2025-09

Vegitation Ecology of Selected Church Forests Ethnobotanical Study of Medicinal Plants in West Gojjam Zone Northwestern Ethiopia

Ayele, Abebe

BAHIR DAR UNIVERSITY

GRADUATE STUDIES OFFICE

COLLEGE OF SCIENCE

DEPARTMENT OF BIOLOGY

VEGETATION ECOLOGY OF SELECTED CHURCH FORESTS AND ETHNOBOTANICAL STUDY OF MEDICINAL PLANTS IN WEST GOJJAM ZONE, NORTHWESTERN ETHIOPIA

PhD DISSERTATION

BY

ABEBE AYELE HAILE

SEPTEMBER 2025

BAHIR DAR, ETHIOPIA

GRADUATE STUDIES OFFICE

COLLEGE OF SCIENCE

DEPARTMENT OF BIOLOGY

VEGETATION ECOLOGY OF SELECTED CHURCH FORESTS AND ETHNOBOTANICAL STUDY OF MEDICINAL PLANTS IN WEST GOJJAM ZONE, NORTHWESTERN ETHIOPIA

A Dissertation Submitted in Complete Fulfillment of the Requirements for the Degree of Doctor of Philosophy (PhD) in Plant Biology

BY

ABEBE AYELE HAILE

Advisors:

Ali Seid (PhD)

Amare Bitew (PhD)

Wubetie Adnew (PhD)

SEPTEMBER 2025

BAHIR DAR, ETHIOPIA

ADVISOR'S APPROVAL FORM

BAHIR DAR UNIVERSITY

COLLEGE OF SCIENCE

DEPARTMENT OF BIOLOGY

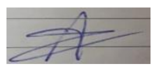
Approval of Dissertation for Defense

We hereby certify that we have supervised, read, and evaluated the dissertation entitled **"Vegetation Ecology of Selected Church Forests and Ethnobotanical Study of Medicinal Plants in the West Gojjam Zone, Northwestern Ethiopia"** by Abebe Ayele, prepared under our guidance. We recommend that the dissertation be submitted for oral defense.

Principal Advisor's Name	Signature	Date
Ali Seid (PhD, Assoc. Prof.)	Ali Seid	19/9/2025
Co-principal Advisor's Name	Signature	Date
Amare Bitew (PhD, Assoc. Prof.)		19/9/2025
Co-principal Advisor's Name	Signature	Date
Wubetie Adnew (PhD, Assoc. Prof.)		19/9/2025
Department Head's Name	Signature	Date
Baye Sitotaw (PhD, Assoc. Prof.)		19/9/2025

DECLARATION

This is to certify that the dissertation entitled "**Vegetation Ecology of Selected Church Forests and Ethnobotanical Study of Medicinal Plants in the West Gojjam Zone, Northwestern Ethiopia**", submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Plant Biology, Department of Biology, Bahir Dar University, is my original work. I, Abebe Ayele, affirm that this dissertation has not been submitted to any other institution for the award of any degree or certificate. All sources and materials used in the preparation of this dissertation have been properly acknowledged.

Name of the candidate	Signature	Date
Abebe Ayele Haile		19/9/2025

Examiner's Approval Form

BAHIR DAR UNIVERSITY

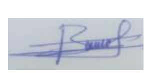
COLLEGE OF SCIENCE

DEPARTMENT OF BIOLOGY

Approval of Dissertation for Defense Result

As members of the board of examiners, we examined the dissertation entitled **"Vegetation Ecology of Selected Church Forests and Ethnobotanical Study of Medicinal Plants in the West Gojjam Zone, Northwestern Ethiopia"** by Abebe Ayele. We hereby recommend that the dissertation be approved in fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Plant Biology**.**

Board of Examiners

External Examiner Name	Signature	Date
Zerihun Woldu (Professor)	------------------------	--------------
External Examiner Name	Signature	Date
Asmamaw Alemu (PhD, Assoc. Prof.)	------------------------	---------------
External Examiner Name	Signature	Date
Liyew Birhanu (PhD, Assoc. Prof.)	-------------------------	---------------
Internal Examiner Name	Signature	Date
Belayneh Ayele (PhD, Assoc. Prof.)	-------------------------	---------------
Chairperson Name	Signature	Date
Baye Sitotaw (PhD, Assoc. Prof.)		19/9/2025

BIOGRPHICAL SKETCH

Abebe Ayele Haile, born in 1993/94 in Wofwasha Kebele, Termaber District, North Shewa Zone, Amhara Region, Ethiopia. He completed his elementary education at Genet Primary School in Wofwasha Subdistrict, progressing through Grade 1 to Grade 8. He then attended Debresina High School in the Termaber District, where he completed his secondary education from Grade 9 to Grade 12. After completing high school, he enrolled in the Department of Biology at Haramaya University in 2013, Ethiopia. He pursued a bachelor's degree and successfully completed it in 2015. After completing his bachelor's degree, he began a master's program in botanical sciences at Haramaya University in 2016 and graduated with his MSc in 2017. From 2018 to 2019, he served as a lecturer at Dambi Dollo University, Ethiopia. In 2020, he joined Debre Berhan University as a lecturer, continuing his teaching career. Since 2021, he has been pursuing a PhD in Plant Biology at Bahir Dar University, focusing on his research in vegetation ecology and ethnobotanical studies in Northwestern Ethiopia.

ACKNOWLEDGEMENTS

I thank God for His help, strength, and patience throughout my research, which enabled me to overcome challenges and persevere to the end.

I would like to express my sincere thanks to my advisors, Dr. Ali Seid, Dr. Amare Bitew, and Dr. Wubetie Adnew, for their constant support and guidance throughout my dissertation journey. The constant support of Dr. Getahun Yemata has been invaluable. I am deeply grateful for the time and effort he dedicated to my work, providing both academic guidance and personal encouragement. I would also like to thank Dr. Amare Bitew for including in his project, which provided me with an excellent opportunity and resources to carry out my study. I am also grateful to Animut Mekuriaw, Endalamaw Yihune, and Lidiya Shimelis for their invaluable assistance with data collection. Their hard work and dedication made a significant difference in the completion of this dissertation. Finally, I would like to thank Bahir Dar University for the financial support that made this research possible. I truly could not have completed this work without the help and support of all these individuals and organizations, and I will always be grateful.

I would like to express my sincere gratitude to my colleagues. I would like to express my gratitude to Misganaw Liyew and Denekew Temesgen for their valuable assistance during the data collection process. Additionally, I would like to extend my appreciation to the priests of the West Gojjam Zone and all the participants for their contributions and cooperation during the data collection. Finally, I would like to extend my heartfelt thanks to all those not mentioned here, including my family and friends, for their unwavering support and encouragement throughout the entire process. Their constant love, patience, and belief in me were essential in helping me to complete this research.

ABBREVIATIONS AND ACRONYMS

AGB	Aboveground Biomass
AGC	Aboveground Carbon
ANOVA	Analysis of Variance
BA	Basal Area
BD	Bulk Density
BGB	Belowground Biomass
CO2	Carbon Dioxide
CSA	Central Statistical Agency of Ethiopia
DBH	Diameter at Breast Height
DON	Dissolved Organic Nitrogen
EBI	Ethiopian Biodiversity Institute
EOTC	Ethiopia Orthodox Tewahido Church
FAO	Food and Agriculture Organization
FDRE	Federal democratic republic of Ethiopia
FGD	Focus Group Discussion
FL	Fidelity Level
GPS	Global Positioning System
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
ICF	Informant Consensus Factor
IFAD	International Fund for Agricultural Development
IK	Indigenous Knowledge
IVI	Importance Values Index
Masl	Measure of Above Sea Level
MEFCC	Ministry of Environment, Forest and Climate Change
NDC	Nationally Determined Contribution
PH	Potential of hydrogen
RD	Relative Density

ABBREVIATIONS AND ACRONYMS (CONTINUED)

RDO	Relative Dominance
REDD	Reducing Emissions from Deforestation and Forest Degradation
RF	Relative Frequency
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TC	Total Carbon
TN	Total Nitrogen
UNDP	United Nations Development Programme
WC	Water Content
WGAZ	West Gojjam Administrative Zone
WHO	World Health Organization

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF APPENDICES

ABSTRCT

Church forests in Ethiopia are vital to preserving biodiversity, mitigating climate change, conserving soil, and the protection of indigenous knowledge systems. Despite, these church forests are facing extreme threats from anthropogenic disturbances. Linking these sacred places with science is important to manage actively. Hence, the present study was aimed to examine the vegetation ecology of selected church forests and ethnobotanical study of medicinal plants in West Gojjam zone, Northwestern Ethiopia. A total of 26 church forests were selected using stratified random sampling based on agroecology, elevation, size, and proximity to population centers to study vegetation ecology. Vegetation data were collected along Gentry transects, with 20 m x 20 m (400 m^2) plots for matured trees diameter at breast height (DBH) ≥ 2.5 cm and height ≥ 2.5 m), 5 m x 5 m (25 m^2) subplots for saplings, and 1 m x 1 m (1 m^2) subplots for seedlings. Soil samples were collected from each church forest, outside church forest and eucalyptus plantations to analyse soil physico-chemical properties. Soil samples were homogenized, followed by nutrient extraction and quantification. To assess the influence of various factors on woody species composition, soil nutrient dynamics, and aboveground biomass (AGB), both ANOVA and linear regression analyses were performed. All statistical analyses were conducted using JMP 17 (SAS Institute Inc.). Ethnobotanical data were also collected from three districts (selected based on agroecology) of the West Gojjam zone. Informants were selected through both purposive and random sampling methods. Ethnobotanical data was analyzed using quantitative and qualitative ethnobotanical parameters. A total of 111 woody species were documented from 26 church forests, of which 82.88% were indigenous, 15.32% exotic, and 1.8% endemic. The most dominant family was Fabaceae. The average density of woody species with DBH ≥ 2.5 cm and height ≥ 2.5 m was 840 individuals' ha^{-1}. *Eucalyptus camaldulensis* was the most dominant frequented species in church forests accounted for 72.57% individuals' ha^{-1}. *Ficus vasta* had the highest basal area. Human disturbances such as expansion of agriculture, grazing, and grave construction in church forest had considerably influence on forest structure and species diversity. Additionally, edge effects endorsed the invasion of exotic species and contributed to reduced soil fertility within the forest. Church forests had highest carbon stocks, with a mean AGB of 31.97 ± 3.31 tons ha^{-1} and a corresponding CO_2 equivalent of 97.15 ± 10.47 tons ha^{-1}, highlighting their notable potential for climate change mitigation. The study area experienced an average human disturbance of 24.35%, reflecting the impact of human activities on the church forests. Woody species abundance was highest in the inner (38.9%) and middle (39.0%) zones but lowest at the edges (22.1%), reflecting greater regeneration and stability in forest interiors. Soil analysis showed that church forest soils were richer in organic carbon, nitrogen, and phosphorus compared to soils outside church forests and in eucalyptus plantations, where widespread soil degradation was observed due to allelopathic effects. Similarly, ethnobotanical investigations were conducted in this zone and documented 97 medicinal plant species that were used to treat human ailments and 53 species that were employed in ethnoveterinary practices. These findings highlight the dual role of church forests as biodiversity hotspots and repositories of traditional medicinal knowledge. Effective conservation strategies are essential to mitigate human disturbances, control exotic species, maintain soil fertility, and safeguard both ecological and cultural values.

Keywords: Church forest, Plant diversity conservation, Carbon sinks, Soil properties, Ethnobotanical knowledge, Human disturbances, Eucalyptus plantations, Climate change mitigation

OUTLINE OF THE DISSERTATION

This dissertation is structured into 8 chapters, outlined as follows:

CHAPTER 1: General Introduction and Methodology: Introduces the study, highlighting the importance of church forests and medicinal plants in the West Gojjam zone of Northwestern Ethiopia. It begins with an overview of the study area, its ecological significance, and the role of church forests in preserving biodiversity. The chapter also includes a literature review, the role of church forests in conservation, and the ethnobotanical knowledge related to medicinal plants in the west Gojjam zone. Additionally, the methodology section describes the research design, data collection methods used to explore the ecological and ethnobotanical aspects of the study area.

Chapter 2: **Woody Species Diversity, Structure, and Regeneration Status of the Church Forests in West Gojjam Zone, Northwestern Ethiopia:** examines the diversity, structure, and regeneration of woody plant species in the church forests. It presents an inventory of the tree species, assessing their richness and distribution, as well as the forest's physical structure, including tree height and diameter. The chapter also evaluates the regeneration status, focusing on the presence of seedlings and saplings. This analysis helps to understand the ecological health and sustainability of these important forest ecosystems.

Chapter 3: **Estimation of Carbon Stocks of Woody Plant Species in Church Forests of West Gojjam Zone, Northwestern Ethiopia: Implications for Climate Change Mitigation:** focuses on assessing the carbon storage potential of the woody plant species found in the church forests. It provides an estimation of the carbon stocks sequestered by these forests, which play a crucial role in mitigating climate change. The chapter likely includes methods for measuring carbon storage, such as calculating aboveground biomass and carbon content of different tree species. It also discusses the ecological significance of these forests in terms of climate regulation and the potential benefits they offer in global efforts to combat climate change. The findings emphasize the importance of preserving church forests as natural carbon sinks.

Chapter 4: **Human Disturbances and their impact on woody species diversity in sacred church forests in West Gojjam zone, Northwestern Ethiopia:** focuses on the effects of various human disturbances on the woody plant diversity in church forests. It examines disturbances such as graves, clearings, grazing, gathering, and digging, which often occur due to religious, cultural, and agricultural practices. The chapter assesses how these activities impact the forest structure, species diversity, and regeneration capacity, potentially leading to a decline in biodiversity and forest health. By exploring these disturbances, the chapter emphasizes the importance of sustainable management practices to safeguard the ecological integrity and diversity of these sacred forests.

Chapter 5: **Soil Fertility and Ecosystem Integrity in Wst Gojjam Zone Selected Church Forests: Effects of Eucalyptus Plantation and Edge Disturbance:** It focuses on how human activities such as the planting of non-native species affect the physical (structure, moisture content) and chemical (e.g., nutrient levels, pH, organic matter) properties of the soil. The chapter also explores edge effects, where the transition from forest to adjacent land alters soil conditions, often worsened by the introduction of exotic species like eucalyptus. These changes can negatively impact soil fertility and forest health, underlining the need for sustainable land and forest management practices to mitigate these disturbances and protect soil integrity.

Chapter 6: **Ethnobotanical Study of the Traditional Use of Medicinal Plants Used for Treating Human Diseases in Selected Districts of West Gojjam Zone, Amhara Region, Ethiopia:** explores the traditional knowledge and practices of local communities in West Gojjam regarding the use of medicinal plants for treating various human diseases. This chapter investigates the plant species commonly used for medicinal purposes, their preparation methods, and the specific diseases they are believed to treat. It likely includes interviews with local healers, community members, and farmers to document their ethnobotanical knowledge, as well as an analysis of the cultural significance and conservation status of these plants.

Chapter 7: **Survey of Ethnoveterinary Practices of Medicinal Plants in West Gojjam Zone, Northwestern Ethiopia:** focuses on the traditional use of medicinal plants for the treatment of livestock diseases in the West Gojjam zone. This chapter investigates the ethnoveterinary knowledge of local communities, documenting the plant species used to treat common diseases in animals. It includes information on how these plants are prepared and administered, as well as the specific conditions they are used to treat. The chapter also explores the cultural importance of these practices in supporting livestock health and livelihood, and the role of local knowledge in preserving animal health in the selected districts.

CHAPTER 8: General Conclusions and Recommendations: This study highlights the critical ecological and cultural roles of church forests in the study area. However, human activities (logging, agriculture, grazing) degrade their edges, reduce biodiversity, and threaten their ecological functions. Conservation efforts such as buffer zones, native species restoration, and community-based management are urgently needed. Integrating these forests into climate policies (e.g., REDD+) and safeguarding traditional knowledge will ensure their preservation as vital refuges for biodiversity, climate resilience, and local livelihoods.

The research presented in this study includes several chapters, four of which have been published, while one hs been submitted to journals for potential publication. Additionally, one review manuscript has been published and is included in **Appendix 1.**

CHAPTER 1: GENERAL INTRODUCTION AND METHODOLOGY

1.1. Background and Justification

A forest ecosystem is a dynamic and intricate community of living organisms and their physical environment, which together form an integrated whole within forests (van Leeuwen and Nieuwenhuis, 2010). It consists of biotic components such as plants, animals, and microorganisms, as well as abiotic components such as soil, water, air, sunlight, and climate, all of which regulate basic ecological processes (Reigosa and González, 2006). The most important element of all the components was vegetation which was the determinant and at the same time the affected factor in the ecosystem comprising of species richness, soil, moisture, temperature, and light (Entrocassi et al., 2019; Mandal and Chatterjee, 2021).

The dry woodlands of Africa, which are the most remarkable ecosystems in this regard, showcase the interplay between factors of nature even more. That is to say, they account for a good share of the world's natural vegetation (Chidumayo & Marunda, 2010; Bodart et al., 2013). Among them, Ethiopia is the country with the largest surface area of this woodland ecosystem. The country's flora is greatly influenced by its vast altitude difference, which is from the Danakil Depression at 125 m below sea level to Mount Ras Dashen at 4,533 m above sea level. This difference causes a variety of temperature and moisture conditions that can support more than 50% of the Africa's Afromontane species (IBC, 2005; Mulugeta and Teketay, 2005; Sayer et al., 1992). Furthermore, Ethiopia harbours several endemic species, such as Erythrina brucei, Millettia ferruginea, and Plumbago zeylanica (Sayer et al., 1992; Fashing et al., 2022). Dry forests cover about 14% of the total African land surface and represent approximately 25% of natural vegetation. They are characterised by a seasonal climate, with a dry season of 4 to 7 months. Large parts of these ecosystems, however, are degrading due to grazing, fire, or exploitation by people (Eshete et al., 2011).

The Flora of Ethiopia and Eritrea contains approximately 6,027 vascular plant species and approximately 10–12% are endemic, a higher percentage than for the neighboring countries lying to the west, such as Cameroon (9%) and Gabon (3%) (UNEP, 2006; Friis et al., 2010; Kelbessa and Demissew, 2014). Even though Ethiopia has historically had a comparatively higher forest cover than Kenya (7.7%) and Uganda (10.5%) (FAO, 2015).

