authentic specimens, illustrations, taxonomic keys, and with the assistance of experts at the National Herbarium (ETH), AAU. Market surveys at three local marketplaces (Balemi, Wayilo, and Bitile) were conducted in the study area. The main purpose of the market survey was to record the marketability of the edible parts and kinds of UWEPs sold in the study area. Thus, a semi-structured interview with edible part sellers and informants and participatory observation were conducted to assess the variety and marketability of the plants.

The collected ethnobotanical information was organized and analyzed by Microsoft Excel 2010 spreadsheet software. The difference in ethnobotanical knowledge between informant groups was computed by one-way ANOVA in the IBM SPSS Statics version 24 package to check the existence of significant differences (at a 95% confidence level) between means.

Preference ranking for more popular or palatable UWEPs, direct matrix ranking for multipurpose UWEPs, and priority ranking of threats to UWEPs were done as follows (Martin, 1995; Cotton, 1996). In the preference ranking process, the values (0 to 5) were given by KIs, and each value was summed up and the value was taken to determine the preference of one over the other. A direct matrix ranking was conducted for ten multipurpose UWEPs commonly and frequently reported in the study district. The purpose is to assess their relative importance to the local people and the extent of the existing threats related to their use values. Based on the service categories, 10 KIs were asked to assign use values for each attribute. The list of these attributes included medicinal, fuel wood (firewood and charcoal), construction, farm and household tools, fodder, live shade, live fence, honey bee forage, and soil and water conservation. The use values (0 to 5) were given. The average use values given for each multipurpose species in each use category by each KI were recorded, and the values were summed up for each species and ranked. Priority ranking on recorded major threatening factors to these plants was also done by 10 KIs based on their degree of destructive effects. Values (1 to 6) were given, and all values given by each KI were summed up to report the most concerning factor.

4.3. Results and Discussion

4.3.1. Taxonomic diversity of underutilized wild edible plants in the study area

In this study, a total of 50 species of UWEPs distributed into 39 genera and 30 families were gathered and documented from the study area (Appendex 4). All the UWEPs were reported by the local community with their vernacular names. Out of these total reports, 36 species (72%), 25 species (50%), 22 species (44%), 21 species (42%), 18 species (36%), 17 species (34%), and 13 species (26%) were reported in the study conducted by Asfaw and Tadesse (2001) at the country level, by Hankiso *et al*. (2023) in Soro District, southern Ethiopia, by Alemayehu *et al*. (2015) in Berehet District, North Shewa Zone of Amhara Region, by Abera and Belay (2022) in Muja District, northwestern Ethiopia, by Addis *et al*. (2013a) in southern Ethiopia, by Alemneh (2020) in West Gojjam, Ethiopia, and by Tahir *et al*. (2023) in Mieso District, eastern Ethiopia, as wild edible plant species, respectively, and 12 species (24%) were reported in a similar ethnobotanical study conducted by Tebkew *et al*. (2014) in the Chilga District, northwestern Ethiopia. The number of UWEPs recorded in the study area was lower than the number of wild edible plants reported by Balemie and Kebebew (2006), Addis *et al*. (2013a), and Hankiso *et al*. (2023) in other parts of Ethiopia. But it was greater than the number of wild edible plants reported in several ethnobotanical studies (e.g., Teklehaymanot and Giday, 2010; Alemneh, 2020; Tebkew *et al*., 2014; Woldemedhin *et al*., 2021; Abera and Belay, 2022; Tahir *et al*., 2023) and compared to the number of species reported as wild edibles in other regions of Ethiopia (Alemayehu *et al*., 2015; Aregay *et al*., 2017; Emire, *et al*., 2022). The relatively higher number indicates that the catchment under study was generally endowed with diverse and rich sources of UWEPs with their associated indigenous knowledge, and such high diversity might be due to the existence of different agroecological zones in the study area. The possible variation among different localities of the country could be due to the existence of variations in community culture, vegetation cover, the size of the study area, and environmental conditions. According to Hedberg and Edwards (1989), Edwards *et al*. (2000), and the assessment report on the ethnobotanical wild edible plants review report at country level by Lulekal *et al*. (2011)

and other similar study reports in the country, out of the total documented species, two species (*Impatiens rothii* Hook. f. and *Urtica simensis* Steudel) were endemic to the country, and three species, *Canarina eminii* Asch. and Schweinf, *Gardenia terniffolia* Schumach and Thonn, and *I. rothii,* which were not previously known as edible plants, were newly discovered and added to the wild edible database of the country.

The highest number of these UWEPs were found in the family *Moraceae* (4 species, 8%), followed by *Fabaceae*, *Flacourtaceae*, *Myrtaceae*, *Rosaceae,* and *Tiliaceae* (each contributed 3 species, 6%). Those species in the family *Moraceae* were contributed by 4 genera (10.3%), in *Fabaceae* by 3 genera (7.7%), in *Flacourtaceae, Rosaceae,* and *Tiliaceae* each by 2 genera (5.1%), and in *Myrtaceae* by 1 genus (2.6%). The remaining 7 families and 17 families each contributed two species (4% each) and one species (2%), respectively. Thus, 43.3% of the families were represented by more than one UWEP species. One or more of these families with the highest edible species contribution were consistently recorded in different ethnobotanical wild edible inventories (Asfaw and Tadesse, 2001; Wondimu *et al*., 2006; Lulekal *et al*., 2011; Woldemedhin *et al*., 2021; Abera and Belay, 2022; Tahir *et al*., 2023). In particular, *Moraceaea, Fabaceae,* and *Tiliaceae* were mentioned for their highest number of wild edible resource contributions in different parts of the country (Lulekal *et al*., 2011). The distribution could be attributed to their wider distribution throughout various agroecological zones all over the country. At the genus taxonomic level, the genera *Ficus* (4 species), followed by *Grewia* and *Syzygium* (3 species each), contributed the highest number of species. Either one or more of these highly wild food-contributing genera were also recorded elsewhere in Ethiopia (Abera and Belay, 2022; Tahir *et al*., 2023; Tebkew *et al*., 2018).

The habitat distribution of the surveyed UWEPs covered a diverse ecological range from low to high land (1290–3058 m) above sea level. Explored habitat analysis showed that the species were recorded from a variety of habitat reservoirs. About 35 species (70.0%) were found in the forest, followed by pasture and grassland (24 species, 46.0%), riverine and homegardens (each 14 species, 28.0%), farm and arable lands (12 species, 24.0%), and the other possible habitat areas indicated in Appendex 7. A low diversity of plant species was recorded from the highlands, while a larger diversity of species was recorded from the midlands and lowlands (Figure 4.3). This could be an indication that the local communities in these two agroecologies have retained more indigenous knowledge of their quoted plants. Similarly, the study conducted on prospects for sustainable use and development of wild food plants (Asfaw and Tadesse, 2001) and the ethnobotanical study of edible wild plants in Ensaro district, Amhara regional state (Woldemedhin *et al*., 2021) in Ethiopia indicated that the midland and lowland agroecology of the country were highly enriched by wild food plants, whereas the highland was known for low diversity, and areas with higher elevations are mostly known for their limited plant diversity (Amin *et al*., 2023).

4.3.2. Underutilized wild edible plants habit and parts used

Habit analysis of UWEPs used as edible food during different conditions in the study area revealed that shrubs constituted the largest category (22 species, 44%), followed by trees (18 species, 36%), whereas herbs consisted of the lowest life form (10 species, 20%) (Figure 4.2). Our finding was agreed with the previous study reports (Balemie and Kebebew, 2006; Alemayehu *et al*., 2015; Abera and Belay, 2022; Tahir *et al*., 2023) which reveal that, the predominant source of underutilized wild edibles were shrubs and trees. The review report analysis done by Lulekal *et al*. (2011) at the country level also reveals that shrubs occupied the dominant position in contributing wild edible resources, followed by trees, herbs, and climbers. The study conducted in Nhema communal area, midlands province, Zimbabwe, by Maroyi, (2011) also indicated that wild edible plant resources were mainly from trees and shrubs. In contrast to our study report, Ashagre *et al*. (2016) reported the dominance of herbs followed by shrubs in an ethnobotanical study conducted in Burji District, Southern Ethiopia. On the other hand, the study conducted by Hankiso *et al*. (2023), which indicated that trees, followed by herbs, contributed the most edible resources, also contrasts our findings.

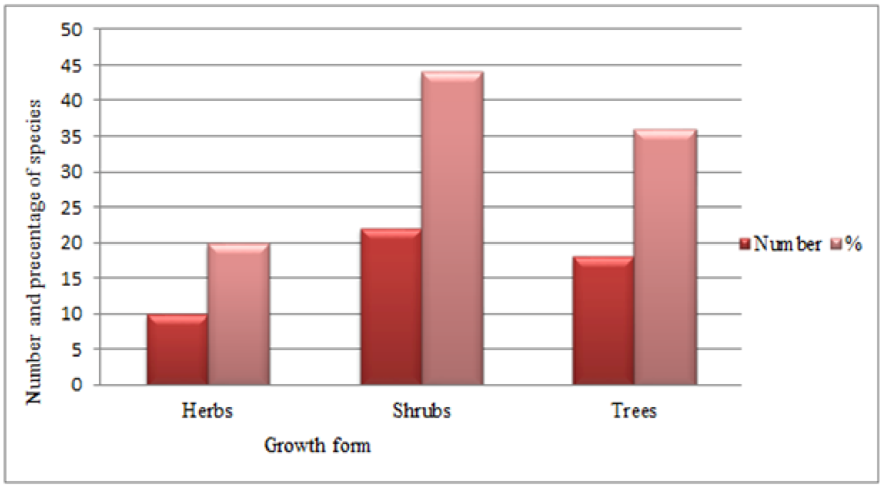


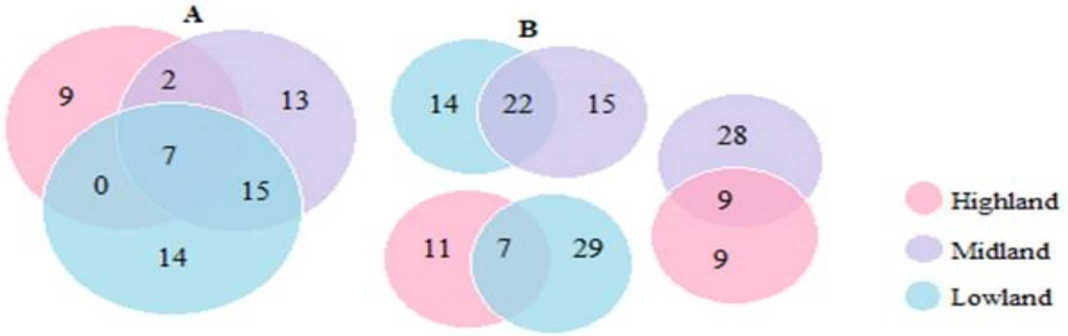
Figure 4.2 Habit of underutilized wild edible plants used in Midakegn District

In this finding, a total of 53 UWEP parts were used as food in the study district under different circumstances. This includes fruits, leaves, leaves and stems, gums or exudates, seeds, young shoots, flowers, root tubers, nectars, and twings (Table 4.2 and Figure 4.3). A smaller number of edibles (34%) were reported in the highland when compared to those reported in the midland and lowland of the study area (69.8% and 67.9 species, respectively). UWEPs commonly harvested for their fruits accounted for 33 species (62.3%), followed by plants harvested for their leaves and stems (5 species, 9.4%), and leaves alone (4 species, 7.5%), whereas those collected for other parts accounted for 20.8%. The study reports on UWEPs in the Chilga district, northwest Ethiopia, by Tebkew *et al*. (2014) and in Tigray, northern Ethiopia, by Aregay *et al*. (2017) also indicated that fruits were the most commonly used parts of UWEPs. Similar to this finding, Wondimu *et al*. (2006), Lulekal *et al*. (2011), Addis *et al*. (2013a), Sina *et al*. (2015), Teklu and Abduljabar (2019), and Tahir *et al*. (2023) reported that fruits were the most widely used parts compared to the others. This is also similar to the report by Arora (2014), in which fruits shared the majority of underutilized wild edible parts in the Asian Pacific region. The study report of Suwardi *et al*. (2023) in Indonesia also indicated that fruits, particularly those from the wild, are plentiful but less well known and underutilized. A cross-comparison of underutilized plant parts commonly reported in the three agroecologies has revealed a high degree of heterogeneity, and only a small proportion (7 species, 13.2%) of the food uses of certain recorded plant parts were commonly shared among the three agroecological areas (Figure 4.3A). In between the three groups (Figure 4.3B), maximum homogeneity was recorded between lowland and midland (22 species, 41.5%), followed by midland and highland (9 species, 17.0%), whereas minimum homogeneity was recorded between highland and lowland (7 species, 13.1%). This could be due to variation in altitudinal and other environmental factors that determine plant diversity in the environment. Different natural environments may lead to different plant utilization (Guo *et al*., 2022). As altitudinal variation increases, the common plant tax shared between the agroecologies of the study area decreases. This is why the minimum homogeneity of UWEP parts between lowland and highland and the relatively maximum homogeneity between lowland and midland and midland and highland were recorded in the study area. The remarkable heterogeneity in the use of wild edible plants among different groups could be referred to as the lack of common practice between different communities (Amin *et al*., 2023).

The local community uses 67.3% and 25% of the quoted edible parts to supplement staple food and as emergency food, respectively, whereas UWEP parts chewed during the drought and utilized to get relief trust each account for 3.8%. Edible plant parts from the wild are used as supplementary, seasonal, or survival food sources in various cultural groups in Ethiopia (Lulekal *et al*., 2011). They support the rural livelihoods of the local community both during ample food production and during the need for emergency safety nets in conditions of food shortage, famine, and poverty (Debela *et al*., 2011; Shumsky *et al*., 2014; Alemayehu *et al*., 2015) and hence play a role in combating food insecurity, especially for rural poor communities. They play a significant role in the subsistence and economy of resource-poor people throughout developing countries (El-Solh, 2016).

Table 4.2 Parts of underutilized wild edible plants used in the Midakegn District

Parts used	**Lowland**		**Midland**		**Highland**		**District level**	
	No	%	No	%	No	%	No	%
Fruit	25	47.2	21	39.6	7	13.2	33	62.3
Leaf	2	3.8	3	5.7	3	5.7	4	7.5
Leaf and stem	3	5.7	5	9.4	3	5.7	5	9.4
Gum or exudate	1	1.9	1	1.9	1	1.9	2	3.8
Seed	2	3.8	1	1.9	0	0.0	2	3.8
Young shoot	0	0	0	0	1	1.9	1	1.9
Flower	0	0	1	1.9	1	1.9	1	1.9
Root tuber	1	1.9	2	3.8	1	1.9	2	3.8
Nectar	1	1.9	2	3.8	1	1.9	2	3.8
Twing	1	1.9	1	1.9	0	0	1	1.9
Total	36	67.9	37	69.8	18	34.0	53	



Figurer 4.3 Venn diagrams show cross-comparisons of UWEP parts in use in the study area. A shows overall homogeneity and heterogeneity among the three agroecologies; B shows homogeneity between agroecology

4.3.3. Condition of preparation, form and mode of consumption

The local community quoted 53 plant parts from the total species reported in this study area. Out of these, 41 edible parts (77.4%) were directly consumed without further processing, whereas 12 plant parts (22.6%) needed further processing prior to use as food. Those edible parts were mainly consumed as fruits (62.3%), followed by those consumed as vegetables (9.6%). Others were consumed in the form of chewing (7.7%), spices (5.8%), condiments (5.8%), nectar sucking (3.8%), bread and/or "*Injera*" (1.9%), and other forms (1.9%). The main mode of consumption (80.4%) was direct utilization of raw fresh or raw dried edibles, followed by those consumed after cooking (9.8%) and fermentation (5.8%), respectively (Figure 4.4). According to study findings from different regions of Ethiopia (Balemie and Kebebew, 2006; Alemayehu *et al*., 2015; Teklu and Abduljabar, 2019; Tahir *et al*., 2023), Zimbabwe (Maroyi, 2011), and Sudan (Saliha and Ali, 2014), raw consumption was noted as the main way that people consumed wild edible foods.

According to the study area respondents, all the recorded fruits were directly consumed raw outdoors in the fields while working, keeping livestock, and traveling from place to place. The wide use of fruits is due to their ease of processing, more preferable taste, day-to-day requirements, and nutritional value (Balemie and Kebebew, 2006; Abera and Belay, 2022), the taste quality reduction during preservation, and the difficulty of preserving plenty of fruits for the indigenous people (Xie *et al*., 2022). For instance, fruits of *Syzygium afromontanum*, *Syzygium guineense* subsp. *guineense*, *Flacourtia indicia*, *Mimusops kummel*, *Ximenia americana*, *Rubus steudneri*, *Ficus sur*, *Dovyalis abyssinica*, *Rubus apetalus*, *Carissa spinarium*, *Rosa abyssinica*, and *Cordia africana* relatively had more appreciation among the local communities and were consumed as supplementary food. In the review report (Lulekal *et al*., 2011), all of those species were listed among the common sources of edible fruits elsewhere in Ethiopia. The same is true for *C. africana* and *Ficus sycomorous* in Sudan (Saliha and Ali, 2014). There were also raw fruits, which received no more appreciation among the local community but served as supplementary food in the study area. Freshly ripened fruits of *Grewia bicolor*, *Grewia ferruginea*, *Grewia villosa*, *Euclea racemosa*, *Myrsine africana*, *Physalis peruviana*, *Saba comorensis*, *and Vepris nobilis* were eaten raw outdoors by all community members except the fruits of *P. peruviana*, which were mainly considered children's food. However, harvesting of fresh edibles for consumption from some species, such as *Ficus* *vasta*, *F. sycomorous*, *Ekebergia kapensis*, *Ficus thonningii*, *Gardenia terniffolia*, *Searsia glutinosa*, and *Phoenix reclinata,* was most commonly to alleviate starvation during famine. In this case, both sexes and all age groups of both wealth classes, especially the elders, tried to access those edibles as alternative sources only during famine. This suggests that the majority of local communities continue to undervalue the potential use of the resources. But whenever edible resources were available, even when there was no scarcity of food, mostly youngsters and herdsmen search for collection and enjoyed consumption in the field. However, consuming excessive amounts of particular fruits, such as *F. sur*, *F. vasta*, *F. sycomorus*, and *F. thonningii*, whether raw or dried, has been linked to gastrointestinal discomfort. Similar to this, (Wondimu *et al*., 2006) stated that in the region of Konso ethnic communities in South Ethiopia, stomach pain and diarrhea are common health problems following the consumption of numerous wild edible plants. Fruits were not the only edibles eaten raw; other parts were also utilized raw and fresh without needing further processing. During times of drought, the local population chewed raw gums of *Vachellia abyssinica* and *Faidherbia albida* as well as fresh, just emerged lateral and terminal shoots of *Rumex nervosus*, mostly to reduce their need for water. Underground root tubers of *Eriosema cardifolium* were chewed raw by children, particularly when keeping cattle. Children in the study area also used the flowers of *I. rothii* and *Justicia ladanoides* to suck the nectar that provided them energy. A fresh flower cavity of *C. eminii* was filled with either fruits of *R. steudneri*, *R. apetalus*, or *R. abyssinica*, which were consumed together by children in the study area. In addition to the fruits consumed as supplementary food, twigs of *E. racemosa* were chewed by all community members to get refreshment.