Between 2005 and 2010, Ethiopia experienced an annual deforestation rate of 1.11%, significantly higher than the global average of 0.14% and Africa's average of 0.5% during the same period. (FAO, 2010). The primary drivers of deforestation are agricultural encroachment, fuelwood, charcoal production, and construction needs (Melaku et al., 2015; Oljirra, 2019).

Despite this deforestation, church forests in Ethiopia are critical biodiversity refugia; some of the last remnants of indigenous vegetation (Admassie, 1995; Wassie, 2002; Bhagwat and Rutte, 2006; Aerts et al., 2016). Although small, these forests are environmentally important as they represent some of the last remaining fragments of Ethiopia's dry Afromontane forests, most of which have been cleared for agriculture (Reynolds et al., 2015; Abbott, 2018). Today, less than 4% of these original forests remain (Wassie et al., 2010; Cardelús et al., 2013; Reynolds et al., 2017). There are around 35,000 church forests are found across Ethiopia, some 8,000 in Amhara, the majority of which are under 5 hectares (Abbott, 2018). Strong religious and cultural traditions uphold these sacred groves, which are protected by the Ethiopian Orthodox Tewahedo Church (EOTC) and provide important ecosystem services and preserve endemic species (FAO, 2012; Aerts et al., 2016; Amare et al., 2019). The forests' continued existence highlights the significant role that spiritual beliefs play in promoting long-term environmental stewardship (Klepeis et al., 2016). In terms of ecology, church forests are outlined by high plant and animal diversity, facilitating natural regeneration, indigenous medicinal plants, and ecosystem function like soil protection and hydrological regulation (Aerts et al., 2016; Endalew et al., 2020). Their conservation is longstanding, with some forests preserved for over 1,500 years, reflecting the enduring commitment of EOTC adherents to environmental conservation (Orlowska and Klepeis, 2018).

In the Amhara region, church forests have long been regarded as sacred sites, deeply valued for their cultural and ecological importance (Aerts et al., 2016). Normally, this respect protected it from temporal alteration of land use over many centuries. However, in recent years, some forests on land belonging to religious authorities have been cleared for cultivation to finance church activities (Abbott, 2018). Analysis of nearly 80 years of historical aerial photographs indicates that church forests have remained relatively stable in size, reflecting notable resilience. However, despite this stability, increasing human disturbance within the forests has intensified their vulnerability and weakened their capacity to function as vital Afromontane refugia for ecological restoration amid extensive land-use and cover (LUC) changes in the surrounding landscapes (Scull et al., 2016).

Church forests hold significant value for traditional knowledge systems. They serve as refuges for wildlife; species of animals, food, and traditional medicines are made available; they serve as seed banks for native tree species; and they are hotspots of biodiversity and ecosystem services (Robinson, 2015; Aerts et al., 2016; Endalew et al., 2020; Wolde, 2023). Hence, these forests provides for the collection of many medicinal plants used in traditional medicine for treating physical ailments, spiritual healing, and general wellness (Anderson, 2007). With the fast rate of biodiversity loss and its threat to the human and environmental well-being, these sacred sites are vital for cultivating biological and cultural diversity, with their conservation deeply intertwined with their cultural significance (Doffana, 2017).

Despite their ecologic and cultural significance, church forests are coming under growing threats and there have been dramatic reductions in number over recent decades (Aerts et al., 2016; Cardelús et al., 2019). Deforestation has been largely driven by the expansion of agriculture, which led to the clearance over 40% of Ethiopia's forest between 2000 and 2013, primarily for cropland conversion (FAO, 2015). Overgrazing, mainly by cattle, disrupts pollination and seed dispersal and thereby limits natural regeneration in church forests (Aerts et al., 2016; Wassie, 2007). The pressure of unsustainable firewood extraction from forest due to land use leading to soil and biological resource degradation in these forests. Furthermore, dependence on biomass energy for more than 90% of our national consumption can be witnessed in most parts of the country leading to fuel wood cutting and deforestation, promoting degrading to forests (Eshetu, 2014).

Land scarcity has led to encroachment and division, with some church forests halving in size during the last hundred years in the Amhara region (Cardelús et al., 2013). All these threats underline the importance of good management of such marshland fragments, so rich in biodiversity but eroding without stop. Climate change further exacerbates human pressure on church forests, for example through the 2015–2016 El Niño drought that led to widespread tree die-offs and increased fire risk (USAID, 2017).

These long-term threats bring into a pressing need for effective conservation measures to protect church forests. However, although the pressures on such ecosystems are increasing, relatively low-level in-depth research has been achieved on some church forests. Earlier research reports different woody species diversity, ranging from 168 species in South Gondar church forests (Wassie et al., 2010), 39 species in Yemrehane Kirstos Church Forest (Amanuel and Dalle, 2018), to 70 species in Debre Libanos Monastery (Koricho et al., 2020). In addition, restoration opportunities and challenges (Wassie, 2002, 2007), soil seed bank (Wassie and Teketay, 2006), tree regeneration (Wassie et al., 2009), and forest resilience (Scull et al., 2016) were studied in particular in South Gonder Administrative Zone church forests.

Studies on church forests bridge sacred values with scientific knowledge, offering ecological and cultural benefits for both present and future generations. Similar to other parts of Ethiopia, church forest conservation practices were studied in some selected church forests of the West Gojjam zone (Woldemedhin & Teketay, 2016). However, comprehensive investigations have not been conducted regarding their carbon sequestration potential, the extent of human-induced disturbances, soil properties, and ethnobotanical aspects of church forests and surrounding area. Furthermore, integrating of ecological and ethnobotanical knowledge is vital to promote collaborative conservation planning in church forest and surrounding areas (Shrestha and Medley, 2017). Addressing these gaps is essential to reposition church forests not only as religious symbols but also as scientifically recognized and actively managed ecological landscapes. Therefore, the present study was aimed to evaluate the vegetation ecology of selected church forests and ethnobotanical assessment of medicinal plants in West Gojjam Zone.

1.2. Objectives and Research Questions

1.2.1. General Objective

The general objective of this study was to study the vegetation ecology of selected church forests and ethnobotanical study of medicinal plants in West Gojjam zone, Northwestern Ethiopia.

Specific Objectives

The specific objectives of the study were:

- To determine woody species diversity, density, vegetation structure, and regeneration status of the church forests
- To estimate the biomass and carbon sequestration potential of the church forests.
- To examine the impacts of human disturbances on the integrity and regeneration potential of the church forests.
- To evaluate the status of soil nutrient content status across different landcover types (church forest, outside forest and eucalyptus plantation), and edge effects.
- To document and analyze medicinal plants used by local communities to treat human and livestock diseases around the church forests of West Gojjam Zone.

1.2.2. Research questions

- ❖ What is the species composition, diversity and structure of woody plants in the the church forests in West Gojjam zone?
- ❖ To what extent do the curch forests serve as a significant carbon sinks?
- ❖ What are the major human disturbances driving degradation of the church forests in the study area?
- ❖ Does soil fertility fluctuate with different land cover types (church forest, outside forest, and eucalyptus plantations) and edge effects?
- ❖ What medicinal plants are used by the local communities to treat human and livestock diseases in and around the church forests of West Gojjam Zone?

1.2.3. Siginificance of the present study

The following are the significance of the study:

1. Conservation of Biodiversity: The church forest study showed how sacred forests in West Gojjam and other areas serve as vital refuges for biodiversity, preserving native species and ecosystems in a heavily degraded landscape. By integrating spiritual values with ecological stewardship, these forests empower local communities to protect nature while benefiting from essential ecosystem services like clean water, soil conservation, and medicinal plants.

2. Traditional Healthcare Support: The report revealed a high number of medicinal plants (97 human and 53 animal) that have been used by the informants. It not only confirms traditional information but also gives evidence for the long-term use of the species in traditional medicine. It forms a foundation for future drug discovery and emphasizes the need for conservation of the species for continued benefits in health to the community.

3. Carbon Sequestration and Climate Change Mitigation: Church forests were found to store significant carbon (31.97 ± 3.31 tons ha^{-1} biomass), contributing to climate change mitigation. This call attention to their role in global environmental efforts and could lead to opportunities for carbon credit programs (REDD+) that benefit the local community economically.

4. Church forests enhance soil fertility by preventing erosion, adding organic matter, and cycling nutrients. Their integral soils benefit nearby agriculture by reducing sediment loss, improving water retention, and decreasing the need for chemical fertilizers. Comparing land uses shows these benefits, supporting sustainable land management, food security, and soil conservation.

5. Integrated Conservation Approach: The study emphasizes the value of community-led conservation through buffer zones, native species restoration, and participatory management, which not only fosters local ownership and cultural alignment but also enables targeted interventions to mitigate threats like arbitrary grave construction, logging, agriculture, and grazing, thereby reducing degradation and preserving both biodiversity and cultural heritage.

1.3. Review of Related Literature

1.3.1. Vegetation of Ethiopia

Vegetation, the most abundant biotic element of the biosphere, refers to the plant life covering a region (Maarel and Franklin, 2013). In Ethiopia, characterized by different geographical contrasts, elevations range from 125 meters below sea level in the Danakil Depression to 4,620 meters above sea level in the Semien Mountains (Husen et al., 2012; Mulugeta and Teketay, 2005). This topographical diversity, combined with climate variability, fosters a wide range of vegetation types, from Afroalpine in the highlands to arid and semi-arid in the lowlands (Asefa et al., 2020). Ethiopia's rich biodiversity, complex terrain, and climatic variations collectively shape its distinct vegetation patterns, which are primarily influenced by the country's geological history and climate, resulting in vegetation types ranging from drought-tolerant species in the lowlands to cold-tolerant species in the highlands.

Additionally, the vegetation reflects a blend of Afrotropical and Palearctic species, a legacy of connections established during the dry glacial period. Plant species richness and distribution along elevation gradients are further influenced by factors such as management intensity, anthropogenic disturbance, and spatial heterogeneity (Kumar et al., 2024; Sánchez and Lopez-Mata, 2005). Protected areas and buffer zones play a crucial role in maintaining biodiversity (IFAD, 2016), which is fundamental to ecosystem structure and function, providing a vast range of ecological goods and services essential for human well-being (Naeem et al., 2009; Leadley et al., 2010). Biodiversity also supports processes like photosynthesis, which contributes to oxygen production (Stewart and Globig, 2011) and includes plant species that serve as valuable sources of medicines and herbs. Conversely, a lack of diversity in ecosystems can have detrimental effects (Naveh, 1994).

According to Matthews (1983) the vegetation type is classified based on their life forms, density, and seasonality (evergreen and deciduous) in association with altitude, climate, and vegetation architecture. Ethiopia's vegetation is classified by different authors in different ways. For example, according to Demsew and Friis (2009), nine types of vegetation were found including Eritrean vegetation. Similarly, Pichi-Sermolli (1957) categorized the Ethiopian vegetation into twenty-four types by using physiognomic characters with little phytogeographical consideration.

Recently Friis et al. (2010) have classified Ethiopian, natural vegetation into 12 major types and subtypes based on their climate and altitude variations. These are (1) Desert and semi-desert scrubland, (2) Acacia-Commiphora with subtypes (2a) Acacia-Commiphora woodland and bushland proper, and (2b) Acacia wooded grassland of the Rift Valley (3), Wooded grassland of the western Gambela region (4), Combretum-Terminalia Woodland and wooded grassland (5), Dry evergreen Afromontane forest and grassland complex with subtypes (5a) Undifferentiated Afromontane forest and (5b) Dry single-dominant Afromontane forest of the Ethiopian highlands (5c) Afromontane woodland, wooded grassland and grassland (5d) Transition between Afromont ane vegetation and Acacia Commiphora bushland on the Eastern escarpment (6) Moist evergreen Afromontane forest with subtypes (6a) Primary or mature secondary moist evergreen Afromontane forest (6b) Edges of moist evergreen Afromontane forest, bushland, woodland, and wooded grassland, (7) Transitional rain forest, (8) Ericaceous belt, (9) Afroalpine belt, (10) Riverine vegetation, (11) Freshwater lakes, lakeshores, marshes, swamps and floodplains vegetation (11a) Freshwater lake vegetation [open water] and (11b) Freshwater marshes and swamps, floodplains and lakeshore vegetation, (12) Salt-water lakes, lakeshores, salt marshes and pan vegetation (12a) Salt-water lake vegetation [open-water] (12b) Salt pans, saline/brackish and intermittent wetlands and salt-lake shore vegetation. However, the vegetation of Ethiopia has faced a strong influence from anthropogenic factors. Because 85% of the rural population is dependent on natural resources for their livelihood, and this results in the decline of vegetation cover in the country (Fessehaie and Tessema, 2014).

A loss of biodiversity means a loss of new inspirations that bring happiness and learning opportunities (Ryu et al., 2020). Therefore, biodiversity conservation is central to achieving recent global commitments for sustainable development under “Agenda 2030,” adopted by the United Nations in 2015 (IFAD, 2016). The International Fund for Agricultural Development (IFAD) recognizes that losing biodiversity means losing opportunities for coping with future challenges, such as those posed by climate change and food insecurity. Successful conservation and management of plant diversity require an explicit exploration of plant species richness patterns and an understanding of the factors that govern these patterns (Gebrehiwot et al., 2019). Two key approaches, in situ and ex situ conservation, are vital for preserving natural vegetation.

Ex situ maintenance of plant species is provided by botanic gardens, while in situ conservation involves protecting forests and other vegetation in their natural habitats (Thomas et al., 2022; Corlett, 2016). The conservation of natural vegetation is essential for maintaining sustainable ecosystems. This involves avoiding practices such as cutting trees and clearing forests for excessive human needs, preventing pollution of soil, water, and air, and ensuring proper monitoring of these resources. Healthy ecosystems provide critical services, such as clean air and water, fertile soil, and climate regulation, which are indispensable for human well-being and survival. By conserving natural vegetation, we safeguard these ecosystem services, ensuring their availability for future generations (Corlett, 2016).

The West Gojjam Zone, located in the Amhara National Regional State of Northwestern Ethiopia, is characterized by diverse vegetation types shaped by variations in altitude, climate, and land-use patterns. The natural vegetation of the zone is dominated by dry Afromontane forests, woodlands, and riverine vegetation, which harbor a wide range of indigenous tree and shrub species. However, much of the original forest cover has been converted into agricultural land, leaving remnant patches of vegetation mainly in sacred church forests and along steep slopes or inaccessible areas. These remnant forests play a critical role in conserving biodiversity, maintaining soil fertility, and supporting traditional ecological knowledge. Common tree species include Juniperus procera, Olea europaea subsp. cuspidata, Croton macrostachyus, and Cordia africana, while understory layers are often composed of shrubs, climbers, and herbaceous species. Despite their ecological significance, the vegetation resources of West Gojjam are increasingly threatened by deforestation, fuelwood collection, grazing pressure, and agricultural expansion (Woldemariam & Teketay, 2016).

1.3.2. Forest Ecosystems, Biodiversity, and Conservation Challenges in Ethiopia

The forest is an ecosystem characterized by a dense and extensive tree cover, often consisting of stands varying in characteristics such as species composition, structure, age class, and associated processes and commonly including meadows, streams, fish, and wildlife (FAO, 2011). According to the United Nation framework convention on climate change, the forest is defined as an area covering at least 0.5 to 1 hectare, containing tree crown cover of more than 10 to 30% with trees that have the potential to reach a minimum height of 2 to 5 m at maturity (UNFCCC, 2002; Coté, 2003). A forest is a continuous stand of trees that may attain a height of 50 m or more with crowns touching or intermingling and often interlaced with lianas (Friis, 1986). Forest cutting is a common type of human disturbance in different part of Ethiopia (Hishe et al., 2021).

Historical sources indicated that Ethiopia land area was covered about 35-40% by forests (EFAP, 1994). Currently, the country has about 17.35 million hectares of forests (15.7% of the country's area), which include bamboo, dense woodland, natural forests, and planted forests (EBI, 2015). Rapid population growth, poverty, deforestation, shifting agriculture, demand for fuelwood and charcoal, human-induced fires, forest cutting, and lack of proper policy frameworks are among the major factors contributing to deforestation (Dinkayoh, 2016; Xi et al., 2021). Habitat loss due to deforestation not only reduces the number of species in the ecosystem but also the number and location of species living together (Mwakalukwa et al., 2014). Human disturbances have an impact on the biodiversity of forest communities (Laurance et al., 2014).

The forest biodiversity is an important renewable natural resource serving tremendous values of scientific, agricultural, medical, pharmaceutical, educational, cultural, and ecological importance (Mewded et al., 2019). Botanical assessments such as floristic composition, species diversity, and structural analysis provide information on species richness of the forest, useful for forest manage-ment purposes, and help in understanding forest ecology and ecosystem function (Zaman et al., 2011).

The status of species composition and structure of forest vegetation are important indicators to understand the trends of threats on local plant communities (Misganaw et al., 2021). To ensure the sustainable use, conservation, and ecological management of natural vegetation, an in-depth study of the remaining forest lands in Ethiopia is urgently needed as basic information are lacking (Gebrehiwot et al., 2019). Thus, studying plant diversity in the forest area is essential for evaluating and documenting species composition, diversity, structure, regeneration status, ecological aspects, and associated traditional knowledge. This information is crucial for the effective management, sustainable utilization, and conservation of the forest before it is lost (Birhanu et al., 2021).

1.3.3. Significance and conservation of Forest

1.3.3.1. Significance of Forest

Forest is important for our survival starting from the air we breathe to the wood we use. It also providing habitats for animals and livelihoods for humans, watershed protection, prevents soil erosion, in sustaining water supply and rainfall, and mitigates climate change (Ekhuemelo et al., 2016). Forests are invaluable assets, offering a wealth of resources. These include timber, fuelwood, fodder, fiber, fruits, medicinal plants, cosmetic ingredients, and raw materials essential for various industries (Chamberlain et al., 2020; Mondo et al., 2024). Wood is also essential in the production of paper. The rubber extracted from trees is used to make several products (Ramage et al., 2017). A diverse array of mammals and birds inhabit these forests, constituting vital living resources. Furthermore, forests play a crucial role in soil formation, water conservation, and the replenishment of oxygen. In general, the importance of forest can be categorized into different major headings as economic, ecological and social significance (Botkin and Keller, 2014; Chamberlain et al., 2020).