On the other hand, only 22.6% of edible parts that needed cooking, backing, condimenting, and spicing were brought home before dish preparation and were consumed by all family members in the home. This result agreed with the finding of Teklu *et al*. (2019), in which a few wild edible plant parts were brought home for cooking before consumption, and dishes prepared from them were consumed by entire groups (Kuyu and Bereka, 2020). But cooking responsibilities were accomplished by women and female youngsters in the study area. For instance, the collection and preparation of the leaves of *A. hybridus,* the leaf and stem of *U. simensis,* and the young shoot of *Oldeania alpina* as vegetables mainly during food scarcity were done by women and young girls. Even though it was a very rare species in the study area, the root tubers of *Colocasia esculenta* were also cooked by women and consumed as vegetables in the study area. Similarly, powdered grain seeds of *Sporobolus pyramidalis* were backed into bread, or "injera," just like *Eragrostis tef* (Zucc.) Trotter flour and seeds of *F. albida* were cooked into boiled grain, *or "Mulluu,"* by women and young girls and consumed by all family members during the famine. Women also mainly participated in the leaf collection of *Olea europaea L.* subsp. *cuspidata, Rhamnus staddo,* and *Gymnanthemum amygdalinum* for use as additives in the fermentation process of different local alcohols, such as "areke,*"* "tela,*"* and "teji*"*. Also, commonly, harvesting the leaves of *Lippia adoenesis* and *Thymus schimperi* and using them in the spicing or flavoring process was done by women. The review report done on the contribution of indigenous food preparation and preservation techniques for the attainment of food security in Ethiopia (Kuyu and Bereka, 2020) indicates that leafy wild edible material collection and processing for consumption are mostly considered the responsibility of women and young girls in Ethiopia. The leaves and stems of *L. adoenesis* var. *adoenesis* and *L. adoenesis* var. *koseret* were used for various food additive spicing purposes (e.g., pepper powder, butter, etc.), and *T. schimperi* was used as tea flavoring. Milk pots and other kitchen equipment were also cleaned and fragranced with the leaves of the two *L. adoenesis* varieties in the study area. The Gurage and Oromo peoples use the fragrant leaves as one of the spices for making spiced butter (Hedberg *et al*., 2006). Food prepared with spiced butter and/or spiced pepper powder had a delicious flavor that attracted people to eat it. In addition to all these recorded underutilized edibles from the wild and semi-wild that were used to maintain the sustainability of food security and food sovereignty in the study area, they have more contributions than the locals are aware of. Especially for the local poor, their utilization not only assures food security but also supplies vital nutrients that prevent malnutrition. As Mokria *et al*. (2022) reported, consumption of wild edible fruit provides more nutritional value, such as vitamins, fibers, and secondary metabolites, to the human diet than cultivated crops, and they have a good content of minerals (cupper, magnesium, and phosphorous), carotenoids, and protein. The nutritional composition analysis done on underutilized edible fruits of *Balanites aegyptiaca* (L.), *Grewia flavescens* Juss., and *Ziziphus spina-christi* Willd. also indicated that their fruits are enriched with major food substances such as carbohydrate, crude protein, crude fat, and minerals (Debela *et al*., 2011). On the other hand, proximate amino acids, minerals, and ant-nutritional factors analysis of popularly consumed fifteen wild edible plants in Hamar and Konso of southern Ethiopia also revealed that wild leafy vegetables contribute good amounts of these essential nutrients to the human diet (Addis *et al*., 2013b). The local community not only benefited from the utilization of these underutilized edible species but also used them for multiple purposes. As an example, active substances from edible parts of *Embelia schimperi*, *G. amygdalina*, *L. adoensis*, *O. europaea*, and *R. nervous* include those that are utilized as traditional remedies. *E. schimperi* fruit was traditionally used to treat tapeworms after the powdered or crushed fruits were mixed with water and taken orally. *G. amygdalina* leaves were chewed, and the juice was then swallowed internally to treat bronchial infections. *L. adoensis's* squeezed and filtered leaf extract was administered orally to treat fibril illness, and the afflicted portion of the eyelid was also directly rubbed with the leaves to cure eye infection. A similar ethnopharmacological importance of these species was also reported by (Haile, 2021). Leaf extract of *G. amygdalina* added to local drinks was also used for treating stomach problems in lowland areas of Ethiopia (Kassa *et al*., 2020). The water-mixed, pounded leaf buds of *O. europaea* were used to protect intestinal parasites. The leaves of *R. nervous* were smashed and directly rubbed over the skin hemorrhage to treat the infected body in the study area.

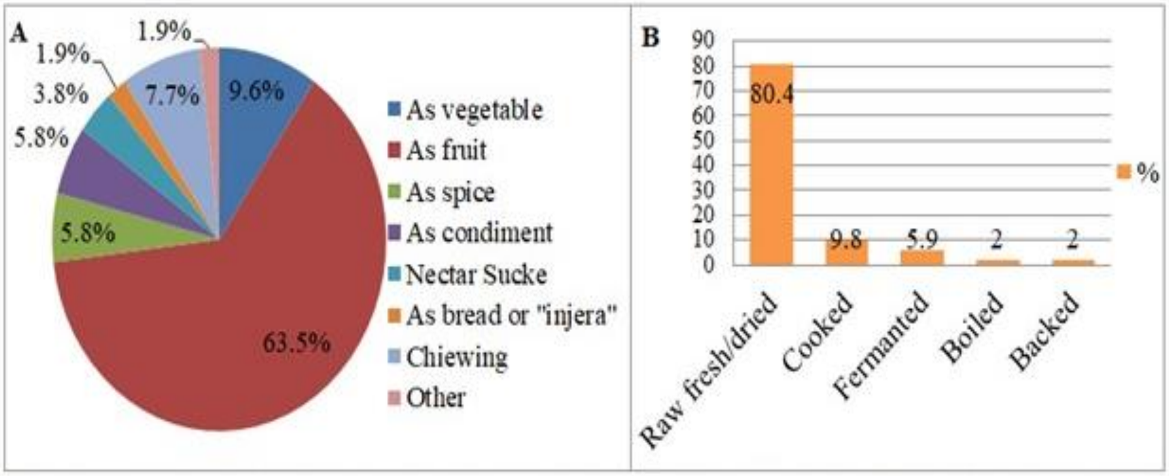


Figure 4.4 Consumption patterns of underutilized wild edible plants, **A** indicates the form of consumption, **B** indicates the mode of consumption.

4.3.4. Marketability of underutilized wild edible parts in the study area

Other than food service, some of the UWEPs in the study area were used as an alternative to supplement household income. The conducted market survey and information assessed from informants revealed that 17% of total UWEP parts recorded in the district were sold in the local market (Table 4.3). Mostly youngsters and sometimes women of the poorest wealth class were observed and reported as the most sellers of edible parts of these species. Similarly, young children in the study report of Addis *et al*. (2013a) and Sina and Degu (2015) were mentioned as the main selling group of wild edible plant parts, especially fruits. Women and children of the Nhema communal area of Zimbabwe were also reported as common sellers of wild edible parts in the local market (Maroyi, 2011). An example and the most frequently cited species for their fruits are *S. afromontanum*, followed by *S. guinense* subsp. *guinense*, *F. indicia*, *M. kummel*, and *X. Americana* (Table 4.3). Currently, some fruits of these species are sold for 2 to 5 Ethiopian birr (≈0.037 to 0.092 USD) per cup or plastic glass in the local market of the study area and were sold for fewer prices for one to three decades before. In agreement with this finding, the fruits of *S. guinense* and *X. americana* in the study conducted by Alemayehu *et al*. (2015*)*, *S. guinense and M. kummel* by Abera and Belay (2022), and *M. kummel*, *S.*

guineense, and *F. indica* Emire *et al*. (2022) were also used for income generation in other parts of Ethiopia. Leafy shoots of *L. adoenesis* var. *adoenesis, Lippia adoenesis* var. *koseret,* and leaves of *T. schimperi* are currently sold in the local market for spicing purposes.

Table 4.3 Marketability of the underutilized edible parts in the study area

Species	**MP**	**MU**	**PR**	**SG**	**WC**	**NR**
F. indica	Fruit	Cup/glass	2–5 ETB	Y	Poor	31
L. adoenesis var.*adoenesis*	Leaf & stem	Can/Jug	10–20 ETB	Y & W	Both	23
L. adoenesis var. *koseret*	Seedling, Leaf & stem	Number, Handful	5 ETB	Y & W	Poor	13
M. kummel	Fruit	Cup/grass	2–5 ETB	Y	Poor	29
R. steudneri	Fruit	Fruit inflorescence	2–5 ETB	Y	Poor	24
S. guineense subsp. *guineense*	Fruit	Cup/Glass	2–5 ETB	Y & W	Poor	39
S. afromontanum	Fruit	Cup/glass	3–5 ETB	Y & W	Poor	55
T. schimperi	Leaf	Can/Jug	5–10 ETB	W	Both	17
X.americana	Fruit	Cup/glass	5 ETB	Y &W	Poor	25

MP, marketable part; MU, measuring unit; PR, price in Ethiopian birr (ETB), 1ETB ≈ 0.0184 USD; SG, seller group, WC, wealth class; NR, number of respondents; Y, young; W, women

4.3.5. Preference ranking of underutilized wild edible plants and threatening factors

The determinant factors of the preference status of one edible plant over another were computed commonly based on taste, availability, accessibility, cultural, psychological, or inherited ancestral practices (Debela *et al*., 2011; Maroyi, 2011). In this study, based on taste quality perceived by KIs and frequency of citation, preference ranking for 7, 9, and 4 underutilized wild edible foods at low, mid, and highland agroecologies of the study areas was carried out to find out their relative importance to the local community (Figure 4.5). The ranks were given by each selected KI from each agroecology at each study site. The total score rank of 10 KIs at midland indicates the most preferred species, in descending order, were *S. afromontanum*, *S. guineense* subsp. *guineense*, *R. steudneri*, *F. sur*, *D. abyssinica*, *R. apetalus*, *C. spinarium*, *R. abyssinica*, and *C. africana*. Compared to the others, *S. afromontanum* got the highest score (total score = 45) due to its best palatability, and was used as a supplementary food in the midland study site. *S. guineense* subsp. *guineense,* which scored second (total score = 37), was used for the same purpose with a better and more pleasant taste; *R. steudneri*, which scored third (total score = 36), was also used as supplementary food with a better and more suitable taste; and *F. sur*, which was used as supplementary food, scored fourth (total score = 34) and had a good taste. *D. abyssinica*, which was scored fifth, and *R. apetalus*, which was scored sixth, got a total score of 29 and 28, respectively, and they serve as supplementary foods with somewhat good taste quality. The supplementary edibles *C. spinarium* was score seventh (total score = 25), and *R. abyssinica* was scored eighth (total score = 23) with fair taste quality. *C. Africana* was scored ninth (total score = 17), which indicates it has the least taste quality. Accordingly, the total score and the ranking excersice were done for those edibles from lowland and highland study sites, and the preference score rank of seven UWEPs done by five KIs at lowland agroecology in descending order also indicates *S. afromontamum*, *F. indica*, *D. abyssinica*, *R. apetalus*, *C. spinarium*, *M. kummel*, and *C. africana* are among the top 7**.** Another rank score done for four species with five KIs at highland agroecology showed more preference for *R. steudneri* over the others, followed by *R. apetalus*, *R. abyssinica*, and *D. abyssinica.* The sequence of ranks at each agroecology was indicated by total score, and edible with the highest total score has better palatability than the next and is hence more preferable to the one with the next highest total score.

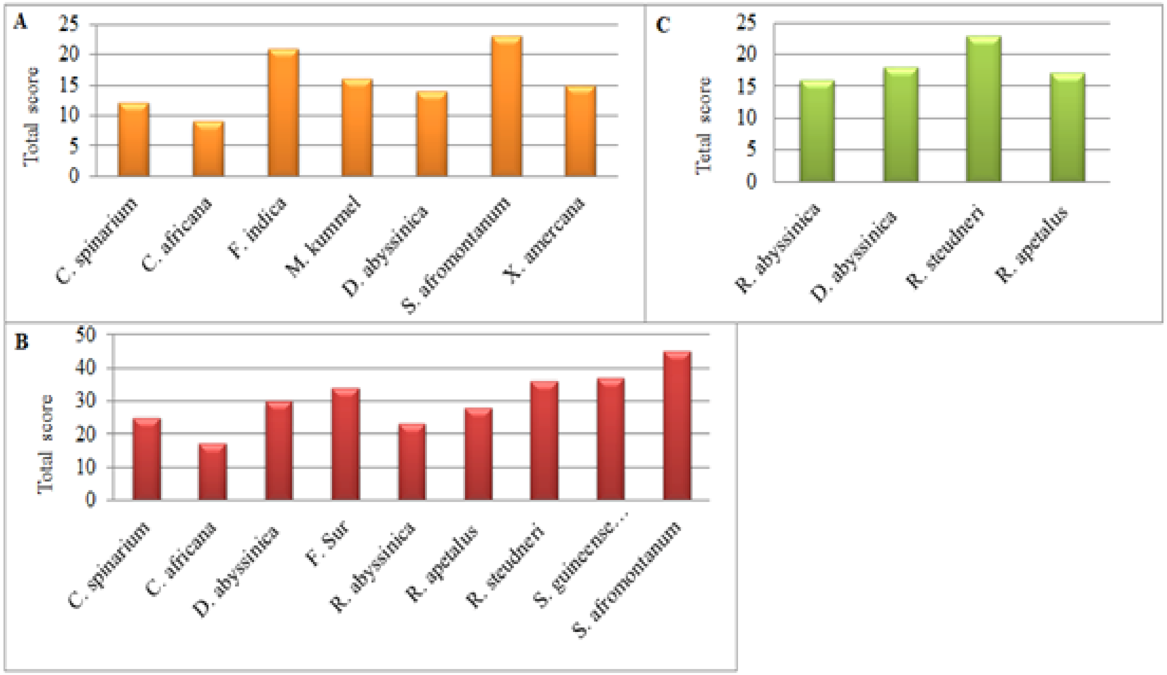


Figure 4.5 Preference ranking of underutilized wild edible parts based on taste quality and frequency of citation at **A** lowland, **B** midland, and **C** highland agroecological areas

The causes of threats to UWEPs can be generally grouped into anthropogenic and naturally induced factors. Human-induced factors recorded by the informants as local threats to UWEPs were agricultural land expansion, fuel wood harvesting, selective harvesting for various purposes, overgrazing, urbanization, and fire, and the natural-induced factors recorded were drought and land degradation. The preference ranking exercise carried out to prioritize the most threatening factors affecting such resources in the study area, indicating agricultural land expansion, overgrazing, and fuel wood collection (harvest for charcoal and firewood) ranking 1st, 2nd, and 3rd respectively, whereas the destructive effects due to selective harvesting for different purposes (construction materials, farm and household tools, traditional medicine, fumigate material), fire hazards, other natural disasters (such as drought, land degradation, etc.), and urbanization held 4th to 7th ranks in the study area, respectively (Table 4.5). Even though the above threatening factors were ranked at the district level, the destructive effect of each factor varies among informants from the three agroecological zones of the district. For instance, KI1–KI3 in Table 4.4 were from the lowlands, and thus the individual values given to agricultural expansion, fire, and overgrazing indicated that they were the principal threats to UWEPs in the lowland agroecological zones of the study area. This is mainly due to increasing demand for farmland and a large mass of livestock moving from highland and midland to the area for grazing purposes. Searching for newly vegetating grass and to protect against animal attack (e.g., snakes), people released fire either deliberately or unintentionally to burn the grassland in the study area. Similar findings and reasons for wild edible plant habitat destruction and conversion were reported in other parts of Ethiopia (Meragiaw *et al*., 2015; Ashagre *et al*., 2016). The causes of threats ranked 1st, 2nd, and 4th in this study were also reported as the principal factors for wild food plants in the Eastern Nuba Mountains, Sudan (Saliha and Ali, 2014). The recent rate of wild edible plant habitat overexploitation for various human needs was indicated as a big threat to the long-term existence of those resources in Ethiopia (Ashagre *et al*., 2016). As observed in the study area, mainly in the highland and midland, those main destructing factors had a significant impact on particular wild edible plants, especially those used for multiple uses. For example, *O. europaea* subsp. *cuspidata*, *E. kapensis*, *C. africana*, *V. abyssinica*, *S. guineense* subsp. *guineense*, and *F. sur* were observed as a single tree either in cultivated land, around homegarden, or riverine, but were rarely observed in the small patchy forests. The situation is definitely linked up with the need for excessive yield production from a few staple crops to balance the demand of an ever-increasing population, overharvesting for multiple uses, and a lack of full understanding of the nutritional, economic, sociocultural, and ecological importance of indigenous wild edible plants and their associated indigenous knowledge to current and future generations. Thus, more strategies have been needed for such species that need conservation priority than the less potential plant biodiversity in the study area.

Table 4.4 Priority ranking on recorded threatening factors to underutilized wild edible plants

Threatening factors	**10 Key informants**											
	L1	**L2**	**L3**	**M1**	**M2**	**M3**	**M4**	**H1**	**H2**	**H3**	**Total**	**Rank**
Agricultural expansion	5	5	5	5	6	6	6	5	5	6	54	1st
Fuel wood harvest	3	5	4	5	4	4	3	4	3	3	38	3rd
Selective harvesting	4	3	3	3	4	4	3	3	4	3	34	4th
Overgrazing	5	4	5	4	5	3	4	3	4	5	42	2nd
Urbanization	1	1	2	1	1	1	1	1	1	1	11	7th
Fire	5	5	5	2	2	3	3	3	2	2	32	5th
Natural disasters (other)	2	1	2	2	2	1	2	2	1	2	17	6th

L1–L3, lowland; M1–M4, midland; H1–H3 highland key informants

4.3.6. Use diversity of the UWEPs in the study area

A total of 50 UWEPs documented in the study area had multiple uses other than food value. Of these, 2 species (4%) were mainly used for consumption only, while 48 species (96%) had multiple uses in addition to their edibility. The multiple uses include: medicinal value accounted for by 23 species (46%), construction by 18 species (36%), fuel wood by 32 species (64%), bee forage by 14 species (28%), fodder by 32 species (64%), farm and household tools by 22 species (44%), live fence by 12 species (24%), live shade by 12 species (24%), soil and water conservation by 11 species (22%), and other use categories (spicing, flavoring, condemning, fumigating, and toothbrush) were by 10 (20%) species. However, other than the edibility function, direct matrix ranking was done for ten very common and frequently reported UWEPs under nine use categories (etic categories) (Table 4.5), and the result showed that *O. europaea* subsp. *cuspidata*, *C. africana*, *V. abyssinica*, *S. guineense* subsp. *guineense*, and *S. afromontanum* were found to be most important in their multiple utility values, respectively. This indicates that these UWEPs were more exploited for their multipurpose function than the others in the study area. Overharvesting of UWEPs for various exploiting uses such as fuel wood, construction, farm, and household tools were found to be the responsible threatening factors aggravating the depletion of the species. Similarly, Addis *et al*. (2013a) said that the reason for the highest exploitation of wild edible plants was because of their multiple uses other than their food values. Thus, such species need urgent complementary conservation action and sustainable use to save and manage the fast-eroding multipurpose UWEPs in the study area.

Table 4.5 Average score of direct matrix ranking of ten UWEPs with different use values other than edibility in the study area

Use category	**Species**									
	V. abyssinica	*C. spinarium*	*C. africana*	*E. racemosa*	*F. sur*	*F. sycomorus*	*F. vasta*	*O. europaea*	*S. afromontanum*	*S. guineense*
Medicinal	3	5	3	3	3	2	3	4	2	2
Fuel wood	5	3	4	4	2	3	3	5	4	4
Construction	2	1	5	2	3	2	3	5	4	4
Farm and household tools	3	0	4	3	1	1	1	5	2	3
Fodder	3	2	3	2	4	3	4	3	3	3
Shade	4	0	3	1	5	4	5	3	3	3
Live fence	2	1	3	2	0	0	0	4	1	1
Bee forage	3	2	5	3	0	0	0	3	5	5
Soil and water conservation	5	2	4	1	4	4	4	3	3	3
Total score	30	16	34	21	22	19	23	35	27	28
Rank	3	10	2	8	7	9	6	1	5	4

4.3.7. Knowledge distribution of underutilized wild edible plants between different informant groups

The mean comparison of knowledge distribution among different informant categories is indicated in Table 4.6 below. The average comparison between different informant groups indicates that significantly higher ($p < 0.05$) numbers of UWEPs were claimed by KIs than GIs, by elder respondents (age > 40 years) than those reported by young to middle-aged adults (18–40 years), by males than females, and by illiterate groups than literate groups.

The results showed that knowledge distribution was almost unequally shared among different informant groups. As the age of informants (both male and female) increases, the level of their indigenous knowledge of UWEPs significantly increases. This could be linked to the opportunities they experienced with new wild edible resources under different climatic conditions. The studies conducted by Alemayehu *et al*. (2015) and Sina and Degu (2015) also indicated that the elder members of the community had higher ethnobotanical knowledge than the youngsters. But contrary to their knowledge level, youngsters have been consuming more than senior age groups in the study area. This is because children have an intimate association with wild edible fruits throughout the year (Aragaw *et al*., 2021), and they have more initiation to harvest the resource than adults (Fentahun and Hager, 2008).

On the other hand, the male informant group quoted more UWEPs than the female informant group. This could be linked with the norm and cultural influence of the study area in that, in day-to-day life activities, females were mostly restricted to working at home and in the homegarden rather than in the field. Gender role stereotyping was reported as an ethnobotanical knowledge level determinant factor between males and females (Sina and Degu, 2015). Male responsibilities such as harvesting wild edible plants for construction, agricultural tools, technologies, and household uses could let males have better knowledge than females (Addis *et al*., 2013a).

Illiterate people in the study area reported more UWEPs than literate, which could probably due to the higher influence of modernization and distance from interaction to natural vegetation on the later informant groups. Another UWEP's citation analysis between economic status groups indicates that there was a significant difference between the poor and other wealth classes. This means UWEP's citation of the poor category was significantly higher ($P < 0.05$) than the medium and rich wealth categories in the study area. However, the citation of UWEPs in the medium and rich wealth categories didn’t show a significant difference. A similar study reported by Tebkew *et al*. (2014) indicates that local people with low economic status cited more wild edible plants than the others. More dependence of low livelihood communities on wild plants might be to ensure food security under different circumstances rather than they have been considered that have better nutritional value. Reliance on wild edible plants was greater in households with food insecurity that lacked off-farm income and had lower levels of assets (Shumsky *et al*., 2014). Those local community members with better income and sufficient grain for food in any circumstance consume less wild edible foods and are taken as famine or low-class food (Dandena, 2010). Lack of awareness forced them to underestimate these plant resources, both nutritionally and socioeconomically, as they have less value than other cereals and pulses. Even when a serious food shortage affects all strata of a population, poor families regularly collect and consume wild food more than the richest families in different parts of Ethiopia (Guinand and Lemessa, 2000).