The economic significance of forest including making houses, furniture, matches, ploughs, bridges, and boats, etc, and as the source of forest products such as tannins, gums, spices, waxes, honey, and musk. The flora and fauna of the forest also hold the key to numerous life-sustaining products such as pharmaceuticals, insecticides, and pesticides. According to FAO (2012), about 350 million of the world's poorest people, including 60 million indigenous people, use forests intensively for their subsistence and survival. Forest is significant in ecology through moderation of global climate by stabilizing global climate and hydrological and carbon cycles. Because forests could absorb carbon dioxide from the atmosphere (source of carbon sink) (Psistaki et al., 2024). Forests are the greatest repository of biodiversity on the land as they provide ideal conditions for the survival and growth of living organisms. Similarly, forest is significant as part of our social and cultural ethos by providing aesthetic, recreational and spiritual value for the people (Pillay et al., 2022). Therefore, forests play an important role in the well-being and survival of the community by providing the necessary materials economically, ecologically, socially and culturally entities.

1.3.3.2. Conservation of Forest

According to FAO (2015), Ethiopian has lost more than two million hectares of forest cover with an annual average loss of 140, 000 ha from 1990-2005. According to the World Bank assessment of the forest cover from 1990-2018 vary from previous reports. In 1990, the Ethiopian forest had covered a total of 204,085.6 square kilometers. However, in 2018, the forest cover reduced to of 172, 145 square kilometers. This trend has shown drastically decrease through the years. Consquently, this may result in the expansion of drought, deforestation and expose the people to famine. Deforestation refers to the removal or destruction of forests. The major causes of deforestations are population explosion, forest fires, grazing of animals, and pest attacks. Forests are vital to the conservation of terrestrial biodiversity, as more than a quarter of the earth's land surface is covered by forests, and more than half of the earth's terrestrial species dwell in or depend on these forests (Hassan et al., 2005; FAO, 2012). However, in many regions, natural forest cover is limited due to human activities (Eycott et al., 2006), making modified forests crucial for biodiversity conservation. Preventing further forest loss requires preserving existing forests and restoring degraded and deforested areas (César et al., 2020).

1.3.4. Church Forests in Ethiopia

According to FAO (2012) in Ethiopia, significant forests are found in and around churches, monasteries, graveyards, mosque compounds, and other sacred sites. Forests in the church are sacred because church is believed to be the house of God and everything in its compound is sacred and respected (Aerts et al., 2016 Amare et al., 2019). Church forests represent an unusual form of community-based protection that integrates locally controlled common property with external institutional arrangements this hybrid system is highly effective at protecting the forest while maintaining cultural practices (Klepeis et al., 2016). Hence, church forests provide a safe habitat for plants and animals, sources of food and traditional medicine, seed bank for native tree species, reduce soil erosion, and are rich in biodiversity (Aerts et al., 2016; Endalew et al., 2020). For centuries, the core religious values of Ethiopian Orthodox Tewahido Church communities have ensured the protection of church forests (Orlowska and Klepeis, 2018).

Ethiopia's church forests, sacred woodlands that encircle EOTC, are the remaining pieces of the vast highland forests that have dwindled to a mere 4% of their original size after centuries of agricultural development. These forests, estimated at 35,000 nationwide (with about 8,000 in the Amhara region), vary in size from 3 to 300 hectares, averaging around 5 hectares, and act as vital havens of biodiversity within a severely deforested region (Wassie et al., 2010; Cardelús et al., 2013; Reynolds et al., 2017). Maintained for more than 1,500 years by religious customs connecting churches and forests, these groves demonstrate a longstanding model of conservation driven by faith, despite facing increasing risks to their ecological health from fragmentation and changing land use (Abbott, 2018). The continued existence of these forests highlights the need to combine cultural heritage with ecological conservation to protect these distinctive ecosystems.

1.3.4.1. Floristic composition and vegetation structure of some church forests in Ethiopia

The Ethiopian orthodox churches play a pivotal role in conserving and protecting forest resources and they harbour diverse flora and fauna (Wassie et al., 2002). Despite this fact, there is inadequate knowledge on the floristic composition, diversity and regeneration status of woody plants in most of the church forests in Ethiopia (Kifle et al., 2022). This implies that, church forests are important refugia of woody species biodiversity in central Ethiopia.

The overall conservation status is higher in older church forests. This is because the church forests have woody species populations with good recruitment potential. Numerous studies have been conducted in Ethiopia to assess the diversity and composition of church forests across different regions. For example, Wassie et al. (2010) documented 168 woody plant species in the South Gondar Zone, including 100 tree species, 51 shrubs, and 17 lianas. Similarly, Amanuel and Dalle (2018) recorded 39 species in Yemrehane Kirstos Church Forest (Lasta Woreda), with 19 (50%) trees, 5 (13%) shrubs, and 14 (36.8%) tree/shrubs. Koricho et al. (2020) identified 70 species in Debre Libanos church forests, consisting of 34 (57%) trees, 21 (36%) shrubs, and 4 (7%) lianas. Birhanu et al. (2021) reported 73 species in Dangila church forests, categorized as 43.06% trees, 12.5% tree/shrubs, 36.11% shrubs, and 8.33% climbers. Additionally, Tadesse Kifle et al. (2022) found 52 species in selected churches of central Ethiopia, with 56% trees, 41% shrubs, and 3% lianas.

1.3.4.2. The importance of Ethiopian church forests

The oldest EOTC date back to the 4th century and contain 35,000 churches and monasteries, some of which are about 1660 years old (Getnet, 1998; Abbot, 2018). The church forests in Ethiopia are small fragments of forest surrounding EOTC. Because these church forests house water supplies, biodiversity (including pollinators of local crops), conserve soil, store carbon, as well as the local churches which represent important spiritual centers. These forests are an important legacy to the health of the Ethiopian people (Wassie et al., 2009, 2010). They are a source of freshwater springs, a place for soil and water conservation (Abiyou et al., 2015). They are important in ecology, ecosystem services. In general, church forests have the following major importance.

For conservation of biodiversity

Vegetation surveys of church forests indicate that they are house of a large proportion of the vulnerable plant species (Wolde, 2023). In many parts of northern Ethiopia, large trees are mainly found in church compounds (Woldemedhin and Teketay, 2016). Church forests are the ideal sites to be chosen for species afforestation programs in their specific localities (in-situ) and that could serve as models of sustainable forest management and biodiversity conservation (Amare et al., 2019).

According to Wassie (2002), indigenous trees and plants are mostly found in the EOTC church. The church community protects the existing plants and the clergy initiate the community to plant trees in the church. This implication is important for the conservation of biodiversity. Therefore, churchyards are safe places for trees and other biodiversity resources for in situ conservation of both endemic and vulnerable plant species (Amare et al., 2019).

Ecosystem services of church forests

Church forests are vital to local communities, providing crucial ecosystem services such as fresh water, pollination, honey production, shade, and spiritual enrichment (Wassie et al., 2010; Reynolds et al., 2017). Functioning as cultural, ecological, and economic assets, these unique ecosystems support a wide array of plants, and animal life (Amare et al., 2019). Furthermore, they play a significant role in preserving forest sustainability, promoting biodiversity, and enhancing social welfare.

One important ecological function of church forests is mitigating climate change through carbon sequestration. Afforestation and sustainable forest management can help counteract climate change, which is largely caused by increasing atmospheric CO_2 levels from human activities (Kabir et al., 2023; Miripanah et al., 2019). Church forests serve as carbon sinks by absorbing CO_2 through photosynthesis and storing it within their biomass, soil, and litter (Alongi, 2012). Plants are essential in this process, stabilizing ecosystems while simultaneously decreasing atmospheric carbon concentrations (Tadesse, 2008). Ethiopian forests are estimated to store 2.76 billion tons of carbon in aboveground biomass, with church forests contributing substantially to this total (Eshetu, 2014). A study conducted on seven church forests in Addis Ababa reported that the mean aboveground and belowground biomass carbon stocks ranged from 129.85 ± 154.11 t ha^{-1} and 25.97 ± 30.82 t ha^{-1}, respectively, underscoring their critical role in climate regulation (Tura, 2013).

1.3.5. Threats and major causes of church forests depletion in Ethiopia

Loss of forest cover and biodiversity due to anthropogenic activities is a growing concern in many parts of the world (Hegde and Enters, 2000). Deforestation and forest degradation, overgrazing, an ever-increasing demand for forest products, forest fire and conversion of forest to farmland, etc. are becoming the main challenges threatening forest development and conservation efforts in Ethiopia (Melkie, 2020). According to Abiyou et al. (2015), the major constraints of church forest depletion are anthropogenic pressure, invasive species, and overgrazing by livestock. Anthropogenic pressure accounts for the largest share of forest destruction followed by grazing by domestic animals and then farm expansion and charcoal production. Human pressure is highly intensified in Mitak Amanuel and Abune Zena Markos natural forest. Farm expansion is also the main problem of Mida Abune Melketsiediek monastery forest forests (Abiyou et al., 2015). The destructive impacts of invasive alien species have been identified in Kewet, Yifratana Gidim districts towards Afar and Dessie. Among the invasive species, *Lantana camara* has replaced all the shrubby plant species at a very rapid rate.

In addition, livestock grazing is the major factor limiting seedling establishment, survival, and growth in church forests (Abiyou et al., 2015). This grazing practice will increase the erosion of soil. Therefore, another appropriate and alternative measurement must be made to stop the major constraints that hinder the green spot of the church forest. According to Cardelús et al. (2017), human disturbance (e.g., trails, plantations, exotic planting; 37%); and that forests close to markets (e.g., cities) have increased in area due to planting of eucalyptus (exotic), indicating a potential threat to their persistence and value as shelters of the church.

The other threatening factors includes shifting cultural practices, the changing economic status of church forest communities and the increasing influence of outside actors (Reynolds et al., 2017). A shift over time among church communities away from desiring extractive uses such as firewood and towards renewable uses including medicines, honey, shade and prayer (Orlowska and Klepeis, 2018). It is possible that these changes in self-reported desires for extractive resources might reflect increased hesitance to report what are increasingly seen as prohibited uses of the church forest (rather than actual changes in behavior concerning forest uses). The depletion of church forests has been increasing annually, unless appropriate measures are implemented (Reynoldse et al., 2017).

1.3.6. Conservation status of Church forests in Ethiopia

Churches and monasteries have a long history of planting, protecting and conserving of trees (Woods et al., 2017). For centuries, the core religious values of EOTC communities have ensured the protection of church forests (Klepeis et al., 2016). Church forests have a very important role in carbon sequestration, mitigate climate change and biodiversity conservation, and thus scaling up the long-term maintenance and management of such small-sized forests in urban green spaces is vital (Yilma and Derero, 2020). Understanding the conservation value, particularly for woody plant species diversity and composition such efforts in relation to other forest management practices in and around church forests is crucial for devising appropriate conservation strategies (Koricho et al., 2020). This is showed that a conservation approach, scientific studies on floristic composition, vegetation structure, and regeneration status of a given forest patches are needed to determine the status of the church forest and take appropriate conservation measures (Kifle et al., 2022).

Only 8 percent of tropical forests are formally recognized as conservation areas (Morales-Hidalgo et al., 2015), however globally, there is a network of sites that are protected because they are sacred and as a result act as 'shadow' conservation for biodiversity (Cardelús et al., 2017). Minimizing exotic tree planting by church authorities would be one approach for improving the regeneration of forests. Reducing forest degradation is more difficult given the active use of these forests by the community (Klepeis et al. 2016). One approach that has been shown to reduce disturbance and increase forest regeneration in these forests is the erection of walls (Woods et al. 2017). The walls reduce grazing by animals and human foot traffic, allowing for seedlings to germinate.

Today there are some 8,000 church forests in the Amhara Regional State, located in the highlands of northern Ethiopia (Cardelús et al., 2017). Church forest communities have preserved the core religious ideas allowing forest protection while being exposed to external influences throughout their history (Orlowska and Klepeis, 2018). Church forests provide invaluable contribution in conserving of high floral and faunal diversity with many indigenous and rare species (Reynolds et al., 2017). Church forests provide important ecosystem services to local communities. Church forest harbors various wildlife including mammals, birds, reptiles, and amphibians.

Indigenous knowledge and attitudes and practices in the Orthodox Tewahedo church forests contribute positively to conserving and effective management strategy of the biodiversity. A holistic study on role of Ethiopian Orthodox church forests in conserving wildlife, and Knowledge of communities should be expanded in other church forests of Ethiopia (Reynolds et al., 2017). Some of the only Afromontane Forest in northern Ethiopia today is on lands managed by followers of the Ethiopian Orthodox Church, where for centuries priests and communities have conserved forest groves around church buildings (Reynolds et al., 2017; Sahle et al., 2021). The ecological value of the thousands of church forests in Ethiopia has been widely acknowledged, but little is known about the diverse local institutions that govern these resources, or how such institutions might be changing in response to Ethiopia’s rapid recent economic development (Reynolds et al., 2017; Teku et al., 2024).

1.3.7. Soil ecology

Soil is a complex and dynamic natural component composed of minerals, organic matter, liquids, and gases, which together occupy space on the Earth’s surface and form a vital part of terrestrial ecosystems (Schoonover and Crim, 2015; Baveye et al., 2016). It is distinguished by its layered structure, or horizons, that develop over time due to the combined effects of physical, chemical, and biological processes (Currie, 1999). These processes are influenced by environmental factors such as climate, organisms, topography, parent material, and time (Brady and Weil, 2017). Soil's ability to support plant growth is a key characteristic that defines its role as a fundamental resource for life on Earth (Gama, 2023).

Soil is far more than just a medium for plants to anchor their roots; it is a dynamic and essential component of Earth's environmental systems, playing a fundamental role in global biogeochemical cycles such as the carbon, water, and nutrient cycles (Smith et al., 2015). It serves as both a reservoir and a transformer of vital nutrients such as carbon, nitrogen, and phosphorus that are indispensable for sustaining life on Earth.For instance, soils act as a massive storage system for carbon, holding it in both organic forms (like decomposed plant and animal matter) and inorganic forms (such as carbonates).

This storage capacity makes soil a cornerstone of the global carbon cycle and a key regulator of atmospheric carbon dioxide levels, which directly influences climate change (Lal, 2004). The role of soil in the nitrogen cycle is equally critical, as it facilitates the transformation of atmospheric nitrogen into bioavailable forms through microbial processes like nitrogen fixation, nitrification, and denitrification. These processes enable nitrogen to move through ecosystems, supporting plant growth and sustaining food webs (Galloway et al., 2008). Similarly, soil plays a crucial role in the phosphorus cycle. Phosphorus, a nutrient essential for DNA, RNA, and ATP in living organisms, undergoes complex transformations in soil. Its availability is controlled by interactions with minerals and organic matter, influencing how much of this nutrient is accessible to plants and microorganisms (Johan et al., 2021).

The decomposition of organic matter within soils is a key driver of these nutrient cycles, and soil organisms are at the heart of this process (Swaminathan et al., 2021). A diverse community of organisms, including bacteria, fungi, and invertebrates such as earthworms, work to break down dead plant and animal material (Griffiths et al., 2021). This decomposition releases nutrients back into the soil, making them available for plant uptake and continuing the cycle of life. These organisms not only help recycle nutrients but also play a vital role in maintaining the physical structure of soils. Through actions such as bioturbation where organisms disturb the soil by burrowing or moving through it, they enhance soil aeration, improve water infiltration, and create pathways for roots to penetrate deeper into the ground (Gabet et al., 2003).

1.3.7.1. Nutrient Dynamics in Forest Soil

Forest stands produce 100–500 ton ha^{-1} stand total biomass on dry matter that contains 60-80% stem wood, 10-20% branches, 5-10% barks, 5-10% roots, and 1-5% leaves (Granier et al., 2000; Osman, 2013). Around 58% of the biomass is carbon. To produce such enormous amounts of biomass, forest cover requires 200-2, 500 kg ha^{-1} N, and the same amounts of K and Ca, and 20–200 kg ha^{-1} P (Osman, 2013). Such enormous amounts of nutrients absorbed to be recycled back into the forest ecosystem annually are by a sequence of processes such as litter fall, stem flow, throughfall, root rot and death and decomposition of soil organisms (Granier et al., 2000). What this implies is that forests have a functioning nutrient cycle system in which nutrients absorbed by trees and other organisms are finally returned to the environment to preserve productivity and ecosystem processes.

Litter falls features as the key path of return of nutrients to the forest environment. This is also confirmed by Panwar (2013) that supplies 3-15 tons of litter per hectare reaching the ground annually, indicating its vital role in soil nutrient recycling. Second, forest tree yearly nutrient intake is not constant and varies enormously with variables such as tree species and soil fertility. This diversity shows biological and environmental regulation of the recycling of nutrients within the forest ecosystem. The evidence for this kind of diversity is provided by Salazar et al. (2010), showing the role of site-specific factors in determining the nutrient dynamics in forest ecosystems. Together, these results give an image of the intricate link between nutrient recycling, uptake, and the sustainability of forest ecosystems.

1.3.7.2. Chemical Properties of Forest Soils

The chemical properties of forest soils are influenced by factors such as land use, soil depth, and environmental condition, which are the major contributory factors for the fertility of the soil, organic carbon storage, and the health of the ecosystem (Hansson et al., 2020). Forest soils tend to be more nutrient-rich and have higher organic carbon content compared to other non-forest soils, with New Zealand, Karnataka, Bangalore, and Brazilian research showing increased organic carbon, nitrogen, phosphorus, and major minerals like calcium, sulfur, manganese, zinc, and copper in the surface layer (Durai, 2023; Loretta et al., 2024; Brasileiro et al., 2023).

These soils prefer vegetation by providing required nutrients, but weather disturbance such as fire, overgrazing, and human actions alter the soil characteristics and undermine ecosystem health as observed in Algeria and the Czech Republic (Dahmani et al., 2023; Neudertová et al., 2024). Soil structure comprises inorganic and organic material, with significant elements such as oxygen, silicon, and aluminum, along with a wide range of chemical compounds, nutrients, and ions under dynamic biochemical activity (Buchanan, 2014; Reddi et al., 2012).

Soil solution contains dissolved organic nitrogen (DON), which often represents the dominant form of nitrogen leached from both coniferous and deciduous forest floors (Sollins & McCorison, 1981). The chemical composition of forest soil DON can vary considerably depending on tree species and the degree of organic matter decomposition. Different types of plants have litter which not only varies in composition but also in water-extractable compound concentrations (Don and Kalbitz, 2005). The physical and chemical properties of Ethiopian forest soils are greatly influenced by land use change, which can reduce or enhance soil quality based on the adopted management measures (Asmare et al., 2023). Plants utilize CO_2 during photosynthesis for carbon, and absorb NO_3^- and NH_4^+ for nitrogen and PO_4^{3-} for phosphorus through their roots during growth to build essential biomolecules like sugars, proteins, and DNA

Forest soils tend to be less dense (bulk density of 1.10 to 1.61 g/cm³) and more porous (39.37% to 58.49%) than agricultural fields, reflecting a superior structure and increased aeration of the soil (Regasa, 2023). This is moderated by higher clay content that facilitates water retention and enhances nutrient availability (Bitew, 2024). Forest soils also contain higher organic matter (0.64% to 5.91%) and nitrogen (0.04% to 0.31%) compared to cultivated soils, whose nutrient content is drained due to intensive cultivation (Regasa, 2023). Forest soils with a pH of 4.92 to 5.55 are more favorable to nutrient availability compared to the higher acidity forest soils associated with overgrazing or agricultural soils (Regasa, 2023).

However, forest conversion to agricultural land or eucalyptus plantations can lead to soil declines. These changes are often associated with declining nutrient levels, soil compaction, and overall degradation (Cardelús et al., 2020). Edge effects, particularly in church forests, also increase soil nutrient loss and loss of carbon (Cardelús et al., 2020), highlighting the need to carry out sustainable land management practices to prevent further degradation. Ethiopian forest soils have chemical and physical properties that vary. They are low to moderate in terms of soil organic matter (SOM) content, slightly acidic to neutral in pH, and have a moderate to high cation exchange capacity (CEC) (Gebrehiwot et al., 2009; Solomon et al., 2014). Physically, the soils are sandy to clayey in texture and have granular or crumb structure in normally well-conserved forests (Hurni, 1985; Lal, 1986). However, nutrient supply, especially phosphorus, is limiting in others (Haile et al., 2012).

1.3.8. Ethnobotany

Ethnobotany refers to the scientific investigation of changing interdependencies of human beings with plants, such as how plant resources are classified, cultivated, and utilized by human societies (Martin, 1995). It particularly studies how various cultural and geographic groups utilize indigenous plant species for food, medicine, habitat, and other traditional purposes (Hill, 1989; Cotton, 1996; Balick and Cox, 1996; Turner, 2000). In its simplest form, ethnobotany relies on everyday ecological information in the form of vernacular classificatory systems and utilitarian plant uses (Martin, 1995). The primary goals of ethnobotanical fieldwork are to document and promote sustainable use of traditional plant knowledge.

As much as there has been increased academic interest, the knowledge corpus is dispersed and poorly recorded due to challenges such as sociocultural transformations, reluctance by traditional healers to communicate, and declining application of local practices. In Ethiopia, various ethnobotanical studies point to the prevalence of medicinal plants in traditional healthcare systems and their effectiveness in the treatment of a range of diseases (Simegniew et al., 2017; Tilahun, 2018; Netsanet et al., 2020). Cotton (1996) highlights that ethnobotany offers information on plants' multidimensional use in addition to subsistence and medicine for rituals, construction, and identity. Ethnobotany is also a vital tool in establishing community needs and guiding biodiversity conservation policy (Martin, 1995). Information on plant uses documented by indigenous plant knowledge represents culturally embedded patterns of utilization like food preparation, medicines, preservation, and pest control. Specifically, ethnobotany also helps the pharmaceutical sciences by facilitating the discovery and lead finding of medicinal plants as drugs through the isolation and characterization of active compounds (Balunas and Kinghorn, 2005).

1.3.8.1. Medicinal Plants in Ethiopia

Plants have been a critical component of world medicine for decades as first-line therapeutic material for different cultures (Fitzgerald et al., 2020). Medicinal plants are plant species used to prevent, diagnose, or treat physical, mental, or social imbalances according to the World Health Organization (WHO, 2002, 2009).

Their shared use persists, particularly among rural populations where they remain an affordable and culturally accepted form of healthcare (Oteng et al., 2019; Welz et al., 2018). This reliance is especially pronounced among developing countries, where it is difficult to access modern medicine, which makes plant medicines even more important (Peters et al., 2008). Globally, there are estimated to be 50,000–80,000 plant species employed in medicine, and around 15,000 under threat of extinction by over-exploitation as well as habitat destruction (Ross, 2005). Those notwithstanding, they still support health systems alongside conservation of biodiversity. In Ethiopia, traditional medicine heals human and animal illnesses as well as ecological preservation, as observed in the back-yard cultivation of medicinal plants (Abebe and Hagos, 1991). Both natural and spiritual approaches to wellness are part of Ethiopia's great botanical diversity and old healing customs (Kassaye et al., 2007). Wide use of medicinal plants across large areas is supported by extensive studies.

For example, 43 species were noted in Abaya, Guji Oromia (Bekele and Ramachandra, 2015), whereas Ada'a in the East Shewa Zone reported 131 species (Alemayehu et al., 2015). Similarly, Chilga in Northwestern Ethiopia reported 101 species (Mekuanent et al., 2015), and Kunama in Northern Ethiopia reported 115 species (Meaza et al., 2015). Other notable studies include Ganta Afeshum in Eastern Tigray (173 species; Kidane et al., 2018), Gera in Amhara (63 species; Netsanet et al., 2020), Gubalafto in Northern Amhara (135 species; Chekole, 2017), and the Wolaita Zone in Southern Ethiopia (102 species; Takele Bassa, 2018). The highest diversity was reported in the Sheka Zone, SNNP State, with 266 species (Kassa et al., 2020), followed by Seharti Samre of Southern Tigray (90 species; Aray et al., 2015). They emphasize the importance of medicinal plants within the traditional healthcare system in Ethiopia.

1.3.8.2. Ethnobotanical Studies of Medicinal plants in the Amhara Region

The Ethiopian highlands of the Amhara are extremely rich in ethnobotanical heritage because, according to many study reports, the people extensively applied medicinal and wild food plants. Accordingly, many studies have been undertaken in this region. For example, in Delanta Woreda (Mmisganaw et al., 2016), 78 medicinal plant species were enumerated, and in Hulet Eju Enese (Abebe Birhanu and Chane, 2021), 67 were documented, adding that *Justicia schimperiana* and *Ocimum lamiifolium* are employed on a day-to-day use to cure gastrointestinal and respiratory diseases.

In Gozamin Woreda (Nigussie et al., 2018), 94 medicinal plants were reported, where decoction was a common method of preparation. In Gubalafto District survey conducted by Chekole (2017), reported 89 species such as *Echinops kebericho* and *Ruta chalepensis* for their antimicrobial application. In addition, Tenta Woreda Tefera and Yihune (2019) accounted for 68 medicinal plants including *Withania somnifera* that has been used traditionally to heal diabetes; 83 medicinal plants accounted for by Alemayehu et al. (2015) in the Manjar-Shenkora. Ankober Woreda was well documented (Lulekal et al., 2014) and accounted for 135 medicinal plant species, and *Eucalyptus globulus* was tapped occasionally for respiratory conditions.

Moreover, Menz Gera Midir (Yohannis et al., 2018) documented 62 species identifying the role played by elderly toward conservation of such traditional knowledge. Besides medicinal plants, wild edibles are equally significant in the local food system, as depicted by research in Chilga (Mekuanent et al., 2015), with a total of 36 species that included Carissa spinarum. In Quarit and Yilmana Densa, 45 wild food species that enhance food security were documented (Alemneh, 2020). All these ethnobotanical studies together emphasize the crucial contribution of plant resources to health and nutrition in the Amhara region. They also emphasize the danger of environmental degradation and loss of traditional knowledge and the need to emphasize the conservation activities and further studies to safeguard this rich ethnobotanical data.

1.3.8.3. Indigenous Knowledge (IK)

Indigenous Knowledge (IK) is a collective repository of knowledge, beliefs, and practice gained over the centuries with intense interface with nature (Witharana et al., 2025). IK is cultural practice, environmental care, and use of technology (Bruchac, 2014). Conservation of IK is crucial for biodiversity conservation and forms a valuable wealth for sustainable development (Duria et al., 2023). Owing to this, its conservation is threatened due to enhanced socio-economic and environmental change. Documentation of IK is significant in saving cultural heritage and advancing sustainable solutions to indigenous problems (Emery, 2000).

1.3.8.4. Role of Church Forests in Medicinal Plant Conservation

Church forests are used for medicinal plant species conservation as biodiverse refugia in the face of widespread deforestation (Tadesse, 2020). Studies have indicated that such sacred places have amazingly high density of endemic and medicinal species compared to those in adjacent agricultural fields (Aerts et al., 2016). Spiritual and cultural emptiness of the region is a barrier to exploitation, which aids in the preservation of the existence of plants that otherwise would be pushed to extinction by agricultural encroachment and over-harvesting (Fullas, 2001). Furthermore, ethnobotanical surveys document that local communities derive between 80% of medicinal herb needs from these forests, further indicating their socio-ecological utility (Abebe and Ayehu, 1993). For instance, Fitsumbirhan (2018) conducted an ethnobotanical study in church-based forests of Tahtay Koraro Wereda, Northwestern Tigray, Ethiopia, documenting 102 medicinal plant species used by local communities, primarily for treating human and livestock diseases. The research highlights the critical role of church forests as sanctuaries for conserving diverse medicinal plants and preserving indigenous knowledge vital for local healthcare systems. Even in protected areas, however, encroachment and climate change threaten these ecosystems, just like elsewhere in the world where some 15,000 medicinal plant species are threatened with extinction (Ross, 2005). Strengthening protection by law and the conservation is thus key to securing these irreplaceable hotspots of biodiversity and traditional knowledge.

1.4. GENERAL METHODOLOGY

1.4.1. Description of the study area

The research was conducted in 26 selected church forests to study vegetation ecology (Fig. 1.1), along with an ethnobotanical study carried out in three selected districts, located in the West Gojjam zone, Amhara region, Northwestern Ethiopia (Fig. 1.2). The capital town of the zone, Finote Selam, is located 388 kilometers northwest of Addis Ababa. West Gojjam Zone is bordered to the south by the Abay River, which separates it from the Oromia and Benishangul-Gumuz Regions, to the northwest by Alefa District in Central Gondar Zone, to the east by East Gojjam Zone, to the north by South Gondar Zone, and to the west by Awi Zone (Worku, 2023). West Gojjam Zone covers a total area of 13,312 km^2 with a total population of 2,106,596 consisting of 1,058,272 males and 1,048,324 females. Approximately 89% of the populations are members of the Ethiopian Orthodox Tewahedo Church (EOTC) (CSA, 2007). West Gojjam Zone is a highly dissected plateau (1,200–3,000 m.a.s.l.) with flat-topped plateaus, deep gorges of the Abay River, and erosion-prone slopes, dominated by fertile Nitosols and heavy Vertisols. According to Motbainor et al. (2016), the mean annual temperature varies from 22–27°C in the lowlands and 10–22°C in the highlands, with bimodal rainfall marked by the main Kiremt season (June–Sept, >1,200 mm), a shorter Belg season (Feb–Apr), and a dry period (Oct–Jan). The potential natural vegetation is Afro-montane forest, but centuries of agricultural expansion have left mainly anthropogenic cover; remnant native trees such as *Juniperus procera* and *Podocarpus falcatus* survive in sacred church forests (Woldemedhin & Teketay, 2016), while croplands dominate the landscape alongside widespread Eucalyptus globulus plantations and grazing grasslands.

Agriculture is the backbone of the economy, with most land devoted to crops and communal grazing, producing teff, maize, wheat, barley, pulses, and niger seed, as well as cash crops like potatoes and eucalyptus, while integrated crop-livestock systems (cattle, sheep, goats, poultry) support both subsistence and market production. The zone is one of Ethiopia’s most densely populated rural regions, with densities often exceeding 200 persons/km^2; settlement is predominantly rural with scattered homesteads.

The climate and living conditions also shape health challenges: malaria is widespread in low-lying gorges, while respiratory infections, diarrheal diseases, intestinal parasites, meningitis, and malnutrition remain common among humans. Livestock face major threats from bovine pasteurellosis, blackleg, anthrax, foot and mouth disease, and heavy burdens of internal and external parasites, reducing productivity and food security. West Gojjam Administrative Zone (WGAZ) contains a high density of church forests with relatively extensive forest cover when compared to other parts of Ethiopia, protected by traditional Ethiopian Orthodox Tewahedo Church conservation practices supported by the predominantly EOTC-following population (Woldemedhin and Teketay, 2016). The study focused on 26 church forests across highland (upper montane) and midland (montane) agroecological zones, as no forested churches were found in the kolla zone based on Google Earth Pro searches. Hence, the study was focused only two agroecological zones. Agriculture dominates the area, with teff, maize, and millet as major crops, and some church lands are cultivated, contributing to forest degradation (Ayele et al., 2024)

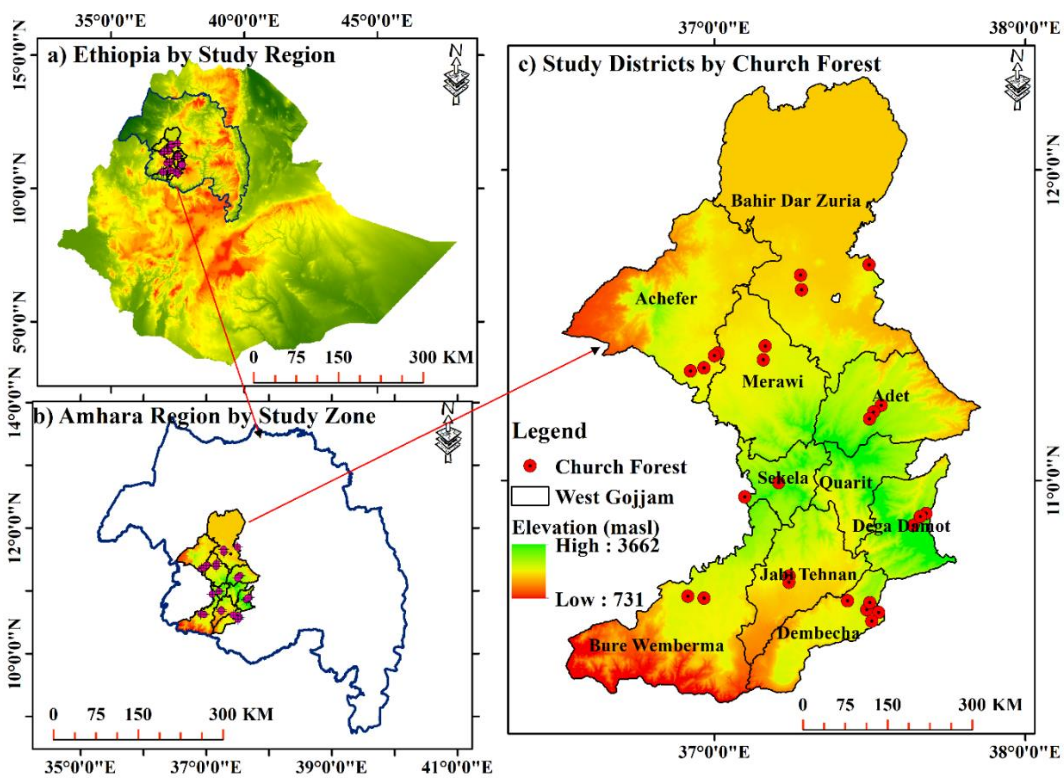


Figure 1.1. Map of study sites for vegetation ecology data collection in the West Gojjam zone church forest

The ethnobotanical survey was conducted in three districts. However, the vegetation ecology survey was conducted in 26 church forests distributed across nine districts. The previously studied districts were not included for ethnobotanical study. Because although some of church forests were found within previously surveyed ethnobotanical districts, they were excluded from this ethnobotanical component of the study to avoid redundancy. Hence, the ethnobotanical study was conducted in three districts of West Gojjam zone; namely: Dembecha, Sekala and South achefer. Dembecha is one of the districts found in the West Gojjam Zone and has an altitude range of 1400- 2083 masl. Its annual rainfall and temperature are 1100 mm and 22.8 ° C, respectively. Dembecha is bordered in the west by Bure, in the northwest by Jabi Tehnan, on the north by Highland Damot, and on the east and south by the east Gojjam zone. The main agricultural crops include sorgum, wheat, teff, maize, and other legume groups (Mekonnen et al., 2017). South Achefer is another district found in the West Gojjam zone and lies in an altitude range of 1500- 2500 masl. Its annual rainfall and temperature are 1452mm and 21°C, respectively.

The South Achefer is bordered on the south and west by the Awi Zone, on the north by the North Achefer and on the east by the Mecha; the Lesser Abay River defines the eastern boundary (Fig. 1.2). Sekela is also one of the districts of the West Gojjam Zone and is in the altitude range of 1800- 2744 masl. Its annual rainfall and temperature are 1700 mm and 18°C, respectively. Sekela is bordered in the southwest by Bure, in the west by the Agew Awi Zone, on the north by Mecha, on the northeast by Yilmana Densa, on the east by Kuarit, and on the southeast by Jabi Tehnan (Fig. 1.2).

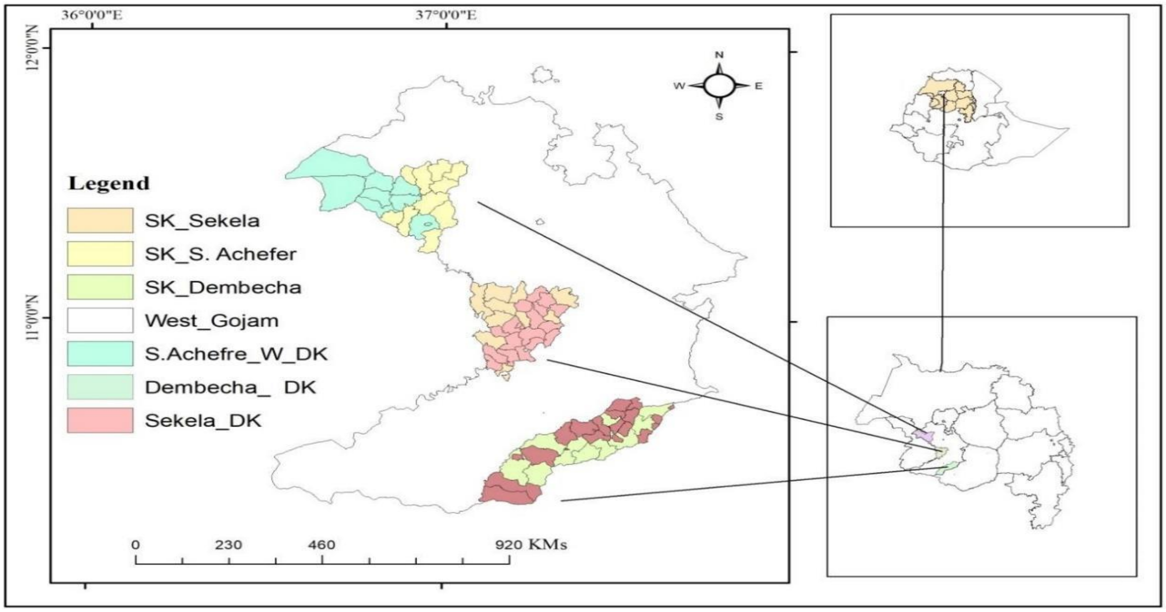


Figure 1.2. Map of Study areas for ethnobotanical study (Note: SK= sample kebeles; S.Achefer=South achefer; DK= district kebele)

1.4.2. Research methods for Ethnobotanical data collection

1.4.2.1. Reconnaissance survey

Before any data collection was undertaken, the ethical clearance and legal evidence were obtained from the three study districts by show the supporting letter written from Biology department of Bahir Dar University. Then, the district administration official wrote a letter for each kebele leader. Finally, directly contacted the leader of each kebele and introduced the objective of the research, aiming to ensure the community had a shared understanding of the research. Then, the ethnobotanical data was collected. The data was collected from June 2021 to September 2021 and from November 2021 to February 2022.