The assessed information reflected that indigenous knowledge related to UWEPs has been passed down from generation to generation through oral transmission in families and neighborhoods. However, it has shown a declining trend and become out-dated due to the lack of appreciation by younger generations because of a shift in attitude and on-going socio-economic changes in the study area. Such phenomena could result in both the eradication of wild food culture and its associated indigenous knowledge (Suwardi *et al*., 2023), and their inheritance is faced with great risks (Xie *et al*., 2022).

Table 4.6 Mean comparison of the numbers of underutilized wild edible plants reported by different informant groups in Midakegn District

Parameters	**Informant categories**	**Number**	**Mean ± SD**
Age	18-40 years old	159	5.99 ± 2.02
	> 40 years old	199	9.06 ± 2.75
Informants	Key informants	25	11.72 ± 3.03
	General informants	333	7.39 ± 2.64
Sex	Female	67	6.70 ± 2.76
	Male	291	7.92 ± 2.87
Education level	Illiterate (0-4 grade)	268	8.06 ± 2.93
	Literate (> 4 grade)	90	6.59 ± 2.46
Economic status	Poor	116	10.03 ± 2.73
	Medium	129	6.76 ± 2.25
	Rich	113	6.36 ± 2.89

A significant difference ($p < 0.05$) between the means of the different categories

As information assessed from 25KIs indicates, consumption of edible parts from UWEPs is currently much reduced when compared to the past. Nineteen KIs (76%) of them reported that the reason behind the consumption decline of UWEPs in the study area is an increase in staple food crop production and community reliance on a few plant products to sustain their livelihoods. According to Debela *et al*. (2011), farmers' intentions toward better cultivars, modernization, acculturation, and a lack of knowledge about the advantages of both native wild edible plants and their associated indigenous knowledge may lead to the reduction or loss of the resource in the near future. Under normal circumstances, the contribution of wild edible plants to the overall food supply for the society of Ethiopia is relatively small and is simply utilized as supplementary or occasional snacks during certain periods (Asfaw and Tadesse, 2001), and except in a few southern part, the majority of the country has often perceived its consumption as a sign of poverty (Addis *et al*., 2013b). The globalization of agricultural marketing has become the most constraint to the promotion of UWEPs on a global scale (Ashebo, 2019). Reduction in utilization may gradually cause the removal of indigenous knowledge associated with the species and thus pose a danger to low-income people who are relatively more reliant on these cheap foods.

On the other hand, 13 KIs (52%) mentioned that the UWEP consumption decline was due to the difficulty of getting edible materials at near distances under current climate conditions. Lack of awareness of their nutritional function was also mentioned by 3 KIs (12%) as another impact factor that has caused a reduction in the utilization of wild edible parts in the local community. An increased distance traveled to harvest edible materials by the collector and difficulties accessing them, as well as an increase in economic status, significantly correlate to lower levels of WEP use (Shumsky *et al*., 2014; Kagunyu and Wanjohi, 2022). On the other hand, wild plants have been affected by climate variability, and many of the plants have disappeared (Kagunyu and Wanjohi, 2022). The continuous use of different plant species in a sustainable manner has been questioned as a result of land degradation and the worsening of climate change from time to time (Ashebo, 2019).

4.3.8. Management and conservation practice to underutilized wild edible plants

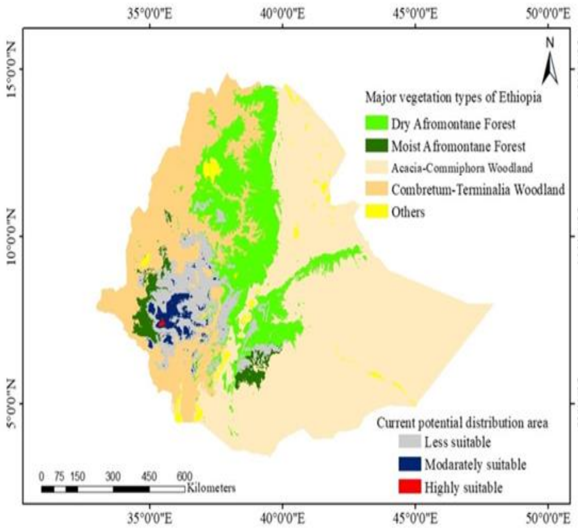
Information from both discussants revealed that there was no measurable participatory action implemented on the part of governmental and non-governmental agents to engage the local community to scientifically improve management practices for the conservation and utilization of UWEPs. Even at the country level, no conservation action or programs that support efficient utilization of wild edible plants have been undertaken (Asfaw and Tadesse, 2001). However, 19 (38%) UWEPs were conserved by local communities through three traditional practices. One of the strategies informed and observed in the study area was culturally protecting plants in their natural environments because of their multiple uses. For instance, *V. abyssinica*, *F. albida*, *C. africana*, *F. sur*, *F. vasta*, *F. cycomorus*, and *E. capensis* were left as a single tree in the farmlands, farm boundaries, and watershed areas due to their capability of soil conservation, fertility improvement, and frequent use as a shade. Cutting trees such as *F. cycomorus* was strictly prohibited by community norms because it was considered a seating area for community elders to solve different conflicts in the community. The second management strategy was leaving UWEPs in farmland or around the homegarden for their pollarding and re-pollarding nature, which allows the plants to have more branches for different construction services (e.g., *O. europaea*). Planting and keeping UWEPs around the homegarden for their diverse uses was found to be the third management strategy practiced for conservation. A few species were planted in and around the homegarden for their condiment function in local alcohol drink preparation and spicing function (e.g., *G. amygdaninum* and *L. adoenesis* var.). Others, such as *D. caffra* and *J. ladanoides,* were semi-cultivated for their life-fencing services, and *O. alpina* for its construction material provision. Similar management strategies were also reported in other parts of Ethiopia for the conservation and enhancement of multipurpose wild edible plants and for the preservation of the indigenous knowledge associated with them (Alemayehu *et al*., 2015, Tebkew *et al*., 2018). However, very limited management activities were practiced when compared to those enacted for other staple food plants.

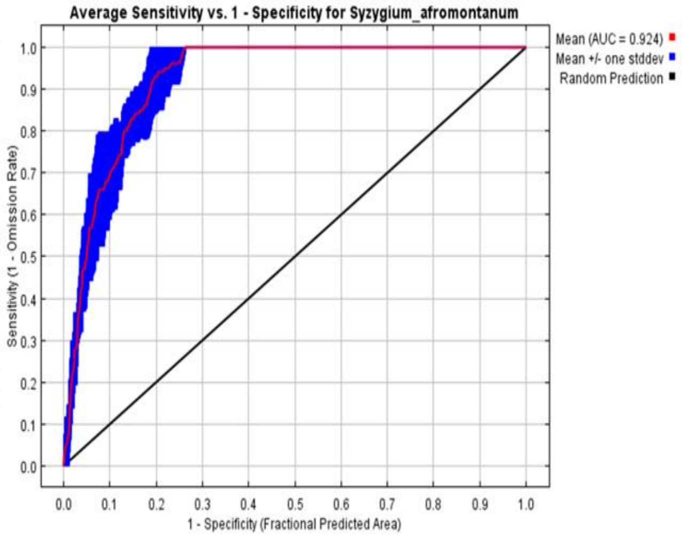
4.4. Conclusion and recommendation

The present study revealed that Midakeng District is endowed with diverse UWEPs and associated indigenous knowledge. Fifty UWEPs belonging to 39 genera and 30 families were collected and documented in the study area. Nevertheless, a variety of their habitat types were recorded, and the majority of them were collected and distributed in the patchy forests. The analysis of the information from the discussant and interviewers showed that underutilized wild edible materials collected from shrubs and trees made the largest contribution to the local community and were consumed to supplement the staple food, as emergency food to get relief, and chewed during drought. Relatively, the significant contribution of UWEPs to the regular diet was greater for the poorest wealth class than the medium and higher classes in the study area. Other than food value, most UWEPs have multiple uses, such as medicinal, fuel wood, construction, farm and household tools, fodder, bee forage, live shade, life-fence, and soil and water conservation. Thereby, income is generated from the sale of their edible and other parts. Priority ranking based on recorded threatening factors for UWEPs indicates that many of the species are under growing pressure, mainly from various human-induced factors. They suffer from destruction for different uses, including agricultural land expansion, fuel wood harvesting, selective harvesting, overgrazing, urbanization, and fire. Natural disasters and a lack of intervention from the government and other bodies for scientifically managed action are also threating the sustainability of UWEPs. The local community only practices traditional management strategies for conservation action in the study district. Even though the current study emphasized on the documentation of UWEP species diversity along with their potential function in socio-economic activities, indigenous knowledge associated with them, and threats to them, the negligence to use UWEPs, which is fully linked with a lack of awareness of their nutritional and economic value, should be minimized. Thus, community awareness through training and further studies on the nutritional content analysis and economic valuation of promising UWEPs are needed. This could help the stockholders (consumers) realize the benefits of UWEPs, which in turn could encourage policymakers and investigators to optimize and promote the benefits. These actions might encourage domestication and further conservation of promising UWEPs through integration into existing land use types and, thus, ultimately have positive impacts on the future livelihoods of rural communities.

CHAPTER FIVE

Predicting current and future distribution of wild edible *Syzygium afromontanum* (F. White) Byng. under climate change in Ethiopia





A paper published at Brazilian Journal of Botany

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5. Predicting current and future distribution of wild edible *Syzygium afromontanum* (F. White) Byng. under climate change in Ethiopia

Abstract

Plant species tend to shift their geographical ranges in response to climate change. The extent to which they are sensitive to the change is less understood in the tropics. Here, we predicted the current and future distribution of Syzygium afromontanum, a highly prioritized plant that contributes nutritious and edible fruits but has a narrow ecological range in Ethiopia. The MaxEnt algorithm method was used to predict potential suitable habitats for the species in the long run. Twenty-two environmental variables were downloaded from the WorldClim database, and 47 spatially rarefied occurrence points were used. The current and two climate change scenarios (RCP 4.5 and RCP 8.5) for 2050 and 2070 were used. Model evaluation by AUC value ranges from 0.914–0.931 under all scenarios, placing the models in the excellent category. The jackknife evaluation of the 25 random test percentage entry for model calibration showed that solar radiation, and precipitation in the coldest, and driest quarters are significant predictors of the distribution model. Compared to the current, the potential distribution area of the species would be reduced by 3.21% and 3.32% under RCP 4.5 and RCP 8.5 of 2050 and by 2.77% and 2.86% under RCP 4.5 and RCP 8.5 of 2070, respectively. The consequence of this situation will have a long-term effect on the conservation of the species and the indigenous knowledge associated with the species. Thus, modeling plays an essential role in designing and implementing conservation policies to conserve species that have narrow ecological ranges besides being highly prioritized and socio-economically valuable plants.

Keywords Environmental variables · Major biomes of Ethiopia · MaxEnt modeling · Potential distribution

5.1. **Introduction**

A change in the world climate would influence the functioning of many ecosystems and the biological health of plants and creatures (McMichael *et al*., 2003; Bellard *et al*., 2014). An increase in temperatures, changes in precipitation, and climate variability would alter the range of distribution of organisms (McMichael *et al*., 2003) either by shifting their suitable habitat or by threatening their viability (Velásquez-Tibatá *et al*., 2013). In response to such climate change, the distribution of most species commonly shifts in range towards higher altitudes (Chen *et al*., 2011; Muluneh, 2021). Rapid human population growth, habitat fragmentation, overexploitation of natural resources, pollution, and invasion by invasive and alien species are the primary causes and most significant factors of current climate change and affect the structural and functional integrity of ecosystems (Adhikari *et al*., 2012). Particularly in developing countries, extreme population growth, which causes habitat fragmentation for farmland expansion, is considered the main factor. These factors have accelerated the decline of natural resources and led to environmental degradation such as soil erosion, loss of biodiversity, and impoverishment of ecosystems (McMichael *et al*., 2003; Berhan and Bekele, 2006; Wakjira, 2006). Plant species with a narrow ecological range are more susceptible to the impact of climate change (Trew and Maclean, 2021), and wild species in particular (Muluneh, 2021). This is because they do not receive management interventions that help them adapt to changing conditions (Muluneh, 2021). Climate change in East Africa generally shows a consistent change in precipitation (Dosio *et al*., 2019) and a continuous increase in temperature (Hulme *et al*., 2001). Particularly in Ethiopia, the mean annual temperature was raised by 1.3°C at an average rate of 0.28°C per decade over the last 40–50 years (McSweeney *et al*., 2010). But a decreasing trend in precipitation has been reported in the highlands of Ethiopia (Dosio *et al*., 2019). Such circumstances resulted in dramatic shifts in the geographical distribution of species and ecosystems (Kelly and Goulden, 2008; Sintayehu, 2018) and consequently affected their suitable habitats, which might in turn cause the loss of genes, species, and ecosystems with the functioning and services associated with them (Sintayehu, 2018).

To this end, a number of alternative approaches can be used for the purpose of predicting the distribution of species in time or space to estimate the consequences of global change, assess ecological status, and for other ecological applications (Guisan *et al.,* 2007; Hallstan, 2011). Of these, species distribution modeling is one of the basic approaches that are broadly used in ecological and evolutionary studies (Scheldeman and Zonneveld, 2010). It becomes increasingly important in landscape ecology to understand the distribution patterns of species in the face of climate change and many other ongoing environmental changes (Guisan and Thuiller, 2005; Hallstan, 2011; Brown, 2014). This is because it is used for the estimation of climate change impacts on living organisms (McMichael *et al*., 2003; Trew and Maclean, 2021) and plays a great role in biodiversity conservation and management (Scheldeman and Zonneveld, 2010; Guisan *et al*., 2007). It makes inferences about habitat suitability, geographical range contraction, range shift, and future extinction risk of species in response to human-related disturbances (Fordham *et al*., 2012). Thus, determining the current and future potential distribution through modeling has great value, especially for those with narrow ecological ranges and endemic species, which are more vulnerable to climate change (Hallstan, 2011; Mbatudde *et al*., 2012; Trew and Maclean, 2021).

A number of modeling methods, including sophisticated machine learning methods (such as neural networks, random forests, MaxEnt entropy, and genetic algorithms for rule set production approaches), BIOCLIM models, classic regression models, sophisticated classification tree approaches, and hierarchical models, are a few of the more well-liked models that have been developed with the aim of predicting the distribution of species in conservation biology (Elith *et al*., 2006; Sinclair *et al*., 2010; Hallstan, 2011). Out of those, the MaxEnt algorithm is a general-purpose method for making predictions or inferences from incomplete information and is suitable for all existing applications involving presence-only data sets (Phillips *et al*., 2006). This is due to the better predictive accuracy when compared with many other presences-only occurrence data methods (Elith *et al*., 2006; Merow *et al*., 2013), the statistically measurability of the model performance (Phillips, 2006), and the easily useable nature of the software (Merow *et al*., 2013). It does not require the user to choose pseudo-absences during distribution modeling (Williams *et al*., 2009). Based on presence-only occurrence data, the software finds the distribution of maximum entropy subject to the constraint expected value of each environmental variable under its empirical average (Phillips *et al*., 2006).

The study species, *Syzygium guineense* subsp. *afromontanum* F. White, which belongs to the genus *Myrtaceae*, has been ranked at species level as *S. afromontanum* (F. White) Byng. The synonym name was accepted and first published in the Global Flora, Special Edition, Part 1, Volume 4 (Christenhusz *et al*., 2018). Online accesses at https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:77184165-1 indicated that species is native to Angola, Kenya, Malawi, Mozambique, Sudan, Tanzania, Uganda, Zambia, Zaire, and Zimbabwe. Many ecological research reports (e.g., Kebede *et al*., 2014; Raga and Seid, 2017; Tegene, 2018) and the lists of the species recorded in the GBIF backbone in the catalog of life that were accessed on June 2021 indicated that *S. afromontanum* is also native to Ethiopia. This tree plant species, grown up to 35 m high and geographically localized to upland rain forest, riverine, forest edge, or secondary growth, is occasionally left as a single tree in farmland cleared from forest in Ethiopia at an altitude range of 1400–2600 m (Edwards *et al*., 1995).

Socio-economically important plant species widely used for multipurpose functions are also affected by climate change. Plant species that could be suitable for biofuel production (biodiesel and ethanol technology) suffer extinction risk due to an increase in climate change (Telwala *et al*., 2013). In this case, *S. afromontanum,* which culturally has many use diversities (food, medicinal, construction and tools, firewood and charcoal, fence, animal feed, and fodder) for the local community, is under threat (Demise and Asfaw, 2020). The use diversity indices reported by Kassa *et al*., (2020) also revealed that, out of the entire plant data set in the report, *S. afromontanum* was ranked first in its multipurpose function. The fruits have been harvested by local communities, particularly at the transition between lowland and midland areas of the country, for their use as supplementary and famine food, as well as being widely sold in different local markets for income generation. In some parts of the country, the fruit can be further processed into jams, marmalades, and jellies (Asfaw and Tadesse, 2001) and nutritionally endowed with minerals (Calcium, Iron, and Zinc), Vitamins (A and C), high energy value nutrition, and anti-nutritional factors, of which its high energy value (2.45 kcalg^{-1}) is almost comparable to the average energy value for maize (2.78 kcalg^{-1}) and has good sources of Vitamin C (3.31 mgg^{-1}) (Aragaw *et al*., 2021). The macronutrient combination content of the fruits, such as fat, protein (a variety of amino acids), and carbohydrate, was reported by Sibiya *et al*., (2021). The plant species also commonly serves as shade in *Coffea arabica* L. farmland in the southern and southwestern parts of Ethiopia. The project completion report for supporting sustainable forest management through reducing emissions from deforestation and forest degradation in developing countries and certified forest coffee production and promotion in Ethiopia indicates that the middle canopy of Moist Afromontane forests in the southwestern part of the country, known as the homeland of *C. arabica*, has been occupied with diversified coffee shade trees, including *S. afromontanum* (FDRE, 2020). Medicinal importance is another contribution of the plant species in the country. A qualitative chemical assay from the leaf extract of the species revealed that the plant species is endowed with different plant secondary metabolites such as terpenoids, alkaloids, triterpenes, flavonoids, anthraquinones, tannins, glycosides, saponins, and phenols, and the alkaloids present in this plant product are generally known for their anti-malarial activity (Tadesse and Wubneh, 2017). Based on the priority for removal done by the Ethiopian Biodiversity Institute for the identified socio-economically important trees and shrubs, the species is included among the top priority conservation lists suggested for plants (IBC, 2012). To mitigate the risk of climate change on such socio-economically important plants, integration of indigenous knowledge into climate change adaptation processes in an appropriate and mutually agreed-upon manner has a beneficial effect (Mafongoya and Ajayi, 2017). Such integration into climate change policy ensures poverty reduction and sustainable development (Ajani *et al*., 2013). Traditional and indigenous ecological knowledge could decrease further biodiversity loss and meet food security under climate change scenarios (Ajani *et al*., 2013).

Hence, distribution modeling is essential to studying various aspects of species restoration and management to conserve and improve their economic, social, and ecological values (Piri Sahragard *et al*., 2021). In this study, distribution modeling was done to understand the current distribution of *S. afromontanum* and predict its response to future climate change. This is used to examine habitat determinants as well as the impact of climate change on future species distribution. These can inform policymakers about the likely shifts in suitable habitat areas and categorize which areas of this ethnobotanically valuable and prioritized wild edible plant will likely be changed in the future. It can also benefit conservationists to understand the implications that range shifts have on local and indigenous knowledge associated with the plant. This is because modeling is widely used as a tool in ecology and conservation biology (Guisan and Thuiller, 2005; Brown, 2014; Brown *et al*., 2017) and is one of the main possible approaches to obtaining a comprehensive, quantitative understanding of the potential complexity of factors limiting the range of highly valuable wild edible plants such as the species under study. Thus, the following question was addressed: (1) will there be any significant change in the area coverage of future potential habitats for *S. afromontanum* under the climate change scenarios of Representative Concentration Pathway (RCP) 4.5 and RCP 8.5?