1.4.2.2. Selection of study sites, sampling method and informants' selection

Selection of study sites: In the West Gojjam Zone, there are 14 districts. From these, three potential districts were selected based on the agroecological representation (Highland, Midland, and Kolla). For ethnobotanical data collection on medicinal plants were collected from a total of 30 kebeles (i.e., 10 kebeles per district) (Table 1.1). The selection of these kebeles was based on crietria such as population density, availability of traditional healers, distance from the main road, access to modern healthcare facilities, and forest patch cover for data collection. In the study area, key informants and general informants were selected using purposive and systematic random sampling methods, respectively. Accordingly, key informants per kebele, who are knowledgeable elders and traditional healers, were selected purposively for interviews based on the recommendations of each selected kebele's administrative body, local authority, and religious leaders (Martins, 1995).

To collect ethnobotanical data for this research, the sample size was determined using Cochran's (1977) formula, as presented by Bartlett et al. (2001), as follows:

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

Where, n = sample size for the research, N = total number of households in sample kebeles (210, 511)
e = maximum variability or margin of error 5% (0.05), P = proportion of sampled population (6/14=0.43).
The numbers of informants for each study kebele were determined from the total number of households in each kebele, the sample size obtained above and the total number of households in the study districts as follows:

Number of informants in each kebele = TNHH*n/TNHH in the study districts

Where TNHH = Total number of households; n = sample size and TNHH = Total number of households in the study districts (Table 1).

Table 1.1. Distribution of general informants by gender, kebele, and district in the study area. Note: M= male; F= female; T= total, HHS= households. While 30 key informants were selected purposively

Name of Districts	Name of kebele	Total HHS	General informants		
			M	F	T
Dembecha	Gelila	9164	11	6	17
	Daba	7681	10	4	14
	Lejat	7156	9	5	14
	Enamora	3294	5	3	8
	Yemehel	6101	8	4	12
	Yetsed	6090	8	4	12
	Wad	7174	9	5	14
	Jajirab	6686	10	3	13
	Gedeb	5155	5	5	10
	Yezeleka	9442	11	7	18

	Subtotal	**67,943**	86	46	132
South achefer	Yebodenabashema	7929	8	5	13
	Kaire	1288	3	2	5
	Guta	9789	12	5	17
	Keltafadebretsion	13406	11	10	21
	Lalibela	10461	10	10	20
	Korench	6094	10	6	16
	Kurbaha	7510	7	7	14
	Luhidi	6767	8	5	13
	Dilamo	5309	10	5	15
	Qat	7933	9	6	15
	Subtotal	**76,486**	88	61	149
Sekela	Surbabifeta	9511	13	5	18
	Gitimtrara	8906	10	7	17
	Abiyotchora	4873	6	3	9
	Lijamberateta	9023	4	8	12
	Belakirach	6925	7	6	13
	Kolelicha	6483	8	4	12
	Sewsa	4079	4	3	7
	Magearegira	2385	3	2	5
	Gundil	8512	9	4	13
	Lelimadedana	5385	7	5	12
	Subtotal	**66, 082**	71	47	118
	Total	**210,511**	245	154	399

In this study, the total number of households in three districts were summed and calculated (Table 1.1). Thus, the sample size was determined based on the sum of total number of households in three districts. Hence, the sample size for the study was determined using Cochran's formula, resulting in a total of 429 informants (399 general and 30 key informants) being interviewed. According to Martin (1995), key and general informats serve as a complementary in study of ethnobotany. Key informants are traditional healers that have in-depth knowledge about plants while general informants are provide commonly shared knowledge across the community. Including both ensures a balanced understanding key informants offer detailed, expert insights, while general informants help validate these and reveal broader cultural practices, ensuring data accuracy, diversity, and representativeness (Martin, 1995; Cotton, 1996; Alexiades, 1996).

1.4.2.3. Ethnobotanical data collection and semi-structured interviews

Ethnobotanical data were collected between November 28, 2021 to December 22, 2022. A total of 429 (399 general and 30 key informants) informants were interviewed. Data were collected from key 30 (22 males and 8 females) and general 399 (245 males and 154 females) informants aged ≥ 20 years. Semi- structured interviews, focus group discussions, and field observation were employed to get vital information from the informants. Semi-structured interviews were conducted with general and key household informants based on a questionnaire previously prepared in English and subsequently translated into the local Amharic language. The content of the questionnaire incorporated the plant parts used, diseases treated, method of remedy preparation and route of remedy administration. The informants were interviewed twice to validate the information. On average, 30 focus group discussions were conducted, 6 in each kebele. Groups of informants were assembled to talk about medicinal plants that are used to treat human and livestock diseases. The informants mentioned many medicinal plants that are used to treat various diseases. The parts and uses of medicinal plants were listed. The preparation techniques for the medicinal plants, however, were not thoroughly explained by the informants during group discussion. They claimed not to have discussions in groups about the techniques for preparing medicinal plants. They kept each other's preparations confidential and secret. Finally, field observation was undertaken to visit and collect the medicinal plants.

1.4.3. Site selection and sample size determination for vegetation data collection

Site Selection

To assess the current state of church forests in West Gojjam, detailed approach that was included reconnaissance surveys, stratified sampling, and systematic data collection. The reconnaissance survey, conducted from February 29 to March 6, 2023, provided an overview of the study area and guided the selection of districts and church forests based on key parameters such as agroecological zones, elevation, forest size, and proximity to population centers. The development of a strong sampling framework was directed by this preliminary assessment. Using a stratified random sampling approach, 26 church forests were selected to capture ecological variability. Stratification of church forests based on elevation was done following Cardelus et al. (2017).

Therefore, 13 forests from the montane zone (1700–2100 masl) and 13 from the upper montane zone (2101–2945 masl) were selected. In addition, forests were categorized based on size into small (<5 ha), medium (5.1–8 ha), and large (>8.1 ha), following classification standards from previous studies (Cardelús et al., 2013; Abbot et al., 2018). In total, (8) small, (9) medium and (9) large forests were selected (Table 1.2). The forests were categorized based on their distance from population centers: those within 30 km (16 forests) and those beyond 30 km (10 forests). Gentry transect methods (Gentry, 1988) were used for systematic collection of the vegetation data. In each church forest, plots were laid down along the three cardinal direction of gentry transect to collect data. Correspondingly, soil samples were collected from each church forests, outised forest and eucalyptus plantations.

Table 1.2. Sample size to be distributed based on the following strata

Size of the forest	Montane	Upper montane	Total
Large	5	4	9
Medium	3	6	9
Small	5	3	8
Total	13	13	26

Note: Distance from the population center: Near <30Km = 16; Far > 30Km = 10; Total sample size=26

Sample size determination

The number of sample of church forests was determined based on the Kothari (2004) formula. This required estimation of tolerable error margin as 0.05 allowing 95% confidence level. Hence, the formula is stated below.

$$n = \frac{Z^2 * P(1-P) * N}{e^2(N-1) + Z^2 * P(1-P)}$$

Where: n = the minimum number of sample size within the range of acceptable error margin.

N = the total number of church forests in the study area
Z = confidence level (95%) and which is 1.96
e = acceptable error margin (0.05)
P = proportion of sampled population (0.025)

Based on the above equation, the minimum number of sample church forest selected was 26.

1.4.4. Methods in vegetation, disturbance and soil data collection

Sampling Design and vegetation data collection

The sampling design followed a systematic approach based on the methods outlined by Mueller-Dombois & Ellenberg (1974). Gentry transect lines were established in three cardinal directions (60°, 180°, and 300°) surrounding the church (Fig. 1.3). These gentry transect lines were laid down purposively from the inner wall of the church center to the edge of the forest. The length of gentry transect lines was determined based on the size of the church forest. In each selected church forest, plots of 20 m x 20 m (400 m^2) were established for mature trees, 5 m x 5 m (25 m^2) for saplings, and 1 m x 1 m (1 m^2) for seedlings. The gentry transect lines were spaced 50 meters apart, and the plots were spaced 20 meters apart. The number of plots varied depending on the size of the church forest, with a minimum of six and a maximum of sixteen plots per forest. In total, 175 plots for mature trees, 875 plots for saplings, and 875 plots for seedlings were laid down to collect vegetation data. All woody plant species within each sampling plot were recorded, using both their vernacular and botanical names. Species occurring outside the sampling plots but within the forest were noted as present but were not included in the subsequent vegetation data analysis. The height of the tree was measured by clinometer, and it was used to measure the angle to the top of the tree from a known distance. When difficulty to measure by clinometer, calibrated bamboo stick was used for direct height measurement and visual estimation above the bamboo and impossible to measure. If trees or shrubs branched around breast height, the circumference was measured separately, and an average value was used for DBH. The population structure of woody plant species was categorized into seedlings, saplings, and adult plants, based on height and DBH classes (Chinasho et al., 2015; Temesgen and Serekebirhan, 2019). Specifically: seedlings: Height < 1 m and DBH < 1 cm; saplings: Height between 1 m and 2.5 m and DBH < 2.5 cm; adult plants: Height $\geq$ 2.5 m and DBH $\geq$ 2.5 cm. The DBH of each woody species were measured at 1.3 meters above the ground. A multi-stem tree was considered a single individual if the stems converge above 1.3 meters, but each stem below this height was treated as a separate individual (Atsbha et al., 2019; Eyasu et al., 2020).

Regeneration status of forests

In each of the 1m x 1m plots, the numbers of all seedlings less than 0.5 m in height were recorded. Individuals attaining > 0.5 m with a DBH less than 2.5 cm were considered saplings and were counted. The regeneration status of the forest was analyzed by comparing saplings and seedlings with the mature trees. According to Dhaulkhandi et al. (2008) and Tiwari et al. (2010), the regeneration status was considered good if seedlings > saplings > adults; fair regeneration if seedlings > or ≤ saplings ≤ adults; poor regeneration if the species survived only in the sapling stage, with no seedlings (saplings may be <, >, or = adults); and if a species was present only in an adult form, it was considered not regenerating.

Dissturbance

Both anthropogenic and natural disturbances were recorded across all sampled plots within the church forests. Disturbance categories encompassed natural factors, such as windthrow and lightning strikes, as well as human-induced activities, including grave construction, clearings, trails, grazing, gatherings, building activities, plantations, invasive weed proliferation, and tree cutting or stumps. The magnitude of each disturbance type was assessed by estimating the proportion of the transect area affected. Since natural disturbances were relatively minor, the analysis focused exclusively on anthropogenic factors. Following the approach of Cardelús et al. (2019), the extent of each disturbance type was quantified using the formula:

$$\%\text{Area covered by disturbance} = \frac{\text{Area covered by category inside transect}}{\text{Area of transect}} * 100$$

Soil data collection

Following the methodology of Cardelús et al. (2019), soil samples were collected to a depth of 10 cm using an auger from each church forest plot, as well as from adjacent areas outside the forest (aligned with the inner plots) and from nearby eucalyptus plantations. This sampling design was employed to evaluate the physico-chemical properties of church forest soils in comparison with those of surrounding land cover types, including outside forest areas and eucalyptus plantations.

1.4.4.2. Plant Specimens Identification

Specimens collected from the study area were numbered, pressed, and dried for further identification. The identification process involved comparing the collected specimens with authentic specimens, illustrations, and taxonomic keys from the Flora of Ethiopia and Eritrea (Volumes 1-7). Identification was carried out both in the field and at Bahir Dar University, where voucher specimens were deposited for further reference and validation.

The analyses of the data are presented in detail within each chapter.

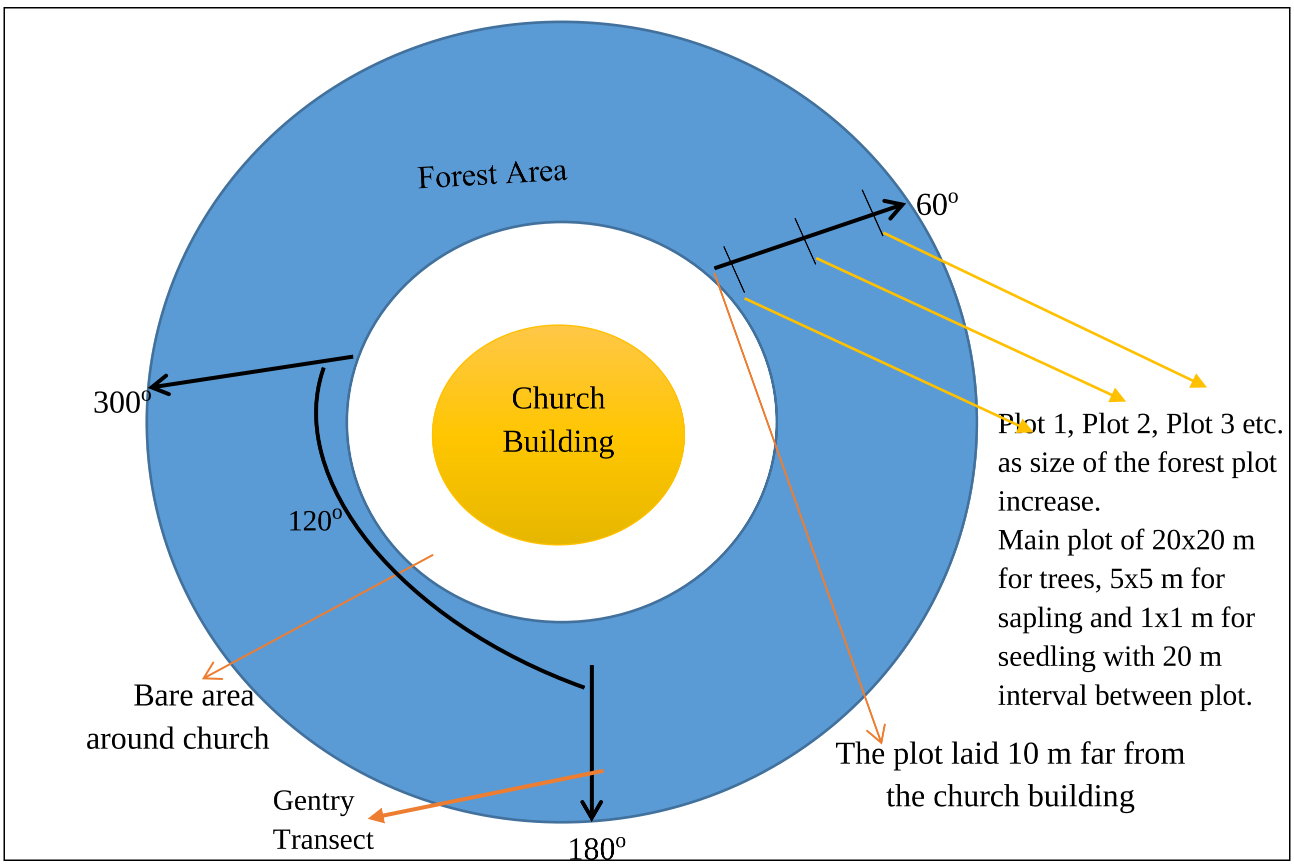


Figure 1.3. Sampling design for vegetation data collection

CHAPTER 2: Woody species diversity, vegetation structure and regeneration status of selected church forests in West Gojjam Zone, Northwestern Ethiopia

Abebe Ayele Haile [a, b, *], Ali seid [a], Amare Bitew Mekonnen [a], Wubetie Adnew [a], Getahun Yemata [a], Endalamaw Yihune [a], Animut Mekuriaw [a], Lidiya Shimeles [a]

[a]Department of Biology, Science College, Bahir Dar University, P.O. Box 79, Bahir Dar, Ethiopia

[b]Department of Biology, College of Natural and Computational Sciences, Debre Birhan University, P. O. Box 445, Debre Birhan, Ethiopia

* abebeayele230@dbu.edu.et

This chapter is published in Trees, Forests and People; 16 (2024), 100570.

https://doi.org/10.1016/j.tfp.2024.100570

ABSTRACT

Widespread deforestation is still a challenge to Ethiopia's diverse ecology. While church forests are experiencing agricultural, grave house construction, and climate-related pressures, they are still faring better than other areas. The present study was aimed to assess the composition and structure of woody species as well as the regeneration status in church forests of West Gojjam Zone. Based on agroecology, elevation, size of the forest, and distance to the center of the population, 26 church forests were selected through stratified random sampling. For mature tree data collection, a total of 175 main plots of 20 m x 20 m (400 m^2) were laid down. In addition, 875 subplots to saplings of 5 m x 5 m (25 m^2) and 875 subplots of 1 m x 1 m (1 m^2) for seedlings were established. DBH was recorded for woody plants with DBH ≥ 2.5 cm and height ≥ 2.5 m. The collected data was analyzed using vegetation structural parameters. A total of 111 woody species, representing 95 genera and 51 families, were recorded. These included 72 tree species (64.86%), 23 shrubs (20.72%), 8 shrub/tree species (7.2%), and 8 lianas (7.2%). Among them, 82.88% were indigenous, 15.32% exotic, and 1.8% endemic species. The Fabaceae family was the most dominant in these forests. Species richness ranged from 7 to 45, with a mean of 23.81 species per site. The average density of woody species with DBH ≥ 2.5 cm and height ≥ 2.5 m was 840 individuals' ha^{-1}. The overall tree stem density was about 5,880 individuals per hectare, while saplings and seedlings were 5,923 and 6,136, respectively, per hectare. The most abundant species included *Eucalyptus camaldulensis*, *Calpurnia aurea*, and *Juniperus procera*. The average basal area across all forests was 29.268 m^2/ha. *Ficus vasta* had the highest individual basal area. *Juniperus procera* and *Rhus vulgaris* had the highest IVI. The forests had a good regeneration status even they exhibited significant differences in woody species composition and diversity among church forests. This study emphasizes the importance of church forests not only for the conservation of plant biodiversity, but also for sustainable forestry. On the other hand, the transformation of some church forest regions into farmland as a strategy for income generation endangers the survival of endemic species while accelerating deforestation. Thus, these churches need to be encouraged most strongly to adopt alternative sustainable income solutions in order to avoid further ecosystem damage.

Keywords: Church forests, Deforestation, West Gojjam Zone, Regeneration, woody species

2.1. Introduction

Africa, being the second largest continent on our planet, has the most amazing biodiversity with a variety of different environments ranging from thick rainforests to massive deserts (Myers et al., 2000). Its diversity is provided by the variety of different aspects, including its size, diversified landscape, and distinct evolutionary past. Africa, being an international hub of biodiversity, houses a high proportion of world plant species, resulting in ecological stability and human well-being (Sintayehu, 2018). Since centuries, researchers have been interested in the botanical richness of the continent and, therefore, extensive research has been conducted to reveal the mysteries of its exclusive vegetation. Africa's fluctuating climatic conditions and biomes, ranging from Sahara deserts to Congo Basin rainforests, are home to between 30,000 flowering plant species, a treasure of botanical diversity guaranteeing ecological integrity and with medicinal, agricultural and environmental prospecting (Linder and Verboom, 2015). Most African plant vegetation is endemic in nature, symbolising their uniqueness and biodiversity conservation value of biodiversity (Procheş and Ramdhani, 2023; Catarino and Romeiras, 2020; Turner, 2014). They play crucial roles in food security, medicine, and culture and must be used sustainably.

Diversity exists in diverse ecoregions, for instance, diverse cape floristic region and Central Africa to eastern Africa tropical rainforests. The variable ecosystems and landforms of eastern Africa support variable flora (Asefa et al., 2020), which is crucial to its ecological and human health (Kokwaro, 1993). Ethiopia's landscapes, the Great Rift Valley, and grasslands boost biodiversity with rare vegetation species that are maintained in situ (Haile, 2016). East and Central African forests are faced with several threats, including change in floristic composition of Echuya Central Forest Reserve owing to human interference (Bitariho et al., 2023). Climate change does not appear to ravish forests; the major threats are in fact overexploitation of its resources and conversion of forest lands into agricultural lands (Banana et al., 2010; Jolly et al., 1997). East African forest decentralization reforms in forest management have been met with varying degrees of successes (Tebkew and Atinkut, 2022).

Deforestation has significantly reduced Ethiopian forests, which were once dense with a variety of tree species such as *Podocarpus falcatus*, *Croton macrostachyus*, *Olea europaea subsp. cuspidata*, and *Vachellia abyssinica* (Kewessa et al., 2022; Atsbha and Wayu, 2020), resulting in negative environmental and economic effects. Despite this, woods are still important in Ethiopian society, supplying energy, food security, and boosting the agricultural sector and GDP (Cherinet and Lemi, 2023). Monitoring and management strategies are critical for preventing further deforestation and promoting sustainable forest management (Eshetu and Högberg, 2000; Newton et al., 2021), particularly in the northern and central regions where land use changes, urbanization, and agricultural practices have depleted forest cover, biodiversity, and soil fertility (Manaye et al., 2021; Deribew and Dalacho, 2019).

Notably, natural forest patches contained within church forests provide vital conservation functions in the Ethiopian Highlands, from the standpoint of Orthodox Tewahido Churches' protection (Bhagwat and Rutte, 2006). These forests accommodate many plant and animal species (Wassie, 2002), conserve native plant diversity (Sewagegn and Abate, 2022; Wolde, 2023; Abebe et al., 2023), conserve biodiversity (Alem et al., 2022), and play a key role in climate change mitigation through carbon sequestration, while the biotic community in the region gains almost all of its direct ecosystems services from these forests (Wolde, 2023; Cherinet and Lemi, 2023).

Numerous studies have examined the diversity and composition of church forests in Ethiopia, with various studies reporting varying levels of woody plant species. For example, Wassie et al. (2010) found 168 species in the South Gondar Zone, while Hordofa Koricho et al. (2020) found 70 species in Debre Libanos. Abunie and Dalle (2018) found 39 species in Yemrehane Kirstos Church Forest, while Kifle et al. (2022) found 52 species in central Ethiopia. Similarly, Birhanu et al. (2021) found 73 species in Dangila woreda church forests. Church forests of South Gondar Administrative Zone have also been studied and the opportunities and difficulties for restoration have been identified (Wassie, 2002; Wassie and Teketay, 2006; Wassie et al., 2009; Scull et al., 2016).

West Gojjam church forests, though small in size, fragmented, and isolated from their surroundings by extensive small-scale farmlands and a challenging landscape, are highly vulnerable to edge effects and various forms of disturbance. These growing threats highlight the need to assess the current status of woody species composition, density, diversity, vegetation structure, and regeneration potential within the church forests. In this study, we also examined how elevation (montane and upper montane), forest size (small, medium, and large), proximity to population centers (near or far), the presence or absence of protective walls, and the degree of human disturbance influence woody species composition, richness, density, diversity, and structural patterns in West Gojjam church forests. This study was aimed to fill this gap of knowledge by measuring woody species diversity, structure, and regeneration status in these distinct ecosystems, hypothesizing significant variations amongst the church forests. To accomplish these goals, the following research questions were derived: (1) what is the diversity of the woody species in the church forests of West Gojjam zone? (2) How are church forests structured in terms of, tree density, basal area, and size class distribution? (3) What is the regeneration status of woody species in church forests, including the number and density of seedlings and saplings?

2.2. Materials and Methods

2.2.1. Description of study area

The study area was well described in chapter 1, General methodology, Section 1.4.1 of the general methodology, including a map of the study area.

2.2.2. Site selection and sample size determination

A total of 26 church forests were selected using stratified sampling methods based on forest size, elevation, the presence or absence of stone wall, and distance from population centers. In addition, the sample size was determined. These were briefly described in chapter 1, General methodology, section 1.4.3 and Table 1.2.

2.2.3. Methods in vegetation data collection

Vegetation data was collected from 26 church forests by laid down a plot along gentry transects lines. Three gentry transect lines were laid down at three cardinal directions in each church forest with 120o interval at 60º, 180º and 300º. The detailed was described in Chapter 1, General methodology, section 1.4.4 and Figure 1.3.

2.2.4. Vegetation data analysis

2.2.4.1. Diversity indices

The Shannon diversity (H') and evenness (J) indices are used to measure both species richness and species evenness (Kent, 2012). The Shannon Wiener diversity index (H') was computed for each plant community types using the equation:

$$\mathbf{H' = -\sum_{=1}^{S} Pi(ln(Pi))}$$

Where pi, is the proportion of individuals found in the ith species.

To compare the species diversity among the 26 studied church forests, we calculated the Shannon diversity index (H') for each site based on vegetation data collected from multiple plots. However, since the number of plots varied among sites (ranging from 6 to 16 plots), direct comparisons of raw Shannon diversity values could be biased by differences in sampling effort.To correct for this, we standardized the diversity values using a proportional rarefaction method, following the guidelines of Magurran (2004). The observed Shannon diversity ($H'_{observed}$) for each forest was adjusted to a common sampling effort equivalent to six plots (the minimum number of plots among the sites) using the formula:

$$H'\text{adjusted} = H'\text{observed}\left(\frac{\text{Minimum plots across sites}}{\text{Number of plots at site}}\right)$$

This rarefaction approach corrects for sampling artifacts and allows valid ecological comparisons across sites with differing plot numbers (Magurran, 2004; Gotelli and Colwell, 2001).
The Shannon evenness (J) was calculated from the ratio of observed diversity to maximum diversity using the equation:

J=H'/Hmax=H'/lns Where Hmax is the maximum level of diversity possible within a given population, which equals ln (number of species). J (species evenness) is normally ranges between 0 and 1, and with 1 representing a situation in which all species are equally abundant (Magurran, 1988).

2.2.4.2. Structural data analysis

DBH, basal area, species density, evenness, frequency and importance value index (IVI) were analyzed to show the vegetation structure of woody plant species (Mucheye and Yemata, 2020; Birhanu et al., 2021).

DBH: To calculate DBH (above ground 1.3 m) ≥2.5 cm of trees, lianas and shrubs was measured and recorded in each plot by diameter tape. For multiple stems, the DBH of the thickest stem was measured and undertaken (Wassie et al., 2010). To analyze the population structure of woody plant species, the DBH tree was classified into seven DBH classes as DBH ≥ 2.5 cm based on Kent and Coker (1992). Based on this, the DBH classes were classified into seven: A= 2.5-14.5 cm, B = 14.51-26.5 cm, C = 26.51-38.5cm, D=38.51-50.5cm, E=50.51-62.5cm, F=62.51-74.5cm, G=>74.51cm.

Height: The height of the tree was measured by clinometer, and it was used to measure the angle to the top of the tree from a known distance. Then, we use trigonometry to calculate the tree's height, and the formula is as follow: h = Tan A x d + eye height, where h is the tree height, A is the angle to the top of the tree, and d is the distance from the tree. When difficulty to measure by clinometer, calibrated bamboo stick was used for direct height measurement and visual estimation above the bamboo and impossible to measure. Based on the height of tree and shrubs, height classes were classified according to height class frequency distribution of trees and shrubs in the area. Based on the height of trees they were classified into six height classes: A=< 7m, B=7.1-14m, C=14.1-21m, D=21.1-28m, E=28.1-35m, F>35.1m.

Species density refers to the number of individuals of plant species in a plot. It is measured in individuals per unit area. Tree density was computed by converting the count from the total plots into hectare basis (Mueller-Dombois and Ellenberg, 1974) and calculated by summing of all trees in the sample and changing into the hectare and compute by the following formula:

$$\text{Density} = \frac{\text{number of individuals of species A}}{\text{Sample area in hectare}}$$

Relative density = $\frac{\text{Density of species A}}{\text{Average density of all species}} x\ 100$

Basal Area (BA)

Basal area is the area outline of a plant near ground surface. It is expressed in square meter/hectare or (m^2/ha) (Mueller and Ellenberg, 1974). It is also used to calculate the species dominance (Kent, 2012). There is direct relationship between DBH and basal area.

Basal area of a tree = $\frac{(DBH)^2\pi}{4}$

Dominance= $\frac{\text{Basal area of species A}}{\text{Area of plots in hectare}}$; Relative dominance (RDO) = $\frac{\text{Dominance for species A}}{\text{Total Dominance of all species}}$x100

Frequency (F) is the chance of finding a species in a particular area in a single plot. It is obtained by using plots and expressed as the number of plots in which a species occurs per the total number of plots (Goldsmith *et al*., 1986).

Frequency measure indicates the uniformity of the distribution of the species in the study area, which again tells about the habitat.

Frequency (F) = $\frac{\text{Number of plots in which species occur}}{\text{Total number of plots laid down in the study site}}$

Relative frequency (RF) = $\frac{\text{Frequency of a woody plant species}}{\text{total frequency of woody plant species}}$ x100

Importance values index (IVI) is important in the comparison of ecologically significant species (Kent and Coker, 1992). It can be calculated from the sum of relative density (RD), relative dominance (RDO) and relative frequency (RF).

IVI= RD +RDO+RF; where, RD= Relative Density; RDO= Relative Dominance; RF= Relative Frequency

2.2.4.3. Analysis of the regeneration status of woody plants species

In each of 1m x1m (1 m^2) plots, the numbers of all seedlings that are less than 1 m in height were recorded. Individuals attaining > 1 m less than 2.5 m with DBH less than 2.5 cm were considered as sapling and then counted from 5 m x 5 m (25 m^2) plot. The regeneration status of the church forest was analyzed by comparing saplings and seedlings with the matured trees. According to

Singh et al. (2016); the regeneration status is good, if seedlings >saplings >adults; Fair regeneration, if seedlings >or ≤ saplings ≤ adults; the status is poor regeneration, if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults); and if a species is present only in an adult form it is considered as not regenerating.

2.3. Results

2.3.1. Woody species diversity

A total of 111 woody species belonging to 95 genera and 51 families were identified from 26 church forests (Appendix 4). Of which, 72, 23, 8 and 8 were found to be trees, shrubs, shrubs/trees and lianas, respectively. In the study sites, the woody plant species consist of 82.88% indigenous, 15.32% exotic, and 1.8% endemic species. The Fabaceae family exhibited the highest diversity, comprising (12) species. Rosaceae, Euphorbiaceae, and Myrtaceae, each represented by (6) species, followed this. Rutaceae included (5) species, while Moraceae, Rubiaceae, and Asteraceae were each represented by (4) species. Families such as Capparidaceae, Acanthaceae, Celastraceae, Myrsinaceae, and Oleaceae contained (3) species each. Additionally, Cupressaceae, Ebenaceae, Flacourtiaceae, Lamiaceae, Malvaceae, Meliaceae, Poaceae, Rhamnaceae, Salicaceae, and Sapindaceae were represented by (2) species apiece. The remaining (29) families were each represented by a single species.

The Shannon diversity index varied considerably across the 26 studied church forests. Before rarefaction, Tiemt Bata Lemariam exhibited the highest raw diversity value (H′= 3.47), followed by Gedema Mariam (H′ = 3.37), Care Aregawi (H′ = 3.30), and Abchikili Mariam (H′ = 3.28). However, because the number of plots differed among forests (ranging from 6 to 16 plots), diversity values were standardized to account for sampling effort using a proportional rarefaction method following Magurran (2004). Therefore, after rarefaction to a common minimum of six plots, Gedema Mariam (H′ adjusted = 3.37), Care Aregawi (H′ adjusted = 3.30), and Abchikili Mariam (H′ adjusted = 3.28) maintained the highest diversity levels. In contrast, the adjusted diversity for Tiemt Bata Lemariam decreased substantially (H′ adjusted = 1.30), reflecting the inflation effect caused by its initially larger number of plots. Overall, forests such as Merawi Kidane Mihret (H′ adjusted = 2.67), Guay Mikael (H′ adjusted = 2.99), and Boldin Arbayitu Encesa (H′ adjusted = 2.86) also exhibited relatively high diversity after standardization.

Hence, rarefaction method is important in correcting for sampling effort when comparing biodiversity across forest patches of varying sizes. The variation in individual distribution among species within each forest is reflected in the evenness values, which range from 0.50 in Debre Mihret Mesk Kidanemihret to 0.96 in Care Aregawi. The diverse number of plant species present in each church forest was represented by species richness and ranged from 7 to 45 (Fig. 2.1). Collectively, these parameters offered a comprehensive understanding of the ecological diversity among the church forests in the West Gojjam zone.

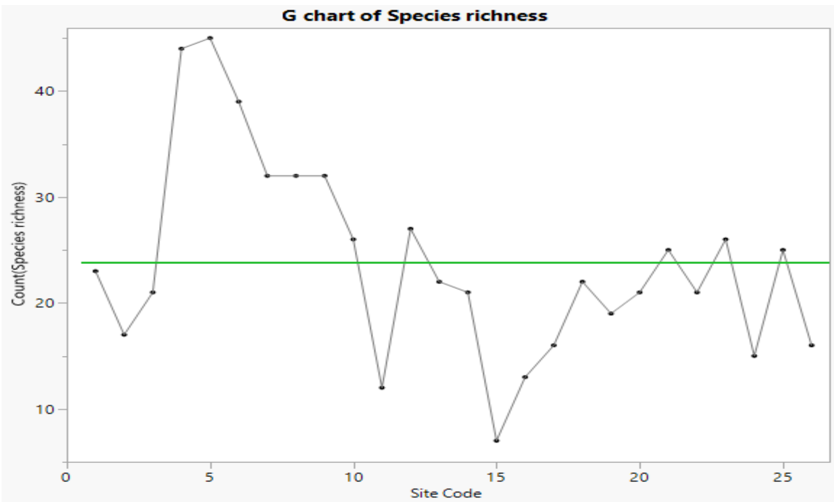


Figure 2.1. Species richness limit summaries across 26 church forests

Based on altitude, the church forests in the study area were divided into montane and upper montane regions (Cardelus et al., 2017). As a result, the species richness and composition of 13 montane and 13 upper montane church forests were compared. Much of the woody species were found in the upper montane zone. The upper montane regions generally exhibited higher abundance values compared to montane areas (Fig. 2.2).

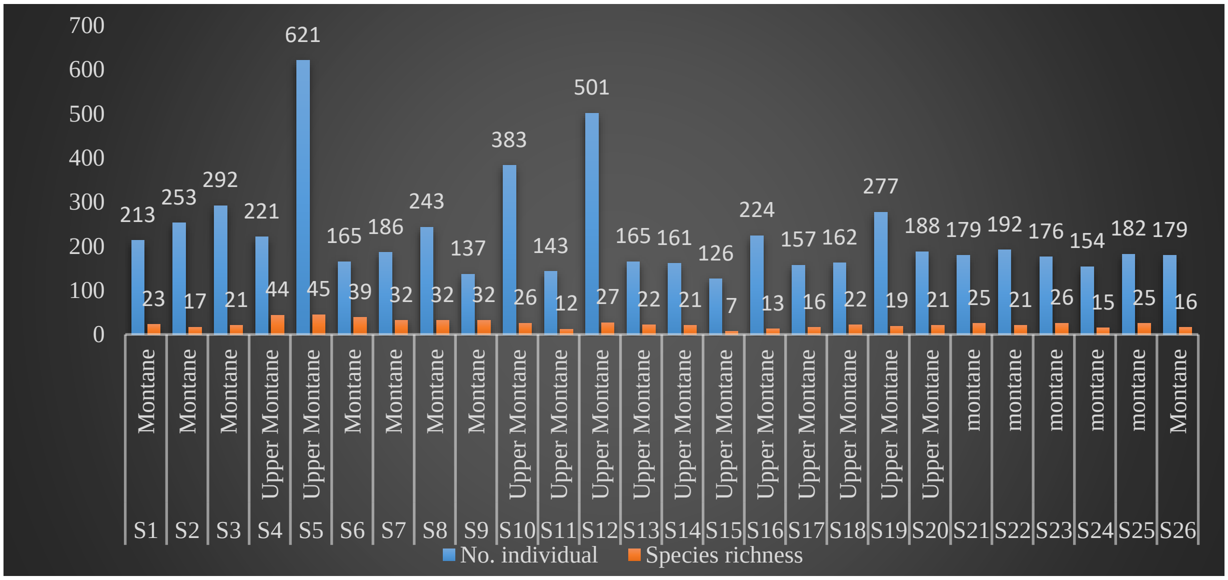


Figure 2.2. Diversity of woody species across the elevation zones in the study sites:

Table 2.1. Analysis of Variance (ANOVA) for church forest variables across elevation levels

Variable	df	F-value	P-Value
Richness	25	1.125	0.042
Density	25	28.836	0.000
Wall	25	0.695	0.509
Size of the forest	25	1.356	0.278
Abundance	25	4.397	0.024
Biomass	25	0.439	0.415

One-way ANOVA showed that some of the ecological variables changed differently at various elevations in the church forests. There was a significant difference in species richness with elevation (p = 0.042). Tree density also showed strong variation (p = 0.000) indicating strong variation in the number of trees per unit area with elevation. On the other hand, wall similar across elevations (p = 0.509) and forest size (p = 0.278) did not vary with elevations. Tree frequency was significantly different among elevations (p = 0.024). Elevation was not siginificatly affect the biomass (p= 0.415).