5.2. Material and Methods

5.2.1. Study area

The species distribution study was carried out at country level in Ethiopia, which is located at the Horn of Africa and lies between 3.30–15^{o}N latitudes and 33–48^{o}E longitudes, covering $1.13x10^{6}$ km^{2} with a heterogeneous landscape ranging from high and rugged mountains, flat-topped plateaus, deep gorges, and incised rivers to valleys and rolling plains with the peripheral arid and semi-arid lowlands (Wakjira, 2006; Sintayehu *et al*., 2020; Zewudie *et al*., 2021). The country has an elevation range of 116 m below sea level at Danakil depression to 4532 m above sea level at Mountain Ras Dashen. Geographically, it is bordered by Eritrea to the North, Djibouti to the East, Somalia to the southeast, Kenya to the South, South Sudan to the West, and Sudan to the northwest. In the past, the country had been known by several vegetation types, which were classified in several ways. But recently, the vegetation of the country has been categorized into 12 potential vegetation types (Friis *et al*., 2010) as indicated in Table 5.1. These vegetation types have been further classified into five adopted major biomes (vegetation types) (EFCCC, 2017). The targeted species has been restricted to certain of these vegetation types in the country. By considering such circumstances and to minimize the color complexity produced in the spatial model, the five major adopted biomes (Figure 5.1, Table 5.1) rather than the twelve potential vegetation types of Ethiopia were used to produce the map that indicates the current and future distribution of the species. This might play an important role in the management practices taken to conserve the species in their suitable ecosystems under climate change conditions.

Table 5.1The five major biomes of Ethiopia that were adopted from the 12 potential vegetation types of Friis et al. (2010)

No	**The 5 adopted major vegetation types**	**Twelve potential vegetation types**
1	Acacia-Commiphora Woodland (ACW)	Acacia-Commiphora woodland and bushland; Acacia wooded grassland; and Desert and semi-desert scrubland
2	Combretum-Terminalia Woodland (CTW)	Combretum-Terminalia woodland and wooded grassland; and Wooded grassland of the Western Gambella region
3	Dry Afromontane Forest (DAF)	Dry evergreen Afromontane Forest and Grassland complex; Afro-Alpine vegetation; and Ericaceous Belt
4	Moist Afromontane Forest (MAF)	Moist Afromontane Forest; and Transitional Rain Forest
5	Others	Salt Pans, Saline/brackish and Intermittent wetlands and Salt-lake Shore Vegetation; Salt Lake open water vegetation; Freshwater marshes and swamps, Floodplains and Lake Shore vegetation; and Freshwater lakes–open water vegetation

5.2.2. Occurrence data collection

Presence records used to model potential distribution areas of *S. afromontanum* were obtained from specimens assessed at the National Herbarium, Addis Ababa University, Ethiopia; published materials (Kebede *et al*., 2014; Raga and Seid, 2017; Tegene, 2018); and records done by using GPS (Global Positioning System) in West Shewa, Ethiopia, during field survey. The data was also sourced from the Global Biodiversity Information Facility (GBIF), which was accessed at www.gbif.org/species on August 12, 2021. After all known niches of the species (a total of 71 occurrence data) were sourced and the removal of redundant records was done, the rarefication of the data by SDMtoolbox version 2.4 at a 1km interval left over a total of 47 actual geographic coordinates, which were arranged on an Excel spreadsheet to have a comma-separated values (csv) file. This process is used to minimize sampling bias by reducing the clustering of occurrence points within a particular radius, which in turn reduces the degree of model overfitting (Driver *et al*., 2020). These points were checked using ArcGIS version 10.7 and Google Earth for visual observation and their spatial accuracy prior to use. These occurrence point distributions were shown on five adopted biomes in Ethiopia (EFCCC, 2017), which are expected to be the potential ecosystems of species (Figure 5.1).

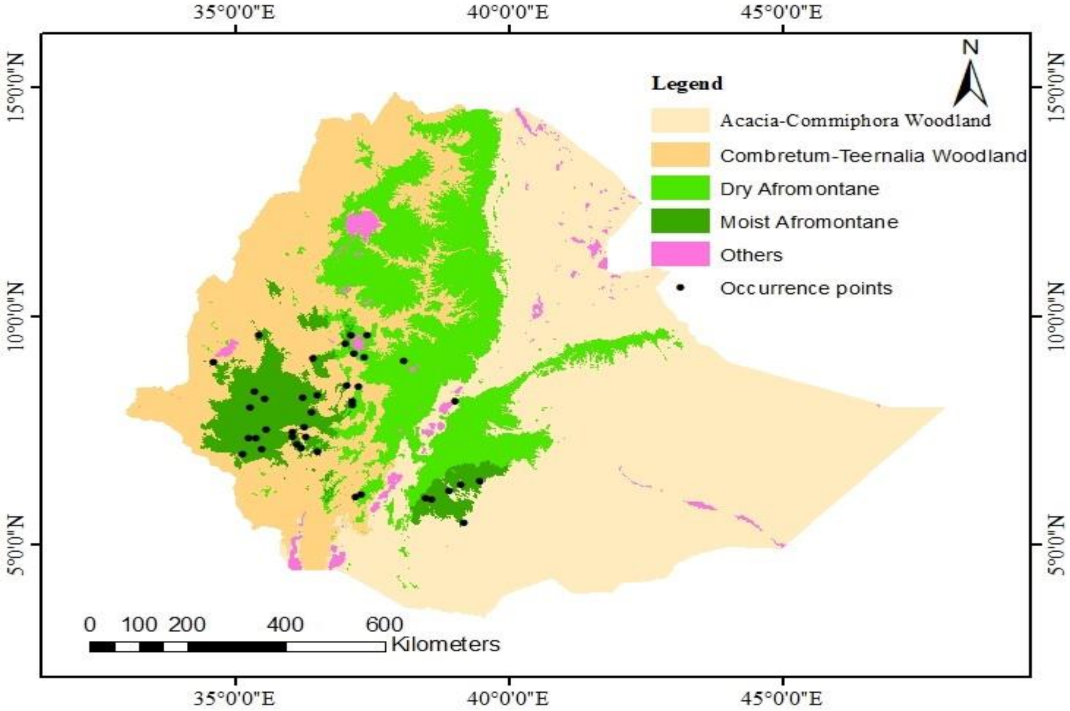

Figure 5.1 Occurrence points of *S. afromontanum* in relation to the major vegetation types of Ethiopia

5.2.3. Predictor variable data

The bioclimatic variables in the WorldClim database were used for modeling the current and future potential distribution areas for the selected species (Elith *et al*., 2006; Phillips *et al*., 2006). Accordingly, the 19 bioclimatic variables having a spatial resolution of 30 arc seconds (~1km^2) and the Solar radiation index (Sri) accessed from www.worldclim.org/data/worldclim21.html of the observation dataset version 2.1 were downloaded in the standardized Tiff format and used as current input data for distribution modeling. Furthermore, two topographic layers (altitude and topographic position index) at www.gscloud.cn from the space-born thermal emission and reflection radiometric Digital Elevation Model (Aster DEM) were downloaded and used for distribution modeling. The details of the variables are provided in Table 5.2.

For future projection, the General Circulation Model (GCM) representative, Coupled Model Intercomparison Project Phase 5 (CMIP5), was used to predict the potential habitat distribution of *S. afromomtanum*. This is because for historical simulations of precipitation in East Africa, the CMIP5-GCM performs well (Ongoma *et al*., 2019). On the 5th assessment report of 2014, the Inter-governmental Panel on Climate Change (IPCC) adopted four RCP scenarios (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5) from the green house concentration trajectories by using emission scenarios from various literature reports as range reports of forcing levels (IPCC, 2008). RCP 2.6 is the climate change scenario with the lowest greenhouse gas (GHG) emissions (Driver *et al*., 2020); RCP 4.5 and 6.0 are intermediate or stabilization scenarios in which climate policies are expected to limit emissions (Thomson *et al*., 2011; Driver *et al*., 2020; Sintayehu *et al.*, 2020); and RCP 8.5 is the most extreme scenario in which an absence of climate change policies leads to the highest future GHG emissions (Riahi *et al*., 2011; Driver *et al*., 2020) and is considered the worst scenario (Sintayehu *et al.*, 2020). Accordingly, the four data combinations RCP 4.5/2050, RCP 8.5/2050, RCP 4.5/2070, and RCP 8.5/2070 of the greenhouse gas concentration trajectories of the 2050s (2041–2060) and the 2070s (2061–2080) were downloaded at http://www.worldclim.com/CMIP5_30s and used to analyze the impact of climate change on species distribution.

In order to assess multicollinearity and to determine and exclude extremely correlated variables, we cross-checked the variable factors by Pearson pairwise correlation matrix analysis (Elith *et al*., 2006; Poloczanska *et al*., 2013). Hence, the 22 environmental variables were subjected to a correlation test using SDMtoolbox version 2.4 after adding the toolbox to the ArcGIS platform. In order to minimize the effect of multicollinearity and model overfitting or underfitting, the correlation coefficient ($r < 0.7$) was used as a cutoff limit to remove one of the highly correlated variables. This cutoff point was commonly used to fit the model into environmental variable data (Barbosa *et al*., 2013; Khan *et al*., 2022; Tadesse *et al*., 2023). Finally, 11 environmental data layers, which include 3 topographic variables (Sri, elevation, and Tpi), and 8 other environmental layers (Bio2, Bio3, Bio4, Bio11, Bio15, Bio17, Bio18, and Bio19) were used for the MaxEnt model manipulation (Appendex 5).

Table 5.2 Environmental variables and codes used in the species distribution modeling

Variable code	Types of Environmental variables	Unit
Bio1	Annual Mean Temperature	^oC
Bio2	Mean Diurnal Range (Mean of monthly (max temp-min temp))	^oC
Bio3	Isothermality (Bio_2/Bio_7)(x 100)	^oC
Bio4	Temperature seasonality (Standard deviation x 100)	^oC
Bio5	Max Temperature of Warmest Month	^oC
Bio6	Min Temperature of Coldest Month	^oC
Bio7	Temperature Annual Range (Bio_5-Bi0_6)	^oC
Bio8	Mean Temperature of Wettest Quarter	^oC
Bio9	Mean Temperature of Driest Quarter	^oC
Bio10	Mean Temperature of Warmest Quarter	^oC
Bio11	Mean Temperature of Coldest Quarter	^oC
Bio12	Annual Precipitation	mm
Bio13	Precipitation of Wettest Month	mm
Bio14	Precipitation of Driest Month	mm
Bio15	Precipitation Seasonality (Coefficient of Variation)	mm
Bio16	Precipitation of Wettest Quarter	mm
Bio17	Precipitation of Driest Quarter	mm
Bio18	Precipitation of Warmest Quarter	mm
Bio19	Precipitation of Coldest Quarter	mm
Sri	Solar radiation index	w/m^2
Elevation	Elevation	m
Tpi	Topographic position index	-

5.2.4. Modeling procedures

In order to extrapolate the model, the current and future climate data layers were converted into grid format, and then data for the required study area was extracted by layer using ArcGIS version 10.7 through masking with the country shape file. Then after, the extent, resolution, and spatial reference of all environmental layers were adjusted to the same spatial resolution of 30 s (~1km^2 at ground level) using geo-processing by data management and spatial analyst tools in ArcGIS to produce Ascii raster grid files that have the same geographic bounders and cell size. After the MaxEnt run, the average distribution map output of both climate change scenarios was clipped and extracted by the mask tool, and the area of each of the five vegetation ecosystems was used as a masking feature. By using the clipped features of each climate change scenario, we reclassified them into potential dispersal area classes. This was done to evaluate the species current distribution and predict distribution areas in the five major biomes under the climate change scenarios RCP 4.5 2050, RCP 8.5 2050, RCP 4.5 2070, and RCP 8.5 2070.

5.2.5. MaxEnt calibration and distribution modeling

The MaxEnt modeling algorithm, version 3.4.1, was used for predicting the current and future potential distribution areas of a species under different climate change scenarios. Hence, the two files, comma-separated values (csv) and ASCII raster grids were uploaded to MaxEnt to perform its calculations across the study area landscape. For the model calibration, the random test percentage entry was fixed to 25. This randomly set aside 25% of the species occurrences recorded for testing, and the remaining 75% were to be selected for training batches. The first batch was the input for the predictive cell values that the model will generate, and the second batch is used as the standard for evaluating how well the model performs (Williams *et al*., 2009). Ten replicated model runs with 500 maximum numbers of iterations, 0.00001 convergence thresholds, 10,000 maximum numbers of background points, and subsample replication run types were used for the MaxEnt run. Multiple runs provide a way to measure the amount of variability in the model (Phillips and Dudík, 2008). Additionally, linear and quadratic features were selected for the modeling process. This is to minimize the complexity of prediction and overfitting (Phillips and Dudík, 2008), and selections of the two processes achieve a higher average AUC value than did just using the linear feature alone (Andersona and Gonzalez, 2011). Then the program was allowed to create a response curve, make a picture of prediction, and do jackknife to measure variable importance under the logistic output format, which gives an estimate of the probability of presence (ranging from 0 to 1) (Phillips and Dudík, 2008).

5.2.6. Species distribution model performance evaluation

The area under the Receiver Operating Characteristic (ROC) curve (AUC) is one of the most common measures of model performance across all possible thresholds (Scheldeman and Zonneveld, 2010; Graham *et al.*, 2011). The AUC value obtained can be interpreted as the estimated probability of the randomly selected grid cell in a correctly adjusted model and defines the success of the model with all possible thresholds (Çoban *et al.*, 2020; Gebrewahid *et al.*, 2020). Thus, model performance evaluation was categorized based on the AUC values, which range from 0 to 1, where 1 indicates perfect discrimination of performance while 0 indicates no predictive ability of the model (Swets, 1988; Elith *et al.*, 2006; Andersona and Gonzalez, 2011); an AUC value < 0.5, which is similar to random prediction, indicates less predictive ability of the model (Swets, 1988; Elith *et al.*, 2006; Scheldeman and Zonneveld, 2010; Mbatudde *et al.*, 2012; Gebrewahid *et al.*, 2020). So, the following threshold categories of AUC values were used in the model: excellent ($0.90<AUC\leq1$), very good ($0.80>AUC\leq0.90$), good ($0.70>AUC\leq0.80$), acceptable ($0.60>AUC\leq0.70$), and bad ($0.50>AUC\leq0.60$) (Swets, 1988). On the other hand, partial area under the ROC curve (p-AUC-ROC) and estimate AUC ratios were computed and used as alternative metrics of model performance evaluation, as underlined by Khan *et al.*, (2022). Hence, the descriptive statics test for p-AUC-ROC at the maximum number of iterations of 500 was estimated at a 95% confidence interval ($P=0.05$) by the Niche Toolbox R package available online at http://shiny.conabio.gob.mx:3838/nichetoolb2/. Model performance evaluation was done based on the p-AUC-ROC curve value, where a value > 0.9 indicates excellent model performance and > 0.8 is considered good (Manel *et al.*, 2001; Khan *et al.*, 2022). Similarly, an AUC ratio value > 1.8 (or closer to 2) is regarded as excellent model fit (Khan *et al.*, 2022).The jackknife test result was used to determine the contribution of each environmental variable to predicting the distribution of *S. afromontanum* in the five major biomes of Ethiopia. This test is important to determine the significance of each independent variable in the creation of the model (Elith *et al.*, 2011; Çoban *et al.*, 2020).

5.2.7. Examination method of climate change impact on a species distribution

ArcGIS 10.7 was used to examine the impact of climate change on the *S. afromontanum* probability distribution and compare the potential distribution areas under current and future climate conditions. The average outputs of raster maps generated in MaxEnt under both climate projections were imported to ArcGIS 10.7, and the pixel values were re-classed based on the band category values (0–1) produced while MaxEnt run. Thus, for four categorical suitability areas, band category values (0.85–1.0) for highly suitable area, (0.69–0.85) for moderately suitable area, (0.38–0.69) for low suitable areas, and (0.0–0.38) for unsuitable areas were used for the classification (Tadesse *et al*., 2023). Finally, potential area change (gain or loss) assessment was computed between current and future climate change scenarios (2050 RCP 4.5, 2070 RCP 4.5, 2050 RCP 8.5, and 2070 RCP 8.5). This was calculated under four categorical suitability areas after classified pixels were exported from ArcGIS 10.7 to an excel spread sheet for further calculations. Therefore, the species suitability area change relative percentage, or hectares, for each suitability category was calculated simply by subtracting the current from the future scenarios of the same suitable area categories.

5.3. Results

5.3.1. Model performance evaluation and the importance of variables under the current climatic conditions

The average AUC value (0.924) for the 10 replicate runs under the current climatic conditions revealed excellent predictive performance of the model for *S. afromontanum* (Figure 5.2). The p-AUC-ROC value (0.937) and the AUC ratio (1.875) recorded for the species distribution model prediction under the current climatic conditions also showed the greatest model fit (Appendex 6). The importance of each environmental variable to the model performance was assessed through Jackknife tests. The test evaluation indicated that the Solar radiation index (Sri) was the strongest predictor, followed by Precipitation of the Coldest Quarter (Bio19), Precipitation of the Driest Quarter (Bio17), and Mean Temperature of the Coldest Quarter (Bio11), respectively, while the mean diurnal range (mean of monthly (max temp-min temp)) (Bio2) was the weakest.

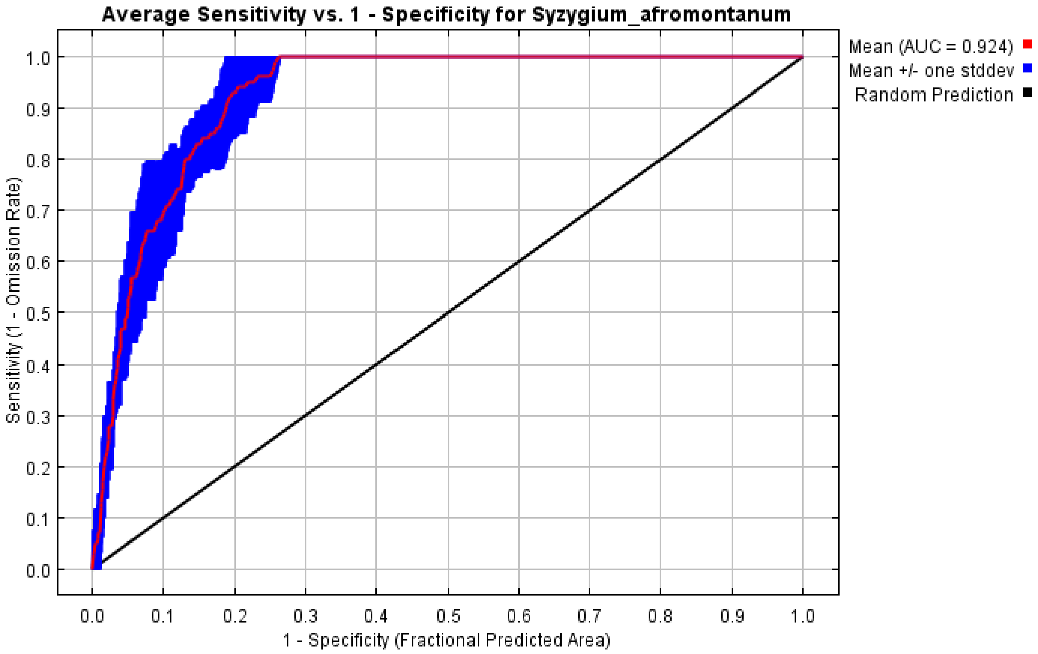

Figure 5.2 ROC curve AUC value under current climatic condition (10 times replicated run)

The variable percentage contributions of the MaxEnt model revealed that Sri (53.1%), Bio19 (17.5%), and Bio17 (8.1%) had the most significant effect on the distribution model prediction, which means that these environmental factors contributed the most to the spread of *S. afromontanum* under the current climatic scenario (Table 5.3). The relevance of the bioclimatic and topographic variables indicated by permutation importance shows that Bio11 and Sri shared the maximum percentage contribution of 39% and 32.8% to the distribution model, respectively, while other variables collectively contributed 28.2% (Table 5.3). The response curves for the important variables show that Sri, Bio19, Bio17, and Bio11 have greater influences on the distribution of *S. afromontanum* (Appendex 7). The species prefers an optimum range of 1500 to 1600 w $(m^2)^{-1}$ solar radiation, 1120 to 1250 mm of Precipitation in the Coldest Quarter, 210 to

240 mm of Precipitation in the Driest Quarter, and 2.5 to 4.3 °C Mean Temperature of the Coldest Quarter.

5.3.2. Current potential distribution of *S. afromontanum*

Out of the total land mass of the study area, 0.04%, 1.24%, and 7.49% were recognized as highly suitable, moderately suitable, and less suitable habitats for *S. afromontanum*, respectively, while 91.22% of the country was identified as unsuitable (Figure 5.3, Table 5.4). The image with red, blue, and gray colors, respectively, revealed a high, moderate, and low probability of prediction for *S. afromontanum* in the major vegetation types of Ethiopia (Figure 5.3).

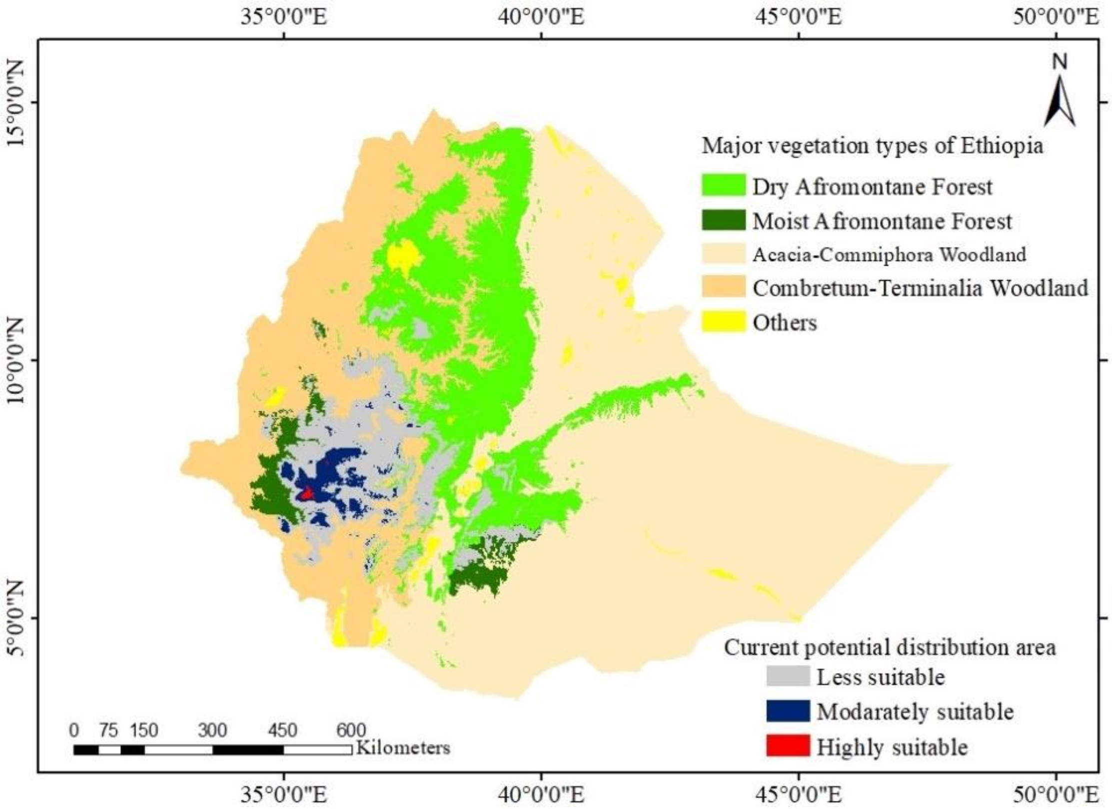

Figure 5.3 Current potential distribution area of *S. afromontanum*

5.3.3. Future model evaluation and the important variables under different scenarios

The AUC values for the predicted models for 2050 RCP 4.5, 2050 RCP 8.5, 2070 RCP 4.5, and 2070 RCP 8.5 were 0.919, 0.914, 0.927, and 0.931, respectively. As per the threshold categories of AUC values stated by Swets (1988) and Elith *et al*. (2006) all results indicated that the predicted model of *S. afromontanum* was evaluated with excellent accuracy and discrimination. The p-AUC-ROC value and the AUC ratio (0.926, 1.852), (0.923, 1.856), (0.939, 1.876), and (0.938, 1.875) recorded for the species distribution model prediction under the 2050 RCP 4.5, 2050 RCP 8.5, 2070 RCP 4.5, and 2070 RCP 8.5 climatic scenarios, respectively, also showed a greater model fit (Appendex 6). The jackknife test of all future scenarios indicated that the distribution of *S. afromontanum* was mainly determined by Sri, while the Bio2 environmental variable contribution indicated a very weak influence (Figure 5.4).

Analysis variables contribution to the model showed that Solar radiation index (Sri) highly contributed to the model prediction under both climate change scenarios and recorded variable percentage contribution importance of 51.1, 50.8, 60.7, and 51.6 for 2050 RCP 4.5, 2050 RCP 8.5, 2070 RCP 4.5, and 2070 RCP 8.5, respectively (Table 5.3). Precipitation of the Warmest Quarter (Bio18) was the second most influential variable in all future predictions except for that of RCP 8.5 2050, where Precipitation of the Driest Quarter (Bio17) was the second most significant influential variable (Table 5.3, Figure 5.4).

Table 5.3 Estimates of relative environmental variable percentage contributions (%) and permutation importance (PI) to the MaxEnt model

Period		**Variable**	**Bio2**	**Bio3**	**Bio4**	**Bio11**	**Bio15**	**Bio17**	**Bio18**	**Bio19**	**Sri**	**Elevation**	**Tpi**
Current	RCP	%	0.1	0.5	1.1	7.1	5.3	8.1	3	17.5	53.1	3.4	0.7
		PI	0.5	-	5.9	39	6.7	-	-	4.7	32.8	9.6	0.8
2050	4.5	%	0.7	1.2	10.7	0.8	1.1	3.5	27.5	2.6	51.1	0.6	0.1
		PI	0.2	0.3	30.8	9.4	0.5	0.2	1.3	0.2	55.3	1.9	0.1
	8.5	%	0.8	3.3	9	0.6	0.9	20.9	8.2	5.3	50.8	0.3	-
		PI	0.2	0.2	64.7	4.1	1.8	0.1	0.9	1.1	25.9	1.1	-
2070	4.5	%	0.5	2.8	9	0.5	1	8.1	13	3.8	60.7	0.4	0.3
		PI	0.1	0.3	29.8	7.9	1	0.2	2.4	0.5	54.4	3	0.4
	8.5	%	0.5	2.5	8.8	0.7	0.6	12.7	20	1.8	51.6	0.6	0.2
		PI	-	-	20.4	9	0.7	-	1.3	0.1	64.2	3.9	0.2

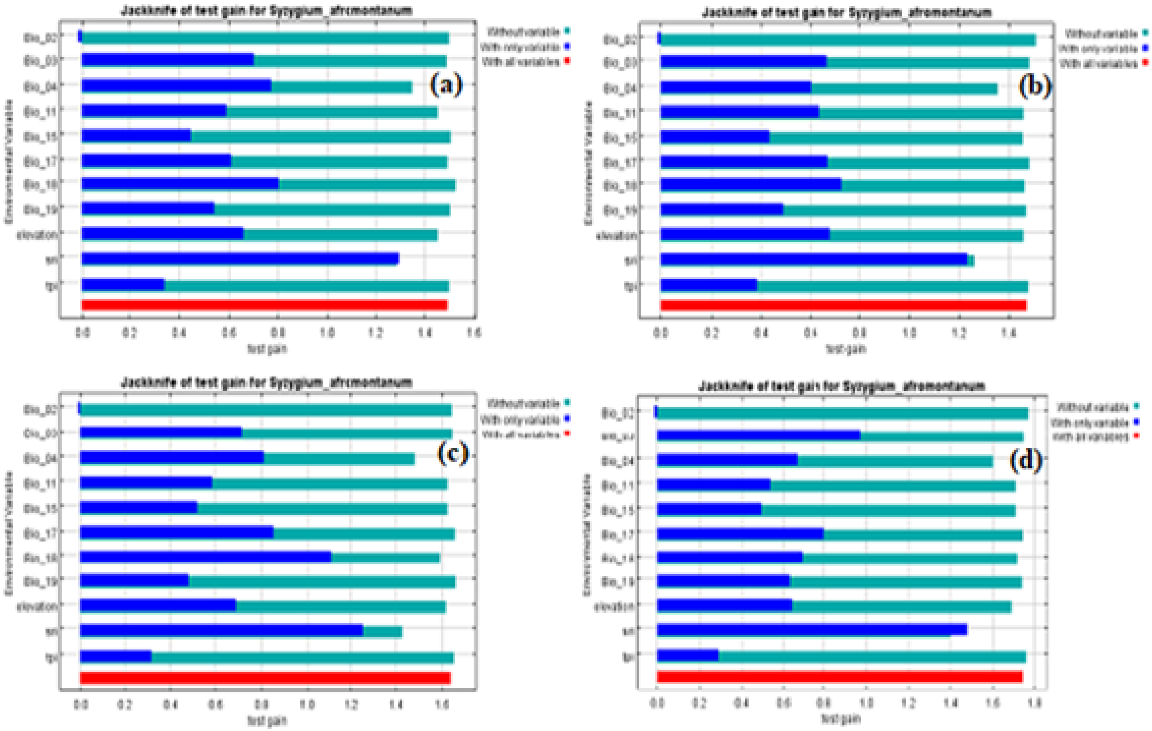

Figure 5.4 Jackknife tests that shows the relative predictive power of variables with respect to test gain under (a) 2050 RCP 4.5, (b) 2050 RCP 8.5, (c) 2070 RCP 4.5, and (d) 2070 RCP 8.5

5.3.4. Predicted potential distribution area of *S. afromontanum* under future scenarios

Projection for potential distribution area spatial analyses by ArcGIS indicated that, out of a total potential area of 1132289457.4 ha, 0.1%, 0.12%, 0.11%, and 0.18% were predicted as highly suitable, 1.29%, 1.37%, 1.39%, and 1.19% as moderately suitable, 4.17%, 3.97%, 4.51%, and 4.55% as less suitable for *S. afromontanum* under climate change scenarios of 2050 RCP 4.5, 2050 RCP 8.5, 2070 RCP 4.5, and 2070 RCP 8.5, respectively, while most of the areas were a part of unsuitable classes and cover an area of 94.43%, 94.54%, 93.99%, and 94.08 % under 2050 RCP 4.5, 2050 RCP 8.5, 2070 RCP 4.5, and 2070 RCP 8.5 climate change scenarios, respectively (Table 4). MaxEnt average predictions under both future scenarios reflected a reduction in total suitable habitats (Table 5.4). Under each future climate condition, high, moderate, and low probability predictions for the species were indicated by red, blue, and gray colors, respectively, and the unsuitable area class category was the total land mass beyond those colors (Figure 5.5).

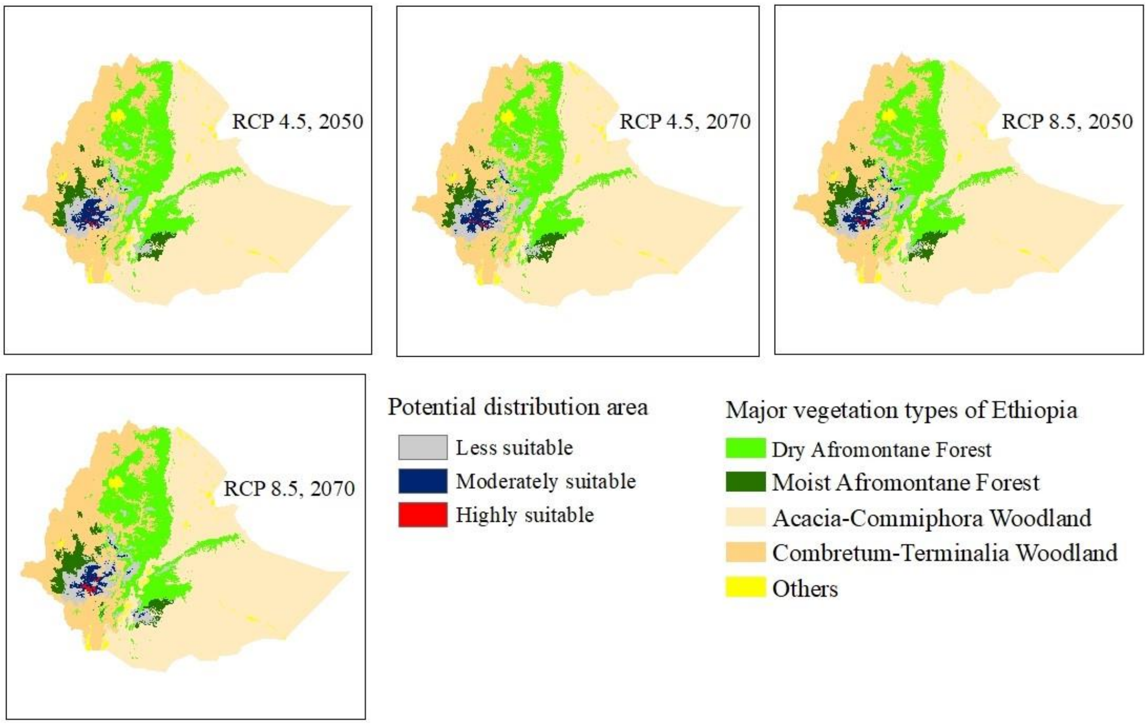

Figure 5.5 *Syzygium afromontanum* potential distribution area of 2050 RCP4.5, 2050 RCP 8.5, 2070 RCP 4.5, and 2070 RCP 8.5 scenarios

5.3.5. Future distribution area change of *S. afromontanum*

The current total distribution areas of the species would decrease by 3.21%, 3.32%, 2.77%, and 2.86% under 2050 RCP 4.5, RCP 8.5, 2070 RCP 4.5, and 2070 RCP 8.5, respectively (Table 5.4). This is because the species would be extremely vulnerable in its low-suitable area in all future scenarios, while the high and moderate-suitable area categories showed a small increment throughout both future climatic conditions when compared to the current highly potential area. Compared to the current situation, the unsuitable area of *S. afromontanum* increased under all future scenarios (Table 5.4).

Table 5.4 Percentage (%) and hectares (ha) of predicted area suitability under current, mid-century (2050) and end century (2070) scenarios with change gain or loss. Few and many digits number in each cell of the table shows % and ha, respectively

	Scenario				
Area	Current	PCR 4.5, 2050	PCR 8.5, 2050	PCR 4.5, 2070	PCR 8.5, 2070
Highly suitable	0.04 48479.3	0.10 114133.7	0.12 140107.8	0.11 127839.9	0.18 202885.6
Moderate suitable	1.24 405477.9	1.29 1463433.2	1.37 1550916	1.39 1571136.8	1.19 1344307.7
Less suitable	7.49 8490230.6	4.17 4727793.6	3.97 4494872.8	4.51 5111651.8	4.55 5156746.9
Unsuitable	91.22 103345269.6	94.43 106984096.9	94.54 107103560.9	93.99 106478828.8	94.08 106585517.2
Total suitable area	8.78 9944187.9	5.57 6305360.5	5.46 6185896.6	6.01 6810628.6	5.92 6703940.2
Area change	-	-3.21 -3638827.4	-3.32 -3758291.3	-2.77 -3133559.3	-2.86 -3240247.7

5.4. Discussions

Distribution modeling is a common approach that correlates species presence with climate and environmental variables and can then be used to project distributions under future climate conditions (Friggens *et al*., 2013). Understanding the potential suitable areas of the species in indigenous flora is very important for designing conservation strategies to mitigate future climate change impacts on the species (Tadesse *et al*., 2023) and the robust methods used to understand current species distribution patterns and predict future distributions are MaxEnt methods of modeling (Hallstan, 2011; Guisan and Thuiller, 2005; Brown, 2014).

5.4.1. Model performance evaluation and environmental variables contribution

As Swets (1988) and Elith *et al*. (2006) stated, an AUC value > 0.75 has a useful amount of model performance discrimination, and even an AUC value > 0.5 performed better than random in evaluating the performance of a niche model. The present and future potential distribution of *S. afromontanum* was modeled as a function of Ethiopia's climate. The model achieved an average AUC value of 0.923, which is within the acceptable range for models to be considered robust. In this regard, the Phillips (2006) statement that species with a restricted biological range might have AUC values that tend to be higher in comparison to the study region as determined by the environmental data is consistent with our findings. Another alternative model accuracy evaluation was recorded for the p-AUC-ROC values and the AUC ratios for the species distribution model prediction under all climatic scenarios, and the two alternative accuracy measuring results indicate a great model fit. According to Manel *et al*. (2001) and Khan *et al*. (2022), the findings of p-AUC-ROC values greater than 0.9, which is closer to 1, and AUC ratios closer to 2 showed excellent model performance. After removing auto-correlated environmental factors (Appendex 5), the MaxEnt result indicated the potential distribution area of *S. afromontanum* is mostly influenced by Sri and precipitations (Bio19), which contributed 70.6% together and determine the current potential distribution range of the species (Table 3). Precipitation and solar radiation were also reported as influential environmental factors in determining the potential distribution of other species, including *Vachellia negrii* (Pic.Serm.) Kyal. & Boatwr. (Semu *et al*., 2021), *Piper capense* L.f., and *Aframomum corrorima* (A.Braun) P.C.M.Jansen (Enkossa *et al*., 2022). Precipitation was also reported as one of the main influential factors in determining the potential distribution of *Prunus africana* (Hook.f.) Kalkman (Mbatudde *et al*., 2012) and *Oxytenanthera abyssinica* (A. Rich.) Munro (Gebrewahid *et al*., 2020) in Ethiopia. The most suitable areas of the plant species under study need an optimum range of 1500 to 1600 w $(m^2)^{-1}$ solar radiation, 1120 to 1250 mm of Precipitation in the Coldest Quarter, and 210 to 240 mm of Precipitation in the Driest Quarter for the species best dispersal, growth, and survival.

5.4.2. *Syzygium afromontanum* potential distribution area changes in the future scenario

The climate change scenarios of the 2050 and 2070 obtained from the Coupled Model Inter-comparison Project Phase 5 (CMIP5) were used in future model projections to assess the significant effect on species distribution. In response to the global climate change scenario, the model predicted that there were four categories of distribution regions: highly suitable, moderately suitable, less suitable, and unsuitable areas, of which the majority of land mass would be unsuitable areas that commonly occupied by ACW and CTW biomes. As indicated in the predicted model, *S. afromontanum* has very narrow ecologically suitable areas for the best dispersal, growth, and survival that are confined to the southern and southwestern parts of the country, which are consistently shown to lie mainly in MAF and DAF ecosystems in the indigenous flora of Kefa, Ilubabor, Jimma, Wollega, Bale, and Shewa floristic regions. Particularly, our model showed that a highly potential area for the species was the southwestern central parts of Ethiopia, most probably in the Moist Afromontane Forest, Transitional Rain Forest, Dry Evergreen Afromontane Forest, and Grassland Complex vegetation types of the country where solar radiation and moisture are prevalent. The finding was consistent with the project completion report for supporting sustainable forest management through reducing CO_2 gas emissions from deforestation and forest degradation in developing countries, and certified forest coffee production and promotion indicates that the middle canopy of Moist Afromontane forests in the southwestern part of the country, known as the homeland of *C. arabica*, has been occupied with diversified coffee shade trees, including *S. afromontanum* (FDRE, 2020). It was also in agreement with the narrow ecological range of the species reported by Tebkew (2015), and the species is geographically restricted to upland rain forests and riverine forests in Ethiopia, where the altitudinal range is 1400–2600 m (Edwards *et al*., 1995).

The result of the future model prediction under the two climatic change scenarios for the years 2050 and 2070 indicated a remarkable reduction tendency in the total suitability areas of *S. afromontanum* in the homeland ecosystems, particularly in the MAF and DAF biomes. On the other hand, the trend showed that the unsuitable habitat of the species would be effectively increasing under these climate change scenarios. Out of total suitable area (8.78%) under current climatic conditions, there would be a reduction by 3.21% and 3.32% under climate change scenarios of RCP 4.5 and RCP 8.5 of the mid-century (2050s), respectively, while it would be reduced by 2.77% and 2.86% under climate change scenarios of RCP 4.5 and RCP 8.5 of the end century (2070s), respectively (Table 4). These circumstances revealed that potential areas of the species would not be similarly reduced under the four climate change conditions. Similar to this, Zewudie *et al*. (2021) stated that the distribution of a species might not be uniformly affected under different climate change scenarios. In agreement with our finding, from the current climate condition to intermediate and extreme climate change scenarios in the future, a decreasing trend in the possible distribution area of *Osyris quadripartita* Decn. by Getaneh *et al*., (2023), *Pouteria adolfi-friederici* (Engl.) A. Meeuse, and *Prunus africana* by Tadesse *et al*., (2023) in the principal vegetation type of Ethiopia was recorded. A comparison of the future climate change scenarios indicated that the total suitable areas for the dispersal, growth, and survival of *S. afromontanum* in the RCP 4.5 climatic condition were lower than the RCP 8.5 both under the mid-century and end-century scenarios. A further increase in temperature could cause potential habitat shifting in its ecological niche towards higher altitudes. Chen *et al*. (2011) reported that the distributions of many terrestrial organisms are shifting in latitude or elevation in response to a changing climate. The ability of species and natural communities to shift geographically in conjunction with climate change is an important aspect of adaptive capacity (Friggens *et al*., 2013).