2.3.2. Vegetation and population structure of church forests

Population structure describes the separation of tree types (like species, or by size or height, or new growth) and shows how they live and are capable of living. Vegetation structure explores the configuration of communities of plants (in other words how they live in density and composition based on degrees of cover or density and rank across the area). Both structures will examine tree height and tree diameter or both. Population structure shows trends for a single type while vegetation structure shows the fact that types compete for dominance. Together, they provide an understanding of the way which nature acts and how we define the boundaries we should try to protect in church forests.

2.3.2.1. Density of woody species

The average density of woody species with DBH ≥ 2.5 cm and height ≥ 2.5 m was 840 individuals' ha^{-1}. The least average density was 18 individuals ha^{-1} from Debre Mihret Mesk Kidanemihret. On the other hand, Tiemt Bata Lemariam had the highest average density among the listed church forests, with a value of 88.71. The most and least dense woody stems inside church forests were 621 and 126 individuals per hectare, respectively. Species wise, *Calpurnia aurea (*1315), had the highest density followed by *Albizia schimperiana (*743), *Croton macrostachyus (*621), *Coffea arabica (*434), *Olea europaea* subsp. *cuspidata (*416), *Eucalyptus camaldulensis (*398), *Juniperus procera* (380), *Carissa spinarum (*376), *Cordia africana (*246), *Euphorbia abyssinica (*210), counted in the study church forests. In contrast, *Salix mucronata subsp. subserrata*, *Allophylus abyssinica*, *Arundo donax*, *Carica papaya*, *Malus sylvestris*, *Prunus persica*, *Senna singueana* and *Stereospermum kunthianum* had the least woody plant density represented by one species in each church forest.

Similarly, a total of 5923 saplings and 6136 seedlings ha^{-1} were recorded for 83 and 66 representative woody plant species, respectively. The average density of saplings and seedlings were 846.14 and 876.57 individuals ha^{-1}, respectively. Most of the sapling density was covered by *Justicia schimperiana*, *Gymnosporia arbutifolia*, *Calpurnia aurea*, and *Vachellia polyacantha*, had the highest density in increasing order, the highest density of seedlings was recorded in *Justicia schimperiana*, *Vachellia polyacantha*, *Vernonia auriculifera*, *Calpurnia aurea*, *Gymnosporia arbutifolia*, *Clausena anisata* species. Among the species surveyed in the study sites, *Calpurnia aurea* exhibited the highest density of 187.86 individuals per hectare, followed by *Albizia schimperiana* with 106.14 individuals per hectare (Fig 2.3).

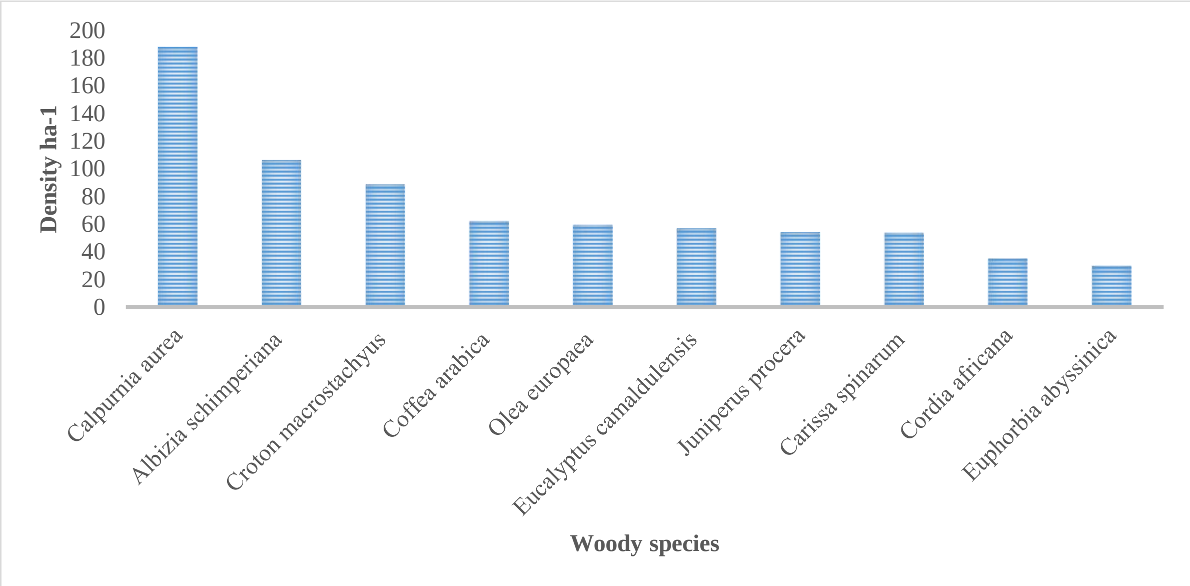


Figure 2.3. Average density of ten selected woody species in the study sites

2.3.2.2. Diameter at breast height (DBH) and Height class distribution

The Diameter at breast height (DBH) of woody species was classified into seven classes: (1) 2.5-14.5 cm; (2) 14.51-26.5 cm; (3) 26.51-38.5 cm; (4) 38.51-50.5 cm; (5) 50.51-62.5 cm (6) 62.51-74.5 cm; (7) >74.51cm. Most of woody species were found under the first DBH class, which accounted for a total of 3810 individuals of 88 woody species. The seventh DBH class had the least individuals (34 ha^{-1}). According to the DBH class distribution, the study forests had an inverted J- shape pattern of regeneration (Fig.2.5). Likewise, the tree heights were classified into six classes based on their height. Thus, 1. < 7 m, 2. 7.1-14 m, 3. 14.1-21 m, 4. 21.1-28 m, 5. 28.1-35 m, 6. > 35.1 m. Most individuals of each species were found in the first height class of distribution, which accounted for 102 woody plant species. The least number of individuals were counted in the sixth height class, represented by 13 species. The height class distribution of these church forests also had J-shaped pattern (Fig. 2.4).

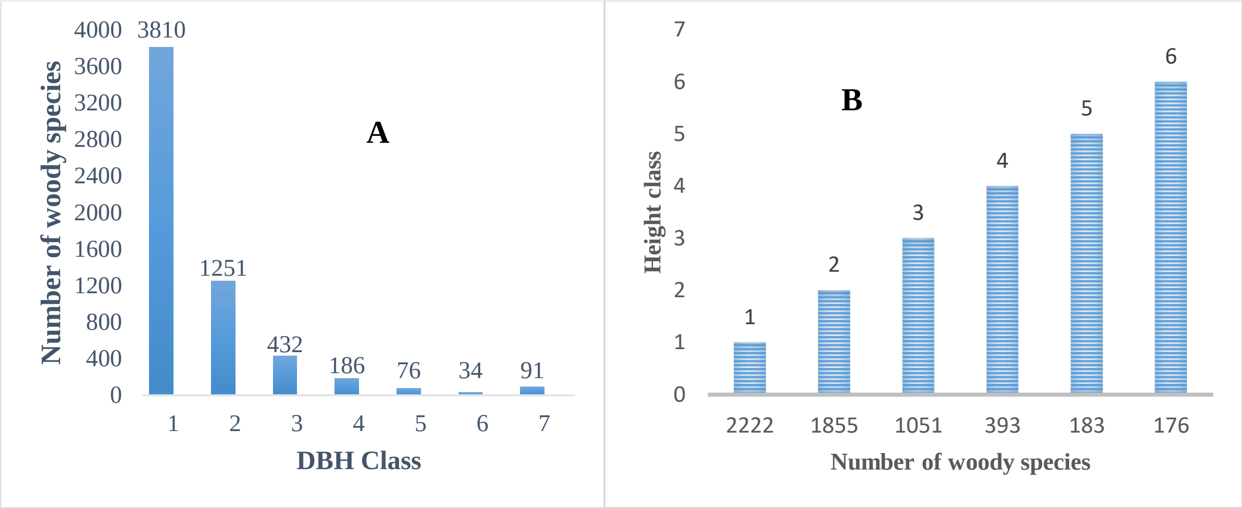


Figure 2.4. The DBH and Height class distributions of all woody plant species in church forests (DBH in cm and height in meter): (A) 1. 2.5-14.5 cm; 2 14.51-26.5 cm; (3) 26.51-38.5 cm; (4) 38.51-50.5 cm; (5) 50.51-62.5 cm (6) 62.51-74.5 cm; (7) >74.51cm. (B) 1. <7m, 2. 7.1-14m, 3. 14.1-21m, 4. 21.1-28m, 5. 28.1-35m, 6. >35.1m

2.3.2.3. Basal Area

The mean basal area was 29.268 m^2 ha^{-1}. From the studied church forests, Wegelsa arbayitu ensesa church had the highest basal area, which accounted for 11.9 m^2/ha. The study reveals the dominant woody species in church forests, *Ficus vasta* had the highest basal area coverage of individuals ha^{-1} (71.37%) followed by *Carica papaya* (28.54%) (Fig. 2.5).

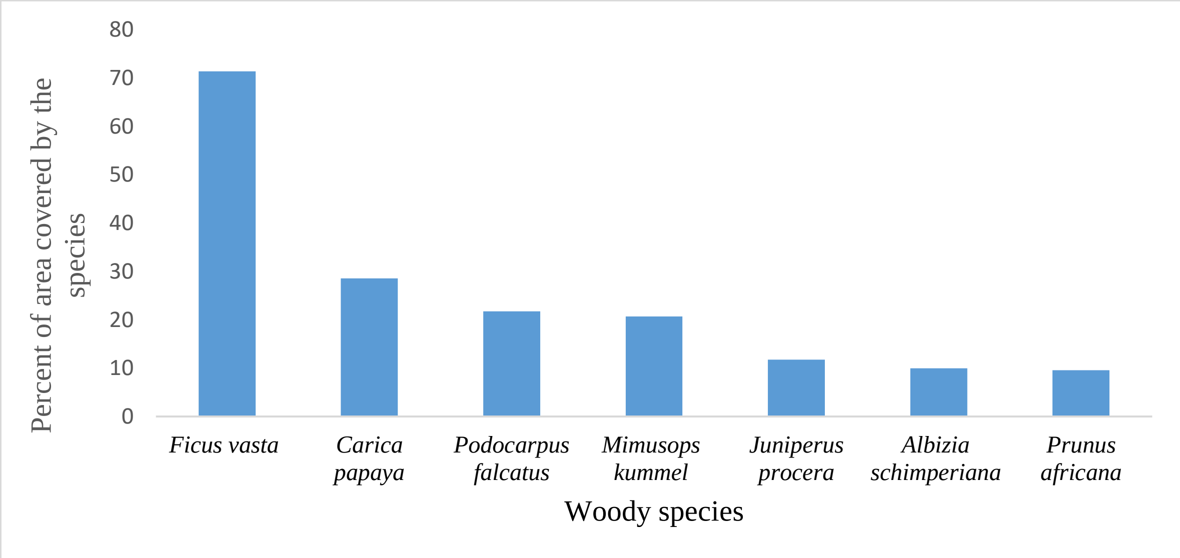


Figure 2.5. The top seven woody plant species with the highest basal area ha^{-1}

2.3.2.4. Frequency

A total of 23 woody species were the least frequent species which accounted for 20.7%. *Eucalyptus camaldulensis* is the predominant frequented woody plant species in church forests, accounting for 72.57% individuals per hectare, followed by *Juniperus procera* 68.75% and *Olea europaea subsp. cuspidata* 67.71% (Fig. 2.6).

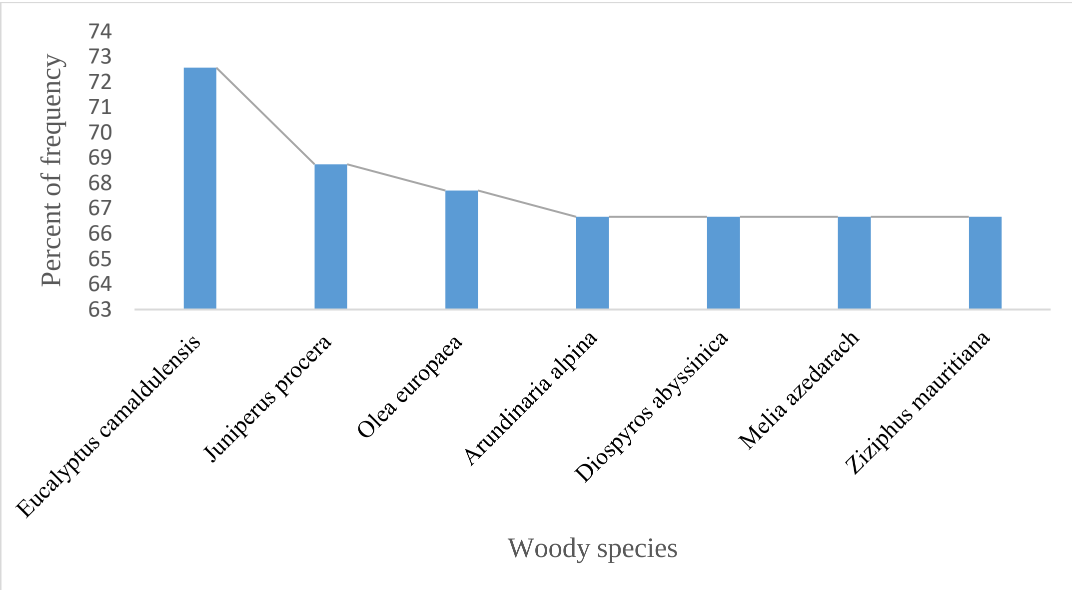


Figure 2.6. Percentage of the most frequented stem woody species in the study areas

2.3.2.5. Importance value index (IVI)

Importance value index (IVI) is important in comparing the ecological significance of a species (Kent and Coker, 1992). A high IVI score denotes a strong species social structure within the community, and this information is utilized to compare the ecological significance of different species. The present study revealed that *Ficus vasta* (25.59) had the highest IVI is followed by *Juniperus procera* (12.23), *Albizia schimperiana* (11.27), *Carica papaya* (10.19), contributing the biggest share to the ecosystem's complexity (Fig. 2.7). Similarly, *Salix mucronata subsp. subserrata*, *Premna schimperi and Myrtus communis* species had the least IVI (Appendix 4).

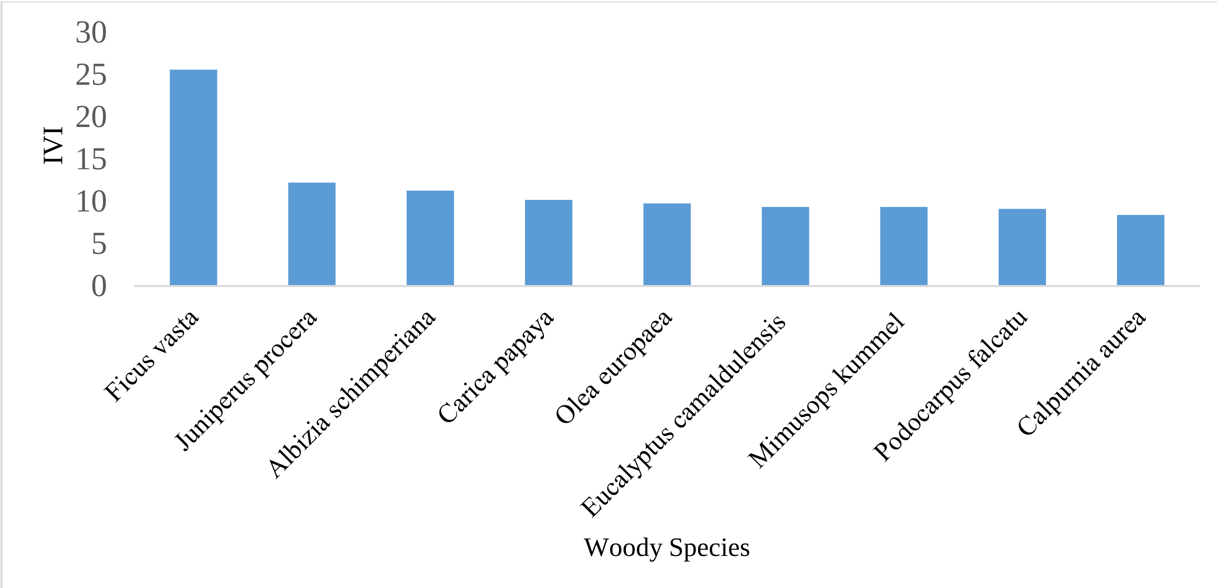


Figure 2.7. The top nine woody plant species with the highest importance value index (IVI)

2.3.2.6. Regeneration status

The regeneration status of the trees, shrubs and lianas was determined by comparing density ratios between seedlings and mature individuals, seedlings and saplings, and sapling and mature individuals. The study found a total of 5923 saplings per hectare, representing 83 woody species in 73 genera and 43 families, and 6136 seedlings per hectare for 65 woody species. There were 5880 mature individuals ha^{-1} (Fig. 2.9). The ratios were as follows: The ratio of seedlings to mature trees and shrubs was 1.09: 1. The saplings to mature trees and shrubs ratio was 1.007: 1. Similarly, the seedling to sapling ratio was 1.035:1, indicating larger seedling, saplings than mature trees and shrubs. According to our result and Balwant et al. (2014) categorization, seedlings (6136) > saplings (5923) > matured trees and shrubs (5880), resulting in a good regeneration status (Fig. 2.8). Hence, the church forest in West Gojjam is a good regeneration status.