Comparing to the current, the mid-century (2050s) provided more favorable outcomes in terms of suitable *S. afromontanum* habitat reduction than the end-century (2070s). This indicated that such ecologically localized species that contribute high socio-economic value among the indigenous people are therefore likely to be highly sensitive to global warming by 2050, and a strong negative impact would be expected in terms of habitat reduction. Similarly, projections from the end-century (2070s) reduce the preservation potential area for the species due to projected climatic change and an increase in temperature, and this might cause range shifting in habitat from the lowland and midland native ecological niches to the more elevated areas. In connection with area shifting, local and indigenous knowledge of the people related to the use and management of such highly prioritized wild edible plants and their potential for better socio-economic uses in the future might be lost or reduced. Communities that use plant species as food and medicine will be affected too (Muluneh, 2021). Within its ecological niche, the plant under study serves as coffee shade on the *C. arabica* farm; its indication of environmental integrity and its role in the restoration of the southern and southwestern degraded ecosystems in the MAF and DAF of the country might also be affected due to potential area reduction. To prevent range shifting of such plants from their native areas, the integration of indigenous and local knowledge into climate change adaptation policy in an appropriate manner is recommended for its beneficial effect (Mafongoya and Ajayi, 2017). Community-based management of genetic resources preserves local varieties or indigenous species with associated indigenous knowledge loss and ensures poverty reduction and sustainable development (Ajani *et al*., 2013). Therefore, this study recommends the inclusion of future climate scenarios into current restoration and conservation policies to protect such socio-economically valuable and ecologically sensitive species in their current habitat. Conservation of the species in its native area is very useful to conserve indigenous and local knowledge associated with the species.

Overall, the current and future potential distribution of *S. afromontanum* was modeled by MaxEnt algorithm methods. The parameters used for evaluating the model performance and its predictive ability were the AUC value, p-AUC-ROC value, and AUC ratio, and the AUC value ranges from 0.914–0.931, p-AUC-ROC value ranges 0.923–0.939, and AUC ratio ranges 1.852–1.876 under all climate change scenarios indicated that each model was robust enough to discriminate the background into presence and absence classes for this species with excellent accuracy. The main determinants of environmental factors in the current distribution model are the solar radiation index and the precipitation in the coldest and driest quarters. The distribution models also revealed that climate change would cause a significant change in future suitable habitat for this species. The Solar radiation index (Sri) also played the greatest role in the predicted model discrimination of all future climate change scenarios. The other most influential variables in the future predictions were the Precipitation of Warmest Quarter (Bio18) and the Precipitation of the Driest Quarter (Bio17). In this way, the proportion of suitable area for the species would be reduced in the mid-century (2050s) and end-century (2070s) under each climatic change scenario. The consequence of this situation has a long-term effect on the use value and its associated local and indigenous knowledge. In order to protect areas shifting from their niche and shifting effect, this study suggests the integration of future climate scenarios into current restoration and conservation policies to conserve such highly prioritized and socio-economically valuable species in their native ecological ranges.

CHAPTER SIX

6. General Discussion, Conclusion, and Recommendation

6.1. General discussion

This study emphasized the evaluation of LULC changes, assessment of woody species diversity potential of various agroforestry systems, and underutilized wild edible plants in the modified landscapes of the western central plateau of Shewa, Ethiopia, and was intended to predict the suitable habitat range of *S. afromontanum* under the current and future climate change conditions in Ethiopia. The influences of long-term land use transformations through traditional agroforestry practices on the diversity of woody species and the potential utilization of wild edible plants, as well as the effect of land use and land cover modifications and climate change pose on the potential distribution of the intended narrow ecological range of edible species were addressed. This is because, over the past three decades, there has been a serious decline in natural vegetation area, particularly of forest (FAO, 2015), and this has affected terrestrial ecosystem quality (Wassie, 2020). This circumstance is highly associated with the weak implementation of governmental and institutional policies, rapid population growth, land degradation, weak management of protected areas, and deforestation (USAID, 2008). Particularly, deforestation and forest degradation in Ethiopia have been linked with the need for land units for different agroforestry systems and harvesting forest products to sustain livelihoods. It is mainly driven by human-induced pressures such as intensive farmland expansion, resettlement programs, overstocking, overharvesting for construction and fuel wood materials, fire hazards, and climate change (Senbeta and Denich, 2006). Biodiversity in the complex multi-functional landscapes beyond the protected area is more prone to human pressure and is exposed to extinction risk (Chappell and Lavalle, 2011), and therefore, land use and management systems have long-term effects on ecosystem functions and services (Harvey *et al*., 2008).

In Chapter 2 (Paper I) of this study, the trends, rates, and extent of LULC dynamics and the drivers in the Midakegn District, West Shewa, Ethiopia, were assessed. The study results showed that the area practiced widespread and growing distribution of spatiotemporal LULC changes in the study period interval, and the changes were mainly driven by farmland expansion that was tightly associated with population growth and caused a severe decline of vegetation cover (shrub and forest cover) and grazing lands of the study site, particularly in the highland and midland agroecological areas of the study area. The reasons behind the change were human activities to balance the needs of increasing population dynamics, poor economic status of the community, regime-governmental change and political instability, and the need for infrastructure and technology development. Intensive farmland expansion for more yield production to balance the demand of an ever-increasing population was the predominant direct driver of LULC change. Several findings in other parts of Ethiopia also indicated that the major shift of grazing land and vegetation covers to farmland expansion occurred on account of population growth (e.g., Tefera and Sterk, 2008; Tolessa *et al*., 2017; Godebo *et al*., 2018; Dinka and Ckaka, 2019; Admasu *et al*., 2023). The need for economic development to improve people's livelihoods has a negative impact on other LULC categories, while it needs more farmland for more production (Othow *et al*., 2017), and consequently significantly affect climate patterns and biodiversity resources, which in turn cause biodiversity loss, increased natural disasters, and global warming in the long run (Sala *et al*., 2000), and decline ecosystem services (Admasu *et al*., 2023). Hence, the impact of further land-use intensification and expansion for agricultural purposes would be a key environmental and biodiversity concern (Ortiz *et al*., 2021).

In Chapter 3 (Paper II), the woody species diversity, structural composition, and distribution across various smallholder farmers' agroforestry land use systems in the intensively modified areas of Midakegn District due to LULC change were assessed. In this study, a total of 77 woody species were documented, of which three least concerned, two vulnerable, and one locally threatened species were documented in four agroforestry land use systems. Socioeconomic activities and the livelihood of the local community in the study area have been mainly dependent on sustainable mixed farming systems. The significant variation in woody species richness and diversity recorded in various agroforestery land use systems is definitely linked mainly with different human-induced pressures arising from various destructive effects such as agricultural land expansion, overgrazing, and harvesting plant products for different purposes. As Duguma and Hager (2010) mentioned that different management interventions practiced by farmers, such as woody species retention, planting, and growing in different land plots, such as in the woodlot, lifefence, hedges, and planting for landowner demarcation was also observed as the determinant factors for the variation of woody secies in different land units serving for agroforestery systems. Concerning species number and diversity per land plot, the linear mixed effects model analysis used in Enkossa *et al*. (2024) also showed significant variations among different land use types on the agricultural landscape. According to Haile *et al.* (2017), woody species richness and diversity was also considerably influenced by altitude, land use types, and household affluence. The highest number of species was recorded in grazing lands and homegardens and belonged to the midland agroecologies on the land managed by rich-class farmers. The relatively higher species assembled at midland study sites were due to the remnant natural forests utilized for grazing purposes, and this is because semi-natural habitats most likely provide a stable and excellent habitat refuge for a range of biota, including species that have specific niche needs and little movement in the more disturbed environments (Le Provost *et al*., 2020). Our results revealed the highest mean value of of species richness and diversity recorded in the midland than in the highland, and this was also influenced by variations in altitudinal gradient of the study sites. This indicates that species diversity, abundance, and structural composition are significantly impacted by altitudinal variation. The results were in line with those of Negash *et al.* (2012), Yirdaw *et al.* (2015), and Enkossa *et al.* (2024), who discovered that the diversity and richness of woody plants at various Ethiopian regions has a tendency to decrease with increasing altitudinal changes. Slop, topography, soil conditions, land management and use approaches were among the other variables that may also affect these circumstances (Negash *et al*., 2012). On the other hand, the highest number record in the homesteads may be attributed to subsistence farmers' careful observation of plants for diversity of uses in terms of economic, socioeconomic, and cultural value (Subitha *et al*., 2016).

Concerning the economic status of households, relatively the highest species richness was recorded on land managed by rich farmers, even though no significant difference in Shannon diversity was recorded. But still, a relatively higher mean value of Shannon diversity was recorded in the agroforestry systems managed by richer classes. The highest number of species richness records in the rich agroforestry land use system in the study area is due to the fact that rich farms possess more agroforestry land use types and large farm sizes, which allows them to retain and conserve a large number of woody plants. In other parts of Ethiopia, a positive correlation between woody species richness and farm size, as well as a comparable association between wealth status and farm size, was recorded (Aklilu *et al.,* 2013; Giday *et al.,* 2019).

In terms of structure, the computed mean comparison indicated that cropland had considerably the highest mean value of DBH and height per hectare, while the lowest woody species basal area and density per hectare were recorded in it. This is definitely due to the fact that a few old and mature enough dispersed woody species, such as *J. procera*, *O. europaea* subsp. *cuspidata*, *A. falcatus,* and *V. abyssinica*, were conserved and managed for different socioeconomic uses. Such fewer or restricted tree species flourish in the region servive without competition and could develop in to large basal area and height (Mengistu and Asfaw, 2016). On the other hand, the lowest DBH but the highest basal area and stem density per hectare were recorded in the woodlot of the study sites, and this indicates the existence of a large number of currently planted exotic species, mainly *E. globulus,* in the study sites. *E. globulus is* most often planted in a narrowly spaced manner, and this could determine the highest basal area and stem density/ha in the woodlot compared to other land use types.

In Chapter 4 (Paper II), we investigated underutilized wild edible plants across different landscapes, which range from lowland to the highlands of the study district, along with the existing treatment factors. A total of 50 UWEPs from 30 botanical families were recorded in the study area, which is greater than the 33 UWEPs reported from Chilga District, Ethiopia (Tebkew *et al*., 2014) and almost comparable to the 53 UWEP species documented from Tigray, northern Ethiopia (Aregay *et al*., 2017). Growth form analysis revealed that shrubs, followed by trees, were the outstanding contributors to potentially underutilized edible resources from the wild and semi-wild natural habitats in the study area. Shruby wild plants are also cited as the main contributor to edible foods in other study reports in Ethiopia (Balemie and Kebebew, 2006; Alemayehu *et al*., 2015; Abera and Belay, 2022; Tahir *et al*., 2023).

These UWEP species were recorded from multiple and various habitat reservoirs in the wide agroecological range between 1290 and 3058 m a.s.l., of which the majority (70%) were hosted in the highly disturbed remnant natural forest. Midland, followed by lowland agroecology, contributed the highest number of these UWEPs, while a small number were recorded in the highland study area. Similarly, in the study report of Asfaw and Tadesse (2001) and Woldemedhin *et al*. (2021), midland and lowland agroecologies were indicated as the highest number of contributors of wild edible resources for the rular community in the country. Such differences may occur due to variations in topographic variables and other environmental variables. For instance, Enkossa *et al*. (2024) reported that altitude is a determining factor in plant species composition and dissimilarity between different landscapes, and the areas with higher elevations are most commonly characterized by their limited species diversity (Amin *et al*., 2023). Such variation also caused the minimum common plant tax shared between the various agroecological zones in the study area, which in turn caused the minimum homogeneity of edible parts shared between them and the maximum heterogeneity of traditional practices related to the edible resource utilization between the local communities from different areas (Amin *et al*., 2023).

Though there is underutlization, local people still use different edible parts of the resource, including fruits, leaves, gums or exudates, leaves and stems, root tubers, young shoots, seeds, flowers, flower nectars, and twings under different circumstances. Out of these, fruits were most commonly harvested and consumed raw without further processing. The dominance of fruit harvest from underutilized wild edible plants was also reported in the northern parts of Ethiopia by Tebkew *et al*. (2014) and Aregay *et al*. (2017), in the Asia-Pacific Region by Arora (2014), and in Indonesia by Suwardi *et al*. (2023). Outdoor direct use of raw, fresh/dried edibles, most commonly fruits, accounted for the majority of consumption, while consumption after cooking and fermentation, backing, and boiling were recorded in the study areas. The loss of flavor during preservation and the challenge indigenous and local people encountered during the preservation process encourage the direct use of plenty of wild edibles (Xie *et al*., 2022).

Most commonly, rural people in the study area use the edible plant parts to supplement staple foods and as emergency food, while some are utilized to get relief and chewed during drought conditions. They play a critical role in maintaining food security, particularly for rural poor communities, by supporting their livelihoods both during inadequate food production and the need for emergency safety nets in circumstances of food shortages (Debela *et al*., 2011; Shumsky *et al*., 2014). Compared to the past utilizing condition, the large percentage (76%) of information assessed form KIs revealed much more declining trends in the study area. The situation was most commonly related to the local community's over-reliance on certain major crops to sustain their livelihoods. The local community was at the fate of expanding croplands for a few main crop productions at the expense of wild edible plants' natural environment conversion. Such overdependence of the local community on a few staple food crops for sustaining their livelihoods, and the other anthropogenic activities are profoundly causing the decline of people's attention for wild edible resources. Malnutrition and chronic disease like cancer and heart attack are becoming more common as a result of the shift from conventional dietary patterns to limiting dietary diversity (Heinrich *et al*., 2005). Debela *et al*. (2011) stated that the possibility to the loss of wild edible plant resources and associated indigenous practice soon in the near future due to farmers' attraction toward modernization, improved cultivars, acculturation, and ignorance of the benefits from indigenous wild edible plants and the knowledge associated with them. Consumption of wild edible plants is perceived as a sign of poverty among the majority of Ethiopian local communities (Addis *et al*., 2013b), and its relatively small contribution to the overall food supply during certain periods (Asfaw and Tadesse, 2001) could contribute to the declining potential use of the plants. Long-distance travel for collection and increased socioeconomic status (Shumsky *et al*., 2014; Kagunyu and Wanjohi, 2022) and the disappearance of species due to climatic change (Kagunyu and Wanjohi, 2022) also has a significant contribution to the potential of wild edible plants. Utilization of plant species and their products in a sustainable manner has been deteriorating due to land degradation and climate change (Ashebo, 2019).

The computed threat-factor ranking exercise revealed that human-induced factors, particularly UWEP habitat destruction at the expense of intensive farm land expansion, overgrazing, fuel wood harvesting, and selective logging for different purposes, were identified as principal factors that caused destructive effects on plant resources in the study area. Though ranked as minimum impact-posing, other anthropogenic activities such as fire, urbanization, and climate change-related outcomes (e.g., drought) were recorded as threats to UWEPs and other biodiversity components. The majority of the factors recorded in this study were also reported in various parts of Ethiopia (e.g., Assefa and Abebe, 2011; Ashagre *et al*., 2016; Teklu and Abduljabar, 2019) and in a neighboring country, Sudan (Saliha and Ali, 2014). Similarly, the fear of local extinction of some wild edible plants due to agriculture and other deforestation-related activities is suspected in Nigeria (Ibrahim *et al*., 2012). Unsustainable utilization not only affects the survival of useful plant species but also threatens the livelihoods of people and hence the national economy as well (Barirega *et al*., 2012). Particularly, those principal threat factors caused significant destruction to the natural vegetation ecosystems which were the major reservoirs of UWEPs in the study areas. Due to this, some multipurpose UWEPs, such as *O. europaea* subsp. *cuspidata*, *V. abyssinica*, *E. kapensi*, *S. guineense* subsp. *guineense*, *S. afromontanum*, *C. africana*, and *F. sur,* were conserved and managed as individual trees through traditional practices either in croplands, farm boundaries, around homesteads, or riverine, but were observed in small patchy forests with limited diversity. Because there are no conservation programs that sustain the efficient utilization of wild edible plants at the country level (Asfaw and Tadesse, 2001), climate change and antropogenic activities might impact them differently.

Climatic change directly affects the distribution patterns, physiological and phenological processes, and adaptive capacity of the species, though all species are not equally exposed to the effect (Hughes, 2000; Lepetz *et al*., 2009). Some species may be forced to migrate or adapt to the new environmental conditions (Massot *et al.,* 2008), while others may face habitat range reduction and some suffer the risk of extinction (Thomas *et al.*, 2004; Parmesan, 2006). Such circumstances cause structural modifications of biodiversity in all regions (Lepetz *et al*., 2009). Hence, in order to foresee the effects of climate changes on local biodiversity, forecasting future distributions of species and biodiversity patterns in a changing climate has acquired global importance (Chapperon *et al*., 2016). It plays a crucial role in developing conservation and management strategies that lessen the effect of climate change on a specific species, which will necessitate knowledge of the species' probable suitable habitats in native flora (Tadesse *et al*., 2023).

In Chapter 5 (Paper IV), the habitat distribution range of *S. afromontanum* was modeled to predict its suitable distribution range under the changing climate scenarios in the country. The species is known for its very narrow ecological distribution range and is mainly restricted to MAF and riverine forest areas of the country (Edwards *et al*., 1995). Ethnobotanically, indigenous and local people have utilized the plants and plant parts in multiple socioeconomic practices and ecological services, such as harvesting for food, medicine, fodder, fuel wood and construction materials, fencing, etc. Particularly, the rural community uses this species to earn income and to supplement staple foods, especially during times of food insecurity. Besides balancing food security, the essential nutritional composition of fruits is very important for maintaining healthy diets (Aragaw *et al*., 2021).

The prediction model revealed that the species is currently restricted to MAF and DAF biomes, which predominately comprise the indigenous flora of the southern, southwestern, and western floristic regions of Ethiopia, including the Bale, Kefa, Jimma, Ilubabor, and Wollega floristic regions. The total potential habitat range, which includes highly, moderately, and less suitable distribution areas, was modeled to be 8.78% under current conditions and between 5.46 and 6.01% in future climate change scenarios. In addition to the impact discovered, this outcome definitely confirmed the narrow ecological range stated by Edwards *et al*. (1995) and Tebkew (2015). The reduction potential area indicates the vulnerability of species within its narrow geographical range to climate change in the long run (Purvis *et al*., 2000; Mbatudde *et al*., 2012; Trew and Maclean, 2021). Because present climate change may be too quick for genetic adaptation to undergo, species are more likely to alter their ranges in response to climate change than to adapt *in situ* (Moreno-Rueda *et al*., 2012).

In this prediction model, Solar radiation index (Sri) followed by Precipitation of the Warmest Quarter (Bio18), significantly affected future suitable habitats of *S. afromontanum* under all climate change conditions, while exceptionally Precipitation of the Driest Quarter (Bio17) found to be the second most influential variable under the RCP 8.5 2050 climate change scenario. Previous studies also showed that solar radiation intensity and precipitation-related environmental variables are the key determinant factors influencing plant distribution under ongoing climate change in terrestrial ecosystems (Enkossa *et al*., 2022; Semu *et al*., 2021). Despite potential area reduction, the prediction model also indicated that the southern, southwest, and western biomes of the country would be found as habitat refugia for *S. afromontanum* in the coming mid-century (2050s) and end-century (2070s) climate change scenarios. However, in addition to climate change, ever-increasing broad scale commercial plantations, mainly coffee and tea, and the expansion of small-scale agroforestry practices, overgrazing, illegal logging, and increasing settlement activities in these vegetation ecosystems (Tadese *et al*., 2021) might increase the susceptibility of the species to increasing global warming. Thus, the main refugia vegetation types (MAF and DAF) should gain high priority for the conservation of this species, characterized by a narrow geographical range.

6.2 Conclusion

The three periods (1986, 2003, and 2020) of quantitative spatio-temporal evidence assessed from interpretations of primary and secondary data reveal that the study area has been experiencing persistent and substantial LULC changes over the past 34 years (1986–

2020) due to various driving factors. The study results highlighted that highly expanded farmland occurred at the expense of severely declining vegetation cover (shrub and forest cover) and grazing lands, particularly in the upstream and mid-agroecology of the study area. This was mainly due to drivers associated with human-related activities such as increased population dynamics, the economic status of the local community, political instability, and the need for infrastructure and technology development. The consequence of the change is that it definitely caused unprecedented and dramatic changes to ecosystems and environmental processes in the study area, particularly, variation in both the diversity and structural composition of woody species in the various agroforestry systems. For instance, the homegarden and forest patches, which were considered part of grazing land, had the highest species richness and diversity, while the lowest were recorded in cropland and woodlots. Similarly, the highest number of UWEPs was recorded in the disturbed natural forest area due to anthropogenic and natural consequences compared to other reservoir areas. For instance, intensive farmland expansion intended to produce more yields of a few staple food crops caused a decline in attention and difficulty in assessing wild edibles at a near distance, and these, together with other factors, caused a reduction in the potential utilization of edible plants in the study area.

The study also addressed about the climate change effect on the potential distribution areas of *S. afromontanum,* which has a very limited distribution range in the vegetation ecosystems of Ethiopia. The prediction model showed that the MAF and DAF major vegetation types in the southern, southwestern, and western parts of Ethiopia are projected to become the principal suitable areas for the species both under the current and future climate change scenarios. Comparison to the current, future potential distribution area shows a range reduction, and therefore conservation of these MAF and DAF major biomes is very important for the conservation of such species having socioeconomic and cultural importance but having a very narrow habitat range under the ongoing climate change conditions.

Overall, assessment of the synergetic effect of land use dynamics and human-induced climate change on biodiversity in an integrative manner has contributed to the sustainable use of natural resources through providing fundamental contributions for land managers and policymakers and biodiversity conservationists to have implementable strategies, plans, and policies that assist landscape biodiversity conservation at the local, regional, and country levels. It helps to develop conservation strategies that promote forest-based ecosystem services and environmental incentive programs that prevent further deforestation and forest degradation.

6.3 **Recommendation**

- To minimize the effect of LULC change on natural vegetation, particularly forest cover areas, and to maintain a safe and stable ecosystem, a prominent and timely intervention should be needed to balance farmland expansion against the proper use of natural resources and the sustainability of the ecosystem in the study district, and therefore, the land managers and policymakers should have considered the significant contribution of such LULC change analysis to develop land management strategies and policies that could be implementable at various levels of the country (including the study district) for the sustainable utilization of natural resources.
- The woodlot that possesses the highest number of woody species density/ha in the study area was most commonly cultivated at the expense of cultivable lands. Therefore, the agricultural and land resource management sectors of the district should control woodlot expansion, particularly *E. globulus* beyond non-crop-growing lands. In order to minimize pressure on the remnant natural forests, these sectors should also do innovative best practices to convince the farmers and create awareness about planting, managing, and conserving woody species of diverse socioeconomic and environmental importance in different agroforestery systems.
- Underutilized wild edible plants are definitely associated with a lack of community awareness of their nutritional, economic, and cultural value. Hence,

community awareness through training by concerned governmental institute (e.g., EPHI and higher research institutes of the country), and NGOs, and further nutritional content analysis and economic valuation for more ferequently cited UWEPs species including *S. afromontanum*, *S. guineense* subsp. *guineense, F. indica*, *R. steudneri*, *F. sur*, *D. abyssinica*, *R. apetalus*, *C. spinarium*, *R. abyssinica, M. kummel*, and *C. africana* by should be done. These actions might inspire domestication and further conservation of the resources in their native environment through integration into present land use types, and consequently, which could have positive implications for maintaining future food security. Because they prone more to threating factors, biodiversity institute, agricultural and food security policy of Ethiopia should include stratagies that actively participate all community members of the country to practice indigenous and ecosystem-based *insitu* conservation activities for multipurpose UWEPs, particularly for such top-ranked species such as *O. europaea, C. africana, V. abyssinica, S. guineense* subsp. *guineense, and S. afromontanum* as in the case of the study area. Ethnobotanists should convince policies related to food security, agriculture development, and natural resource management that could enable more sustainable access to UWEPs and potentially enhance their beneficial effects on community resilience.

- In order to protect shifting or reduction in the potential distribution area and the impacts that *S. afromontanum* faced as a result of the adverse effects of climate change, the Ethiopia Biodiversity Institute should pay attention to the integration of future climate change conditions into current restoration and conservation policies for plants with very limited geographical ranges that have vital socio-economic importance in their native habitat ranges.

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Appendices

Appendex 1 Error matrix produced using Landsat TM, ETM+, and OLI-TIRS

Year	Classified LULC	F	Shl	Fl	Gl	Wb	Bu	Total	UA (%)
1986	F	**9**	1	0	0	0	0	10	90.0
	Shl	1	**10**	0	1	0	0	12	83.3
	Agl	0	0	**9**	1	0	0	10	85.7
	Gl	0	1	1	**11**	1	1	15	86.7
	Wb	0	0	0	0	**4**	0	4	85.7
	Bu	0	0	1	0	0	**3**	4	75.0
	Total	10	12	11	13	5	4	**55**	
	PA (%)	90.0	83.3	81.8	84.6	80.0	75.0		
	OA(%)								**83.6**
	K^								**0.802**

Year	Classified LULC	F	Shl	Agl	Gl	Wb	Bu	Total	UA (%)
2003	F	**9**	1	0	0	0	0	10	90.0
	Shl	1	**10**	0	1	0	0	12	83.3
	Fl	0	0	**12**	1	0	1	14	85.7
	Gl	0	1	1	**12**	0	0	14	85.7
	Wb	0	0	0	0	**4**	0	4	100.0
	Bu	0	0	1	0	1	**4**	6	66.7
	Total	10	12	14	14	5	5	**60**	
	PA (%)	90.0	83.3	85.7	85.7	80.0	80.0		
	OA(%)								**85.0**
	K^								**0.854**

Year	Classified LULC	F	Shl	Fl	Gl	Wb	Bu	Total	UA (%)
2020	F	**8**	1	0	0	0	0	9	88.9
	Shl	1	**16**	0	0	0	0	17	94.1

Fl	0	0	**19**	1	0	0	20	95.0
Gl	0	1	2	**19**	0	0	22	86.4
Wb	0	0	0	0	**5**	1	6	83.3
Bu	0	0	0	0	1	**6**	7	85.7
Total	9	18	21	20	6	7	**81**	
PA (%)	88.9	88.9	90.5	95.0	83.3	85.7		
OA(%)								**90.1**
K^								**0.885**

Where: PU, producer's accuracy; AU, user's accuracy; OCA, overall classification accuracy; K^= kappa coefficient; F, forest; Shl, shrubland; Fl, farmland; Gl, grazing land; Wb, water body and Bu, built up.

Appendix 2 Shows recorded species, generals, and families with their vernacular names and important value indexes in the different agroforestry systems of the study area.

Woody Species	**Family**	**Vernacular Name**	**Grazing land**				**Homegarden**				**Farmland**				**Woodlot**			
			RF	RD	RA	IVI	RF	RD	RA	IVI	RF	RD	RA	IVI	RF	RD	RA	IVI
Acacia melanoxylon R.Br.	*Fabaceae*	-													2.78	0.05	0.67	3.50
Afrocarpus falcatus (Thunb.) C.N.Page	*Podocarpaceae*	Birbirsa	5.66	28.32	11.16	**45.14**	2.30	21.90	0.60	24.80	8.75	15.80	6.48	**30.98**	2.78	2.81	0.13	5.72
Albizia gummifera (J.F.Gmel.) C.A.Sm.	*Fabaceae*	Emala	0.94	0.62	0.60	2.16					1.25	0.23	0.93	2.40				
Allophylus abyssinicus (Hochst.) Radlk.	*Sapindaceae*	Sarara					0.78	0.07	0.14	1.00								
Apodytes dimidiata E. Mey ex Arn.	*Icacinaceae*	Kumbala	1.89	0.71	0.80	3.40	0.39	2.11	0.07	2.57	1.25	0.68	0.93	2.86				
Arundinaria oldeania (K.Schum.) Stapleton	*Poaceae*	Lemana													2.78	0.63	4.72	8.12
*Astropanax myrianth*us (Baker) Lowry, G.M.Plunkett, Gostel & Frodin	*Araliaceae*	Arfatu	0.47	0.17	0.20	0.84												

Bersama abyssinica Fresen.	*Melianthaceae*	Lolchisa	3.30	0.06	3.19	6.55	1.17	0.03	0.50	1.70					5.56	0.02	0.27	5.84
Brucea antidysenterica J.F.Mill.	*Simaroubaceae*	Komogno	1.89	0.02	1.39	3.30	1.17	0.02	0.35	1.55					5.56	0.01	0.27	5.84
Buddleja polystachya Fresen.	*Scrophulariaceae*	Kawisa					2.73	0.22	6.45	9.41	2.50	0.05	6.48	9.03				
Calpurnia aurea (Aiton) Benth.	*Fabaceae*	Cheka	2.83	0.17	5.58	8.58	4.69	0.46	6.80	11.95					5.56	0.06	0.27	5.88
Carissa spinarum L.	*Apocynaceae*	Hagamsa	4.25	0.18	7.37	11.79												
Casimiroa edulis La Llave	*Rutaceae*	-					0.39	0.01	0.07	0.48								
Casuarina cunninghamiana Miq.	*Casuarinaceae*	Shawshawe					0.39	0.37	0.07	0.84								
Clausena anisata (Willd.) Hook.f.ex Benth.	*Rutaceae*	Ulumayi	1.42	0.02	1.39	2.83	0.39	0.01	0.21	0.61								
Cordia africana Lam.	*Boraginaceae*	Wadesa					0.78	0.21	0.28	1.28								
Croton macrostachyus Hochst. ex Delile	*Euphorbiaceae*	Bakanisa	3.77	2.38	2.59	8.75	3.91	2.84	1.91	8.66	10.0	6.34	7.41	23.75	5.56	2.02	0.27	7.85
Discopodium	*Solanacea*	Ajaha	0.47	0.00	0.20	0.67	2.73	0.09	2.83	5.66								

penninervium Hochst.	*e*																	
Dodonaea angustifolia L.	*Sapindaceae*	Itacha	0.94	0.05	1.00	1.99												
Dombeya torrida (J.F.Gmel.) Bamps	*Sterculiaceae*	Danesa	0.94	0.12	0.40	1.46	3.13	1.24	0.85	5.22	2.5	0.28	1.85	4.63	2.78	0.24	0.13	3.15
Dovyalis abyssinica (A. Rich.) Warb.	*Flacourtaceae*	Komsho	1.89	0.12	0.80	2.81												
Dovyalis caffra (Hook.f. & Harv.) Warp.	*Flacourtiaceae*	Koshomi					0.78	0.08	1.77	2.64								
Ekebergia capensis Sparrm.	*Meliaceae*	Sombo	0.47	0.79	0.20	1.46					3.75	8.63	2.78	15.16				
Embelia schimperi Vatke	*Myrsinaceae*	Hanku	1.42	0.03	1.00	2.45												
Erythrina brucei Schweinf.	*Fabaceae*	Walensu					2.73	2.44	4.11	9.29	5.00	0.47	14.81	20.29	5.56	0.35	0.27	6.17
Eucalyptus globulus Labill	*Myrtaceae*	Bargamo	1.42	2.19	2.39	5.99	6.25	20.22	13.18	**39.6**	3.75	7.21	5.56	16.51	25.00	68.49	90.84	**184.3**
Euclea racemosa L.	*Ebenaceae*	Miessa	0.94	0.04	0.60	1.58												
Euphorbia abyssinica J.F.Geml.	*Euphorbiaceae*	Adami	0.47	0.24	0.40	1.11	0.39	0.34	0.07	0.80								

Ficus sur Forssk.	*Moraceae*	Harbu	0.94	11.52	0.40	12.86					2.50	17.81	1.85	22.16				
Grevillea robusta A.Cunn. ex R.Br.	*Proteaceae*	Giraveleya					2.73	0.73	1.28	4.74					2.78	0.14	0.41	3.33
Grewia ferruginea Hochst. ex A. Rich.	*Tiliaceae*	Dokonu	0.94	0.01	0.40	1.35	0.39	0.00	0.07	0.46								
Gymnanthemum amygdalinum (Delile) Schi.Bip.	*Asteraceae*	Ebicha	0.47	0.05	0.60	1.12	5.08	0.49	4.11	9.68								
Gymnanthemum auriculiferum (Hiern) Isawumi	*Asteraceae*	Reji	4.25	0.18	6.37	10.8	6.64	0.48	7.23	14.35	2.51	0.01	1.85	4.37	8.33	0.03	0.54	8.91
Gymnosporia gracilipes (Welw. ex Oliv.) Loes.	*Celasteraceae*	Michire	1.42	0.04	2.19	3.65												
Hagenia abyssinica (Bruce) J.F. Gmel.	*Rosaceae*	Heto					1.17	5.25	2.06	8.47								
Hesperocyparis lusitanica (Mill.) Bartel	*Cupressaceae*	Gatera Bar					6.64	5.4	14.74	**26.78**	1.25	0.26	2.78	4.28	5.56	0.26	0.27	6.08
Hypericum quartinianum A. Rich	*Clusiaceae*	Ulefoni	0.94	0.02	0.40	1.36												
Juniperus procera	*Cupressac*	Gatera	5.66	18.3	11.2	**35.12**	5.08	10.1	1.77	16.99	15.0	6.74	11.1	**32.85**	5.56	9.65	0.27	**15.5**

Hochst. ex Endl.	*eae*																	
Justicia ladanoides (Hochst. ex Nees) T.Anderson.	*Achanthaceae*	Dumuga					5.47	0.23	11.27	16.96								
Lasiosiphon glaucus Fresen.	*Thymelaeaceae*	Kakaro	0.94	0.13	1.00	2.07												
Lippia adoensis Hochst. ex Walp.	*Verbenaceae*	Koshonota					3.13	0.01	0.78	3.91								
Maesa lanceolata Forssk.	*Myrsinaceae*	Abayi	2.36	0.19	1.20	3.75	0.39	0.02	0.07	0.48								
Malus domestica (Suckow) Borkh.	*Rosaceae*	Apili					0.78	0.03	1.56	2.37								
Maytenus addat Loes.	*Celasteraceae*	Kombolcha	4.72	5.93	2.19	12.84	0.78	0.85	0.14	1.77	5.00	3.97	3.70	12.67	2.78	4.14	0.13	7.05
Maytenus senegalensis (Lam.) Loes.	*Celasteraceae*	Bite	2.36	0.21	3.39	5.96												
Myrica salicifolia Hochst.ex A. Rich.	*Myricaceae*	Barodo	1.42	1.82	0.61	3.83					1.25	0.81	0.93	2.98				
Myrsine africana L.	*Myrsinaceae*	Kachama	1.89	0.05	2.99	4.92												
Myrtus communis L.	*Myrtaceae*	Galle	0.94	0.05	0.80	1.79												
Nuxia congesta R.Br.ex	*Loganiace*	Anfare	1.89	0.40	0.80	3.09					1.25	0.04	0.93	2.22				

Fresen	*ae*																	
Nuxia oppositifolia (Hochst.) Benth.	Loganiaceae	Kawisa					1.95	2.12	0.85	4.93	2.50	0.35	1.85	4.70				
Ocimum lamiifolium Hochst. ex Benth.	*Lamiaceae*	Hanchabi	1.42	0.02	1.79	3.23	1.56	0.01	0.35	1.92								
Olea europaea L.	*Oleaceae*	Ejersa	5.19	10.2	3.98	**19.37**	4.30	19.4	1.40	**25.1**	17.5	21.6	15.7	**54.85**	8.33	10.5	0.40	**19.2**
Osyris quadripartita Hochst. & Steud.	*Santalaceae*	Wato	2.83	0.47	1.59	4.89												
Persea americana Mill.	*Lauraceae*	Avokado					0.78	0.03	0.14	0.96								
Phytolacca dodecandra L'Her.	*Phytolaccaceae*	Handode	0.47	0.01	0.20	0.68	2.73	0.02	0.50	3.25								
Pittosporum abyssinicum Delile	*Pittosporaceae*	Soledima	0.94	0.04	0.40	1.38												
Pittosporum viridiflorum Sims.	*Pittosporaceae*	Soleadi	3.30	0.62	2.79	6.71												
Premna schimperi Engl.	*Verbenaceae*	Urgessa	0.47	0.01	0.20	0.68												
Prunus africana (Hook.f.)Kalkman	*Rosaceae*	Okomi	0.47	0.09	0.20	0.76					1.25	1.54	0.39	3.72				
Prunus persica (L.) Batsch	*Rosaceae*	Koki					0.78	0.24	0.14	1.17								

Pterolobium stellatum (Forssk.) Brenan	*Fabaceae*	Harangama	0.94	0.03	0.40	1.38	0.39	0.01	0.07	0.47
Rhamnus prinoides L’Her.	*Rhamnaceae*	Gesho					6.25	0.25	6.87	13.37
Rhamnus staddo A.Rich.	*Rhamnaceae*	Kadida	0.50	0.00	0.20	0.7				
Rhus glutinosa (Hochst. ex A.Rich.) Mofett	*Anacardiaceaea*	Tatesa	1.42	0.68	1.39	3.49				
Ricinus communis L.	*Euphorbiaceae*	Kobo					3.52	0.20	2.55	6.26
Rosa abyssinica R.B. ex Lindl.	*Rosaceae*	Kakawe	2.83	0.05	1.39	4.28	0.39	0.01	0.07	0.47
Rubus apetalus Poir.	*Rosaceae*	Gora gure	1.89	0.02	1.20	3.11				
Rubus steudneri Schweif.	*Rosaceae*	Gora Arba	0.47	0.00	0.20	0.67				
Rumex nervosus Vahl	*Polygonaceae*	Dangago	0.94	0.00	0.40	1.34				
Rydingia integrifolia *(*Benth.) Scheen &V.A.Albert	*Lamiaceae*	Chingiti	0.47	0.02	0.20	0.69				

Rytigynia neglecta (Hiern) Ronyns	*Rubiaceae*	Hudu Farda	1.89	0.07	2.19	4.15	0.78	0.01	0.14	0.49								
Salix mucronata Thumb.	*Salicaceae*	Halaltu	0.47	0.02	0.20	0.69												
Solanecio gigas (Vatke.) C.Jeffery.	*Asteraceae*	Jilba Jaldesa	0.47	0.01	0.40	0.88	0.78	0.03	0.85	1.67								
Syzygium guineense (Willd.) DC.	*Myrtaceae*	Badesa	1.89	7.91	2.79	12.58					2.5	2.59	1.85	6.94				
Vachellia abyssinica (Hochst. ex Benth.) Kyal. & Boatwr.	*Fabaceae*	Lafto	3.30	4.55	1.79	9.64	2.34	1.47	0.64	4.45	7.5	3.82	8.33	19.65	2.78	0.60	0.13	3.51
Vachellia farnesiana(L.) Wight & Arn.	*Fabaceae*	Dodota									1.25	0.81	0.93	2.98				
Vepris nobilis (Delile) Mziray	*Rutaceae*	Hadesa	0.94	0.03	0.40	1.37												

RF: relative frequency; RD: relative dominance; RA: relative abundance; and IVI: importance value index

Appendex 3 IVI of the major woody species in land use types of the study area.

Woody Species	**Grazing land**				**Homegarden**				**Cropland**				**Woodlot**			
	RF	RD	RA	IVI	RF	RD	RA	IVI	RF	RD	RA	IVI	RF	RD	RA	IVI
Calpurnia aurea (Aiton) Benth.	2.8	0.2	5.6	8.6	4.7	0.5	6.8	12.0	0.0	0.0	0.0	0.0	5.6	0.1	0.3	6.0
Croton macrostachyus Hochst. ex Del.	3.8	2.4	2.6	8.8	3.9	2.9	1.9	8.7	10.0	6.3	7.4	23.7	5.6	2.0	0.3	7.9
Hesperocyparis lusitanica (Mill.) Bartel	0.0	0.0	0.0	0.0	6.7	5.4	14.7	26.8	1.2	0.3	2.8	4.3	5.6	0.2	0.3	6.1
Erythrina brucei Schweinf.	0.0	0.0	0.0	0.0	2.7	2.5	4.1	9.3	5.0	0.5	14.8	20.3	5.6	0.3	0.3	6.2
Eucalyptus globulus Labill	1.4	2.2	2.4	6.0	6.2	20.3	20.2	39.7	3.7	7.2	5.6	16.5	25.0	68.5	90.8	184.3
Ficus sur Forssk.	0.9	11.5	0.4	12.8	0.0	0.0	0.0	0.0	2.5	17.8	1.9	22.2	0.0	0.0	0.0	0.0
Juniperus procera Hochst. ex Endl.	5.7	18.3	11.2	35.1	5.1	10.1	1.8	17.0	15.0	6.8	11.1	32.9	5.6	9.6	0.3	15.0
Justicia ladanoides (Hochst. ex Nees) T.Anderson.	0.0	0.0	0.0	0.0	5.5	0.2	11.3	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maytenus addat Loes.	4.7	5.9	2.2	12.8	0.8	0.9	0.1	1.8	5.0	4.0	3.7	12.7	2.8	4.2	0.1	7.1
Olea europaea subsp. *cuspidata* L.	5.2	10.2	4.0	19.4	4.3	19.4	1.4	25.1	17.5	21.6	15.8	54.9	8.3	10.5	0.4	19.2
Afrocarpus falcatus (Thunb.) C.N.Page	5.7	28.3	11.2	45.1	2.3	21.9	0.6	24.8	8.8	15.7	6.5	31.0	2.9	2.8	0.1	5.8
Vachellia abyssinica (Hochst. ex Benth.) Kyal. & Boatwr.	3.3	4.5	1.8	9.6	2.3	1.5	0.6	4.4	7.5	3.8	8.4	19.7	2.8	0.6	0.1	3.5

Gymnanthemum auriculiferum (Hiern) Isawumi	4.2	0.2	6.4	10.8	6.7	0.5	7.2	14.4	2.5	0.0	1.9	4.4	8.3	0.1	0.5	8.9

RF: relative frequency; RD: relative dominance; RA: relative abundance; and IVI: importance value index

Apendex 4 Underutilized wild edible plants collected from Midakegn District

Scientific name	**Family**	**Vernacular name**	**H**	**Hb**	**Pu**	**Mode of consumption**	**Vn**
Acokanthera schimperi (A.DC.) Schweif.	Apocynaceae	Kararu	S	a	F	Raw, rippen	Mk082
Amaranthus hybridus L.	Amaranthaceae	Lamoyi	H	b, e	L, St	Cooked	Mk001
Canarina eminii Asch. & Schweinf.	Campanulaceae	Tuxo	E	i	Fl	Raw, rippen	Mk011
Carissa spinarum L.	Apocynaceae	Agamsa	S	a, c, f	F	Raw, rippen	Mk004
Colocasia esculenta (L.) Schott	Araceae	Godare	H	j	R	Cooked	Mk081
Cordia africana Lam.	Boraginaceae	Wadesa	T	a, b, c, d, e	F	Raw, rippen	Mk009
Dovyalis abyssinica (A. Rich.) Warb.	Flacourtiaceae	Komsho	S	e	F	Raw, rippen	Mk018
Dovyalis caffra (Hook.f. & Harv.) Warb.	Flacourtiaceae	Koshomi	S	e	F	Raw, rippen	Mk010
Ekebergia capensis Sparrm.	Meliaceae	Sombo	T	a, b, d	F	Raw, rippen	Mk077
Embelia schimperi Vatke	Myrsinaceae	Hanku	S	a, d	F	Raw, rippen	Mk019
Eriosema cordifolium Hochest. ex A.Rich	Fabaceae	Kurkufo	H	c, f	R	Raw, chewing	Mk073
Euclea racemosa L.	Ebenaceae	Miessa	S	a, c	F, Tw	Raw, rippen, chewing	Mk014
Faidherbia albida (Delile) *A. Chev.*	Fabaceae	Garbi	T	a, b, c, e, f	G, Se	Raw, chewing Cooked	Mk071
Ficus sur Forssk.	Moraceae	Harbu	T	b, c, d	F	Raw/dried, ripen	Mk008
Ficus sycomorus L.	Moraceae	Oda	T	b, c, d	F	Raw/dried, rippen	Mk021
Ficus thonningii Blume	Moraceae	Dambi	T	a, d, e	F	Raw/dried ripen	Mk075

Ficus vasta Forssk.	Moraceae	Kiltu	T	b, c, d, e	F	Raw/dried rippen	Mk022
Flacourtia indica (Burm.f.) Merr.	Flacourtiaceae	Huda	S	a	F	Raw, 202ipen	Mk021
Gardenia ternifolia Schumach. & Thonn.	Rubiaceae	Gambelo	T	a, c	F	Raw, rippen	Mk024
Grewia bicolor Juss.	Tiliaceae	Haroresa	S	a	F	Raw, rippen	Mk074
Grewia ferruginea Hochst.ex A.Rich	Tiliaceae	Dokonu	S	a	F	Raw, rippen	Mk020
Grewia Villosa Will.	Tiliaceae	Dokonu	S	a	F	Raw, rippen	Mk012
Gymnanthemum amygdalinum (Delile) Sch.Bip.	Asteraceae	Ebicha	S	a, d, e, h	L	Condiment	Mk048
Impatiens rothii Hook. f.	Balsaminaceae	Ansosila	H	a, e	N	Raw, sucking	Mk028
Justicia ladanoides Lam.	Acanthaceae	Dumuga	S	e, f, g	N	Raw, sucking	Mk082
Lippia adoenesis var. adoenesis Hochst. ex Walp.	Verbenaceae	Koshonot	S	e	L, St	Spicing	Mk010
Lippia adoenesis var. *koseret* Hochst. ex Walp.	Verbenaceae	Kusaye	S	a, c, e, f	L, St	Spicing	Mk078
Mimusops kummel Bruce ex A.DC.	Sapotaceae	Koladi	T	a	F	Raw, rippen	Mk079
Myrsine africana L.	Myrsinaceae	Kachama	S	a	F	Raw, rippen	Mk066
Oldeania alpina (K.Schum.) Stapleton	Poaceae	Lemana	H	g, h	Y	Cooked	Mk032
Olea europaea L.	Oleaceae	Ejersa	T	a, b, c, e, f, g	F, L	Raw, rippen, Condiment	Mk042
Phoenix reclinata Jacq.	Arecaceae	Meti	T	a, b, c, d	F	Raw, rippen	Mk026
Physalis peruviana L.	Solanaceae	Awuti	H	e	F	Raw, rippen	Mk027
Rhamnus staddo A.Rich.	Rhamnaceae	Kadida	S	a	L	Condiment	Mk083
Searsia glutinosa (Hochst. ex A.Rich.) Moffett	Anacardiaceae	Tatesa	T	a, c	F	Raw, rippen	Mk003

Searsia retinorrhoea (Steud. ex Oliv.) Moffett	Anacardiaceae	Dabobesa	S	a	F	Raw, rippen	Mk076
Rosa abyssinica R.Br. ex Lindl.	Rosaceae	Kakawe	S	a, c, h	F	Raw, rippen	Mk006
Rubus apetalus Poir.	Rosaceae	Gora gure	S	a, c, d, h	F	Raw, rippen	Mk007
Rubus steudneri Schweinf.	Rosaceae	Gora Arba	S	a, c, d, h	F	Raw, rippen	Mk006
Rumex nervosus Vahl.	Polygonaneae	Dangago	S	a, c	L, St	Raw, chewing	Mk025
Saba comorensis (Bojer ex A.DC.) Pichon	Rubiaceae	Bururi	T	a	F	Raw, rippen	Mk080
Sporobolus pyramidalis P. Beauv.	Poaceae	Muri	H	c, f	Se	Backed	Mk030
Syzygium afromontanum (F. White) Byng.	Myrtaceae	Gosu	T	a, b, c, d	F	Raw, rippen	Mk012
Syzygium guineense (Wild.) DC. subsp. *guineense*	Myrtaceae	Badesa	T	a, b, c, d	F	Raw, rippen	Mk002
Syzygium guineense (Wild.) DC. subsp. macrocarpum (Engl.) F. White	Myrtaceae	Gumari	T	a, c, d	F	Raw, rippen	Mk029
Thymus schimperi Ronniger	Lamiaceae	Tosegn	H	c	L	Boiled	Mk049
Vachellia abyssinica (Hochst. ex Benth.) Kyal. & Boatwr.	Fabaceae	Lafto	T	a, b, c, f	G	Raw, chewing	Mk013
Vepris nobilis (Delile) Mziray	Rutaceae	Hadesa	T	a	F	Raw, rippen	Mk069
Urtica simensis Hochst. ex A.Rich.	Urticaceae	Sama	H	e, f, h	L,St	Cooked	Mk016
Ximenia americana L.	Oleaceae	Akuku	S	a	F	Raw, rippen	Mk072

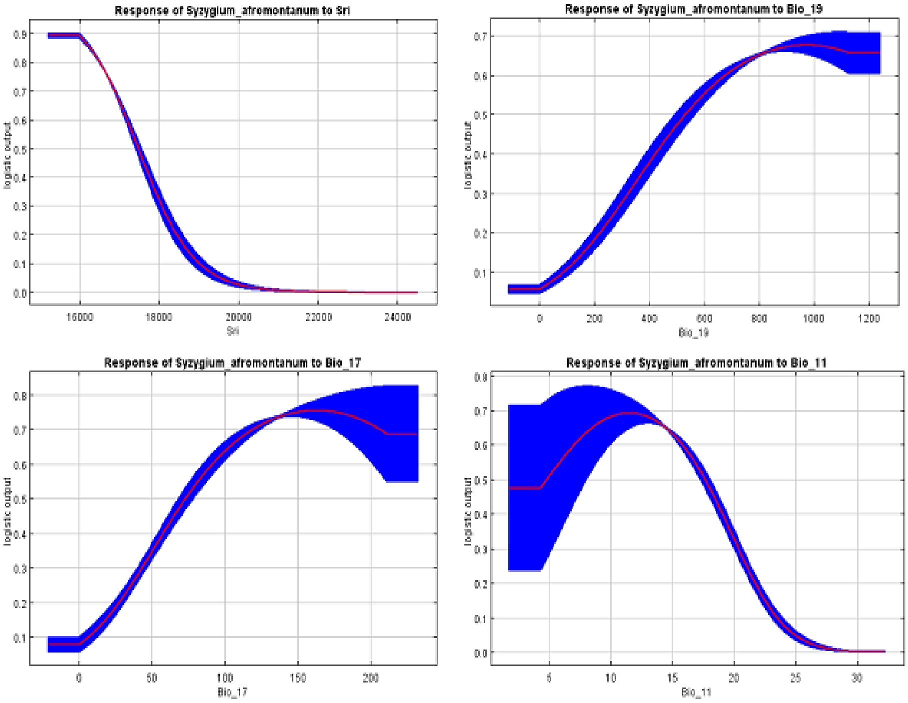
H, habit (T, tree; shrub, S; H, herb; E, epiphyte); Hb, habitat (a, patchy forest; b, farm and arable land; c, pasture and grassland; d, riverine; e, homegarden; f, field margin and roadsides f; g, woodlot; h, wasteland; i, on tree-trunk; j wetland j); Pu, Parts used (G, gum/exudate; Se, seed; F, fruit; L, leaf; St, stem; Fl, flower; R, root tuber; Y, young shoot; Tw, twing; N, nectar); Nn, voucher numbe

Appendex 5 Pearson’s correlations among environmental variables used in the distribution modeling

	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19	Elev	Sri.	Tpi
Bio1	1																					
Bio2	-0.457	1																				
Bio3	-0.532	0.403	1																			
Bio4	0.413	-0.053	-0.875	1																		
Bio5	**0.960**	-0.263	-0.626	0.582	1																	
Bio6	**0.961**	-0.632	-0.419	0.231	0.856	1																
Bio7	-0.049	0.708	-0.357	0.632	0.222	-0.314	1															
Bio8	**0.971**	-0.506	-0.559	0.408	0.929	0.945	-0.075	1														
Bio9	**0.970**	-0.476	-0.461	0.341	0.907	0.948	-0.123	0.914	1													
Bio10	**0.986**	-0.419	-0.629	0.553	**0.979**	0.918	0.066	0.952	0.950	1												
Bio11	**0.984**	-0.465	-0.392	0.254	0.912	**0.976**	-0.167	0.947	**0.969**	0.946	1											
Bio12	-0.632	0.365	0.384	-0.209	-0.608	-0.632	0.077	-0.724	-0.521	-0.595	-0.612	1										
Bio13	-0.616	0.459	0.343	-0.105	-0.553	-0.644	0.198	-0.712	-0.549	-0.556	-0.606	0.858	1									
Bio14	-0.329	0.108	0.293	-0.257	-0.359	-0.294	-0.105	-0.335	-0.236	-0.344	-0.305	0.570	0.212	1								
Bio15	0.168	0.036	0.087	-0.046	0.163	0.182	-0.043	0.153	0.103	0.158	0. 206	-0.313	0.119	-0.673	1							
Bio16	-0.600	0.442	0.313	-0.080	-0.539	-0.633	0.204	-0.706	-0.519	-0.537	-0.595	0.913	**0.984**	0.264	0.011	1						
Bio17	-0.369	0.136	0.294	-0.265	-0.389	-0.339	-0.077	-0.367	-0.277	-0.384	-0.348	0.567	0.176	**0.974**	-0.751	0.236	1					
Bio18	-0.545	0.288	0.409	-0.385	-0.535	-0.514	-0.013	-0.492	-0.534	-0.575	-0.516	0.441	0.234	0.469	-0.353	0.255	0.524	1				
Bio19	-0.317	0.222	0.189	-0.025	-0.306	-0.341	0.082	-0.452	-0.195	-0.273	-0.310	0.779	0.722	0.299	-0.095	0.783	0.262	0.119	1			
Elev	-0.968	0.537	0.456	-0.286	-0.890	-0.968	0.191	-0.944	-0.949	-0.935	-0.973	0.611	0.638	0.301	-0.144	0.617	0.337	0.493	0.333	1		
Sri.	0.579	-0.196	-0.229	0.107	0.570	0.567	-0.022	0.645	0.486	0.531	0.584	-0.811	-0.652	-0.516	0.469	-0.708	-0.526	-0.337	-0.609	-0.552	1	
Tpi.	-0.381	0.220	0.111	0.003	-0.332	-0.396	0.137	-0.399	-0.352	-0.341	-0.394	0.331	0.359	0.212	-0.061	0.346	0.217	0.174	0.235	0.426	-0.264	1

Appendex 6 The AUC, and the mean value of AUC ratio and partial AUC of ROC at 95% confidence interval

Climate change scenarios	AUC	AUC ratio	p-AUC-ROC value
Current	0.924	1.875	0.937
RCP 4.5 2050	0.919	1.852	0.926
RCP 8.5 2050	0.914	1.856	0.923
RCP 4.5 2070	0.927	1.876	0.939
RCP 8.5 2070	0.931	1.875	0.938



Appendix 7 *S. afromontanum* response curve in relation to solar radiation index (Sri), precipitation of the coldest quarter (Bio19), precipitation of the driest quarter (Bio17) and Mean Temperature of Coldest Quarter (Bio11).

Appendix 8 Cuptured photos indicating discussions for different data collection in the study area

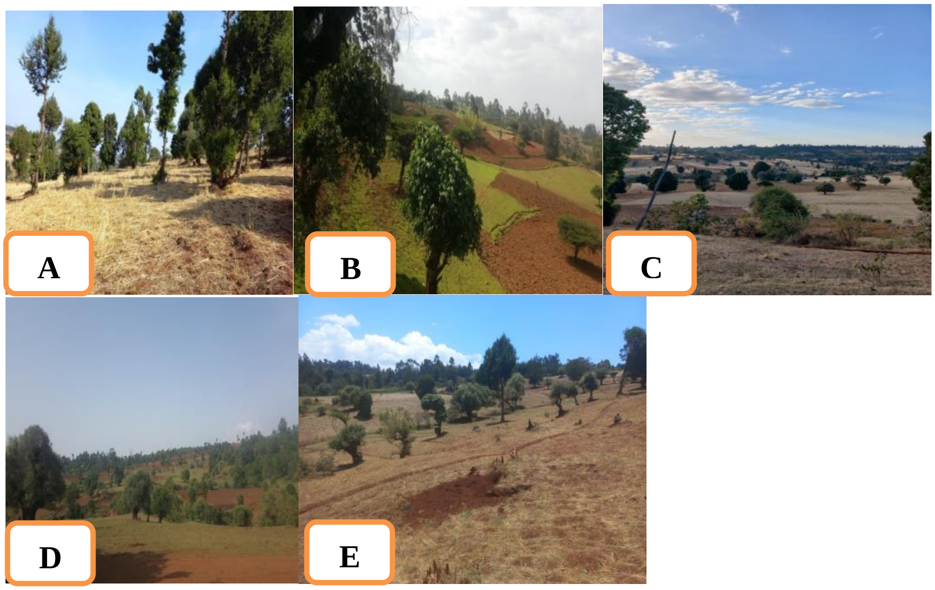
Photos indicating in **A**, focus group discusion; **B**, ranking exercies; and **C**, secondary data collection at district agricultural offece

Appendix 9 Photos indicating different agroforestery systems in the study area

I. Photo shoots showing different homesteads and data collection progress

Photos indicating: **D**, **E**, and **G**, woody species data collection in the homesteads; **F**, interview held around homegarden for underutlized wild edible data collection

II. Photo showing different cropland plotes in the study area



Photo/photos from croplands of Dano (**A** and **E**), Baro (**B**), and Harbu Garba (**C** and **D**) study sites

III. Photo showing different land plots serving for grazing and other multiple purpose in th study area

IV. Photo showing woody species data collection in the woodlot

Photo representing woody species data collection from woodlot at Dano (**A**) and Baro (**B**) study sites

Apendix 10 Photo showing an ethnobotanical data collection in the study area

A) Underutilized wild edible plant sample collection

Photos shows guided field walk with informants to collect underutlized wild plants specimen representing **A**, *R. abyssinica*; **B**, *E. cordifolium*; **D**, *R. appetalus*; **E**, *S. guineense* subsp. *guineense;* and **C**, recording in the patchy forest

B) Markatablility of some underutilized wild edible plants in the study area

Encountered marketable underutlized wild edible plants in the study area which represening **A**, fruits of *S. afromontanum*; **B**, fruits of *D. caffra*; and **C**, leaf and seedilings of *L. adoenesis* var. *koseret*

Appendix 11 Data pressing and transportation in the study area

Appendex 12 Questionnaires and interview questions on LULC dynamics and underutlized data collection

I. Key informant interview guide

1. General information:
    - Date ________________________
    - Name of the respondent _____________________ Gender: M__ F___ Age: ____
2. How long did you live in the area? ______.
3. How is the land history and distribution system of your district?
4. How the land usage was looks like in your areas for more than three decades?
5. Do you think that the land is becoming scarce or it is still abundant in your community?
    6.1. If your answer for question no. 5 is becoming scarce, what are your reasons?
    6.2. If your answer for question no. 5 is still abundant, what are your justifications?
6. Have you noticed any change in the LU/LC in your area for more than three decades?
7. Is there any change observed in your area with regard to vegetation cover, settlement areas, farmland, water body, build up, bare land and any other land use pattern for more than three years?
8. Did the changes modify the land cover types in any ways?
9. Which LULC category became increased/decreased more and more? And at the expense of which category/categories?
10. When/where/why one LULC category largely changed to other?
11. What are the driving forces of land LULC dynamics in your area and how it can be considered as driving factors?
    A. Regime government change followed by political instability
    B. Population growth (Demography)
    C. Increasing demand infrastructures and technology
    D. Economic status of the local community
    E. Natural disasters
    F. Other (specify): ______________________________

12. What is the ultimate (direct) cause of LULC change in the study area?
    A. Farm land expansion
    B. Overgrazing
    C. Infrastructure expansion
    D. Expansion of woodlot (plantation)
    E. Resettlement
    F. Fire
    G. Other (specify)
13. What are the practice for proper land use and management?
14. What are the new skills that you obtained from the district rural land management experts?
15. What are the impacts imposed due to LULC change in the areas?
    A. Decrease in soil quality
    B. Soil erosion /land degradation
    C. Deforestation
    D. Decline of water and nutrient cycle
    E. Decreasing of crop yields.
    F. Migration and extinction of wild animals (Biodiversity loss)
    G. Weather condition/climate change
    H. Other (specify): ________________________
16. What are you recommendations to conserve natural resources and to manage land use land cover change?

II. Survey questioner for collecting ethnobothanical data on underutilized wild edible plants in the study area

A. General information

1. Date _________________________ Residence kebele _________________
2. Name of respondent _________________ Sex ___________ Age ______________

   2.1 Occupation _____________________ 2.2 Marital status _______________

   2.3 Educational background______________

3 How do you classify vegetation traditionally? (*)

4 How do you classify soils traditionally? (*)

5 How do you classify landscapes traditionally? (*)

B. Ethnobotanical data

6 Is there plant species which you use from the wild or semi-wild for consumption?

7 What is the local name of the plant?

8 Who is the collector ?(Children, women, man, both)

9 From where are the plants harvested? (wild, Semi- wild/cultivated)

10 Habit of the plant (tree, shrub, herb, liana, epiphyte and parasite)(etic categories)

11 Habitat type of the plant (Natural forest, grazing land, roadside, farmland, live fence, river side and valley, woodlot etc.)

12 Part of the plant harvested for edibility (Fruit, leaves, root, stem, bark, flower nectar, seed, sap, latex, whole plant).

13 To what extent is it utilized (low, medium, high)?

14 At what time do you use it for consumption? (As supplementary food, as famine food to fill food gap because of drought and famine or both of the two)

15 What consumption form do you use? (as fruit, as vegetables, as spice, as condiment, chewing, nectar suck, specify it need other form).

16 What method of preparation do you use?

    16.3 Preparation forms: (Fresh; prepared/cooked, dried and prepared)

    16.4 Used alone, mixed with other.

17 What mode of consumption do you use? (Raw fresh/dried, cooking, fermentation, boiling, Baking, specify if other)

18 Which age groups of the local people use wild or semi-wild edible plant frequently?

19 Is there any known side effect after consumption? (yes or no)

20 From who do you acquired the knowledge of edible plans?

21 How do you see accessibility of the neglected wild edible plants when compared with the past decade?

22 How do you mention current dependence of local community on wild edible plants? (Reduced, increased) and why? (*)

23 Is any edible plants part/s currently marketable and where?

24 Mention another use value of the plant (Fuel wood, charcoal, medicinal; construction, fencing, soil and water conservation, fodder, shade tree, farm tools, household tools, bee forage and etc.)

25 What are the major threats to wild or semi-wild edible plants? (*)

26 Is there any management practice made to conserve the plants? (*)

27 What are the traditional management practices used by the local people to conserve the edible plant species? (*)

28 Do governmental and non-governmental agents engage the local community to scientifically improve management practice for conservation and utilization of the edible plants? (*)