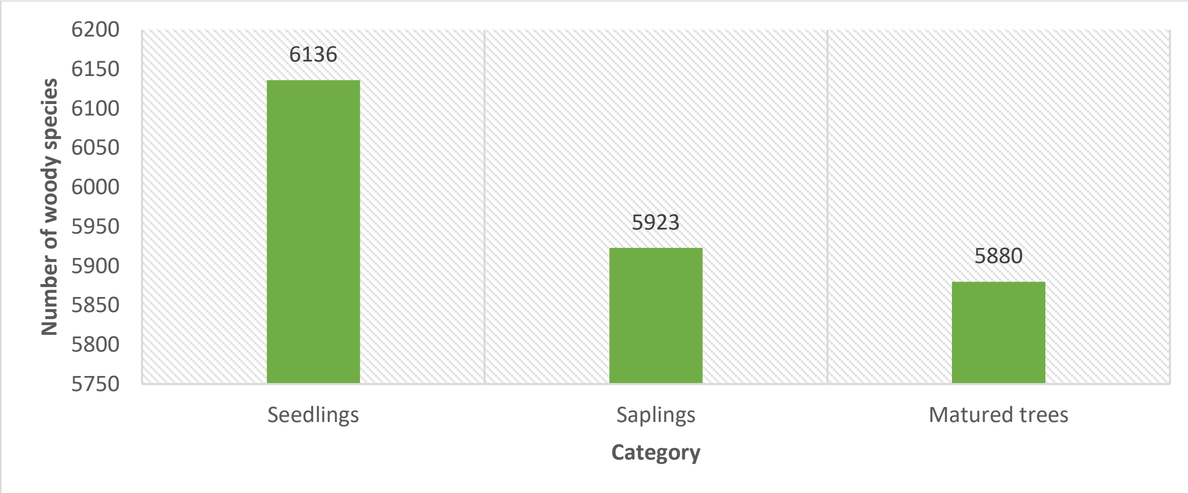


Figure 2.8. Pooled regeneration status of woody plant species in the 26 church forests

2.3.2.7. Species accumulation curve

Species accumulation curves provide several species seen or observed classes that have been seen, allowing them to assess and compare diversity between populations or ascertain the benefits of increased sampling (Deng et al., 2015). The plant species accumulation curve for plant species in this study revealed how cumulative plant species richness responds to an increasing number of sites sampled. The curve initially increases steeply, showing the number of new plant species shown with each additional site sampled. As increasingly more sites are sampled, the curve approaches an asymptote, a continuously diminishing rate of species discovery, and proof that further sampling releases decreasing numbers of sampled species. The flattening is because the sampling effort is almost completed, i.e., the majority of the plant species in the area have been sampled. Then, the curve had reached an asymptote before all the sampling plots were completed, i.e., the sample sites has been thoroughly and well sampled (Fig. 2.9). This result agrees with (Kassa et al., 2025). In summary, these trends suggest that the survey has reasonably accurately sampled a large percentage of the plant richness in the area being studied, and there is good evidence for an adequate regional estimate of species richness and for the sufficiency of the sampling (Kassa et al., 2025).

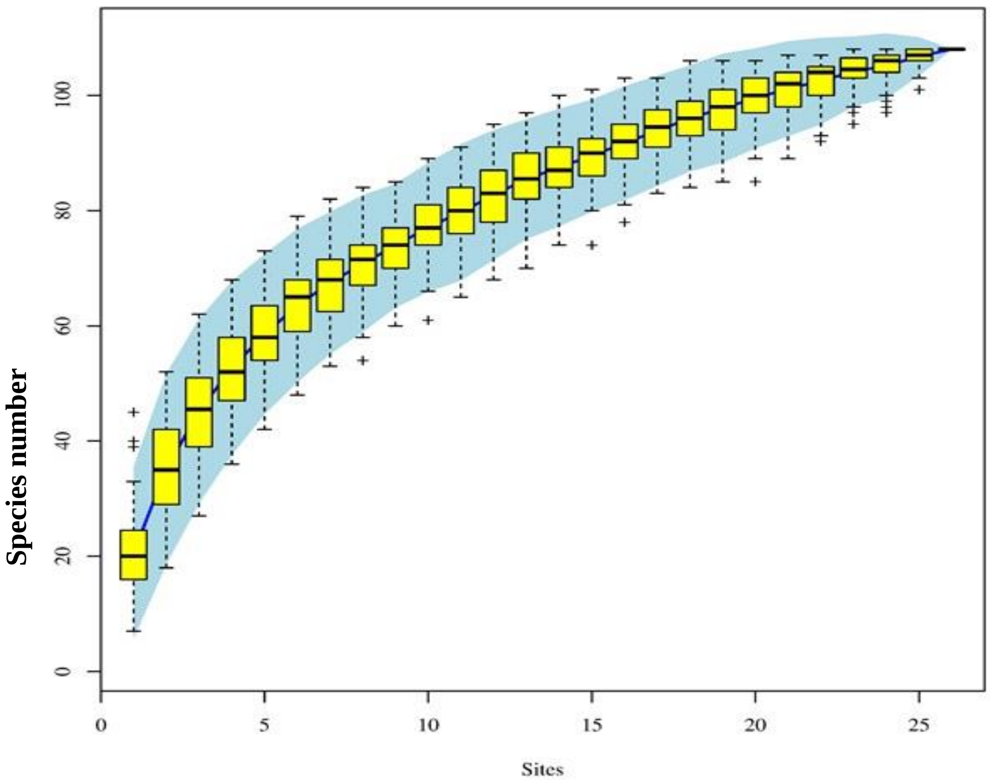


Figure 2.9. Species accumulative curve of sites and number of plant species in West Gojjam Zone Church forests

2.4. Discussion

2.4.1. Woody Species Diversity

The species composition in the church forests of West Gojjam zone, demonstrated a diverse range of woody species, including trees, shrubs, and other perennial plants. It was found that the forests are home to numerous endemic species. The church forests had remarkable resilience despite severe changes in the surrounding landscape, making them crucial for preserving Ethiopia's biodiversity. In the present study a total of 111 woody plant species was identified from the 26 church forests. However, more woody plant species (168) have been identified from church forests of South Gonder zone (Wassie et al., 2010) from 46 sacred groves when compared to the present study. Fabaceae was the most dominant family in this study. This is consistent with the findings of Mekonnen et al. (2022), Sewagegn et al. (2022), Ayanaw and Dalle (2018) in Zijje Maryam, Dangila, and Yemrehane Kirstos church forest, respectively.

Fabaceae was the most dominat family. This is due to several ecological and functional traits of the family: Fabaceae includes many species with broad ecological adaptability, ranging from shrubs to large trees, enabling them to thrive across varied microhabitats. Their nitrogen-fixing ability through root nodules improves soil fertility, giving them a competitive advantage in nutrient-depleted or disturbed environments typical of fragmented church forests. Additionally, many Fabaceae species produce abundant seeds with effective dispersal strategies, ensuring successful regeneration. Their cultural and economic importance such as provision of fodder, fuelwood, shade, and soil improvement also contributes to their protection and intentional planting around sacred landscapes. Taken together, these ecological traits and human-mediated preferences explain why Fabaceae emerges as the most dominant woody plant family in church forests

The church forests had different number of plots, and comparing their diversity by raw result of Shannon diversity creates a bias.Hence, rarefacitation of the raw Shannon diversity is better. Church forests with consistently high diversity after rarefaction, such as Gedema Mariam and Care Aregawi, should be prioritized for conservation due to their robust species richness. The decline of Tiemt Bata Lemariam's church forest after adjusted Shannon diversity showed the need for balanced sampling biodiversity assessments. Standardized methods, e.g., rarefaction, are required for meaningful cross-site comparisons in fragmented landscapes. Conservation of these landscapes requires both ecological monitoring and community engagement to preserve their role as biodiversity refuges. The diversity of woody species in the present study was highest value compared to Wonjeta Mikael (Mekonnen et al., 2023).

The evenness of the church forests varied from 0.5 to 0.96 and reflected an even spacing of individuals among the various species. Tiemt Bata Lemaryam reflected the highest evenness, while Debre Mihret Mesk Kidanemihret reflected the lowest. This would imply that Tiemt Batalemaryam appears to have a more heterogenous and balanced ecosystem compared to Debre Mihret Mesk Kidanemihret, due to the lower diversity of species and uneven distribution to provide a lower Shannon diversity index. Being aware of the reasons behind these variations will prove useful for conservation and biodiversity management of such sites. The mean evenness value was 0.82, indicating high evenness, which aligns with the findings of Cavalcanti et al. (2004). Shannon diversity and evenness values indicate the significance of continued monitoring and management efforts to achieve further ecological stability of church forests and the support of biodiversity conservation. The species richness expressed as the community number of species, ranged from 2.8 to 18.27 with a mean of 9.47 across the 26 churches. Thus, the values indicate a moderately diverse and balanced ecosystem as well as a relatively even species distribution, therefore it is imperative that existing conservation efforts continue to be pursued, and management of ecosystems and species should be continued to promote longevity.

2.4.2. Structure of Vegetation

2.4.2.1. Density of woody species

In the study area, a total of 840 individuals ha^{-1} tree density were recorded, and it is less than that of Zijje Maryam Church Forest, 865.07 individuals ha^{-1} (Mekonnen et al., 2022). In addition, the present result less than from 46 sacred church forests studied at South Gonder (Woods et al., 2020). The species with the highest density in the study areas were *C. aurea*, *A. schimperiana*, *C. macrostachyus*, *C. arabica*, and *O. europaea* subsp. *cuspidata*. These species richness implies their ecological significance and probable impact on the forest ecosystem. Similarly, 5923 saplings and 6136 seedlings ha^{-1} were recorded from 83 and 66 representative woody species, respectively. This result is showed high sapling and seedling density of when compared to other forests, for instance, the Bradi (Yemata and Haregwoien, 2022) and Wofwasha (Fisaha et al., 2013) forests. Bradi forest had lower density saplings and seedling density, whereas higher density is recorded in Wofwasha forest (Yemata and Haregewoien, 2022; Fisaha et al., 2013). All these differences may be attributed to one or more reasons, including environmental factors, population pressure, species composition, and management practices.

2.4.2.2. The distribution of DBH (Diameter at breast height) and Height class

According to the results of the present study, most individuals of each were found in the first DBH and height class, indicating a significant portion of the trees in the church forests are relatively small in diameter and height. This shows that most of the church forests are young and at regenerating stage. Individuals in the higher DBH and height classes were few implying the small number of large trees and less common in the area. Because of this DBH and height class distribution, the overall regeneration pattern of the church forests was found to be inverted J-shape. This aligns with the findings of Boz and Maryo (2020) and Workayehu et al. (2022) who have studied Wurg and Kahitassa forests, respectively. This suggests a common prevalence of many of small-diameter trees and relatively few large-diameter trees across different forest ecosystems.

2.4.2.3. Basal Area

The average basal area of the trees in the 26 church forests was 29.268 m^2 ha^{-1}. This is considered relatively higher compared to previous reports by Mekonnen et al. (2015) at Woynwuha natural forest (20.03 m^2 ha^{-1}), Woldearegay et al. (2018) at Yegof forest (15.85 m^2 ha^{-1}) and (Tadele et al., 2014) at Zengena forest (22.3 m^2 ha^{-1}). However, the present basal area is lower compared to other findings in Dangila church forest (Birhanu et al., 2021) and moist Afromontane Forest of Agama with a basal area is 80.8 m^2/ha (Dibaba et al., 2020). *F. vasta* had the highest basal area, while *Sida tenuicarpa* had the lowest. Among the church forests, Wegelsa arbayitu Ensesa had the highest basal area with a value of 11.9 m^2 ha^{-1} (see the appendix).

2.4.2.4. Frequency

The overall frequency of woody species in the forest under investigation was 69.85%. *Eucalyptus camaldulensis* was the most dominant species, followed by *Juniperus procera* and *Olea europaea subsp. cuspidata*. *Eucalyptus camaldulensis* was the most dominant frequented species in church forests accounted for 72.57% individuals' ha-1. Such dominance suggests reduced native species diversity and potential ecological imbalance within the forests.Hence, the solution is to promote the restoration and enrichment of native tree species through selective removal of Eucalyptus camaldulensis and reforestation with indigenous species to improve biodiversity and ecosystem stability. However, *Juniperus procera* was reported as the most common species in both Zijje Maryam and Saleda Yohannes church forests by Mekonnen et al. (2022, 2023). The results indicate that certain ecological environments must be considered while interpreting frequency data. Alternatively, the least common species was a very small number of plots and represented a total of only 0.57% of the total number of woody species surveyed. This observation is to suggest that such species are very rare distribution in church forests. According to Tamiru et al. (2021), agricultural encroachment, selective logging, cattle grazing, lack of seed and others of some of the drivers may influence the rarity of some woody species in the long term compared to other species. These practices limited the frequency of species. In our study area, some part of the church forests such as Woeneba mikael, Seregela Mariam, Korch silassie, Boldin arbayitu ensesa and Gedema Maryam experienced and fall under agricultural deforestation. Without wise conservation, these activities are likely to contribute to the loss of woody species and habitats (Thorn et al., 2020).

2.4.2.5. Importance value index (IVI)

A high IVI indicates a closed species social structure within the community, and that is utilized to contrast the ecological value of different species (Lemi et al., 2023). Contrast among different species' value to the environment is necessary (Lemessa et al., 2022). In the present study, *F. vasta* recorded the maximum IVI (25.59), followed by *J. procera* (12.23), *A. periana* (11.27), and *C. papaya*, while *S. mucronata*, *P. schimperi*, and *M. communis* had lesser IVI. In contrast to this finding, *C. spinarum* and *C. aurea* contained high IVI, the ecologically most valuable and dominant shrub and tree species of St. Michael Church Forest (Mekonnen et al., 2023). Similarly, *O. europaea subsp. cuspidata* and *A. abyssinicus* had huge IVI at Tara Gedam church Forest (Gedefaw and Soromessa, 2014). Bogale et al. (2023) have also identified an IVI of 15.53 for *J. procera* in their research, which is less than the result of the present study. According to Mekonnen et al. (2023), woody plant species with highest IVI are given a priority for management.

2.4.2.6. Regeneration status

The present study revealed that 5923 ha^{-1} sapling and 6136 ha^{-1} seedlings density. This suggests that these church forests are currently resilient and capable of maintaining their woody species diversity over time. Similar patterns of good regeneration status have been reported in the Tara Gedam and Abebaye forests (Zegeye et al., 2011), the Wanzaye dry Afromontane Forest (Getnet, 2018), the Abbo sacred forest (Yigeremu & Woldearegay, 2022), the Saleda Yohans Church Forest (Mekonnen et al., 2023), and the Zijje Maryam Church Forest (Mekonnen et al., 2022). In contrast, a relatively fair regeneration status was observed in the Dangila Church Forest (Birhanu et al., 2021).

2.5. Conclusion

The study of woody species diversity, structure, and regeneration status in the church forests of West Gojjam Zone, Northwestern Ethiopia highlighted the importance of churches for plant conservation. One hundred eleven woody species with a diversity index varied from 0.99 to 3.47 and evenness from 0.5 to 0.96 were recorded. The results of the statistical analysis revealed a considerable disparity in species composition among church forests. This difference highlights the diverse ecological features of church forests. Structurally, the highest numbers of individuals of each species were found in the lower DBH and height classes producing an overall inverted J-shape pattern of distribution. Moreover, the overall regeneration status of the studied church forests was found to be good, with a balanced number of seedlings, saplings, and mature individuals. Overall, the study provides critical insights for conservation, recognizing the need for site-specific techniques in preserving the diverse and vital church forest ecosystems in the study areas. The research emphasizes the need for tailored conservation strategies for church forests of West Gojjam Zone, Northwestern Ethiopia. Future studies should investigate regeneration dynamics over time, species-specific ecological roles, and the dynamics of invasive species, along with long-term ecological monitoring using permanent plots.

CHAPTER 3: Estimation of Carbon Stocks of Woody Plant Species in Church Forests of West Gojjam Zone, Northwestern Ethiopia: Implications for Climate Change Mitigation

Abebe Ayele Haile [a, b, *], Ali Seid [a], Amare Bitew Mekonnen [a], Wubetie Adnew [a], Getahun Yemata [a], Endalamaw Yihune [a], Animut Mekuriaw [a]

[a]Department of Biology, College of Science, Bahir Dar University, P.O. Box 79, Bahir Dar, Ethiopia

[b]Department of Biology, College of Natural and Computational Sciences, Debre Berhan University, P. O. Box 445, Debre Berhan, Ethiopia

*** abebeayele230@dbu.edu.et**

This chapter is published in Trees, Forests and People, 18 (2024), 100704

https://doi.org/10.1016/j.tfp.2024.100704

ABSTRACT

Church forests are important in mitigating climate change through CO_2 absorption, carbon sequestration, biodiversity conservation, and being vital sinks of carbon. This study was aimed to estimate the biomass and the woody vegetation carbon stock in 26 church forests. Vegetation data were collected from 20 m × 20 m (400 m^2) plots along gentry transect lines at 120° intervals (60°, 180°, and 300°) across each church forest. All woody vegetation with a diameter at breast height (DBH) $\geq$ 2.5 cm and height $\geq$ 2.5 were measured. one –way ANOVA was used to compare the effects of altitude, forest cover, and human disturbance on aboveground biomass (AGB) and carbon stock. Linear regression was also used to examine correlations between vegetation structure like species diversity, density, and richness and biomass accumulation. The study revealed a mean AGB of 31.97±3.31 tons ha^{-1} in the 26 church forests and was equal to 97.15±10.47 tons CO_2 ha^{-1}, with great variation between sites. The highest AGB (99.00 tons ha^{-1}) and carbon content was recorded at the Debre Mihret Mesk Kidanemihret church forest because of the presence of large trees with very large DBH, despite small species richness. On the other hand, Korch Silassie church forest accounted for the minimum AGB with high species richness and smaller DBH of the trees. Hence, the present results indicated that the role of church forests as carbon sinks that can trap atmospheric CO_2 and mitigate climate change. These church forests must be integrated into national and international climate action, such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation), to help achieve their potential contribution to emissions mitigation.

Keywords: Church forests, carbon stock, biodiversity, climate change mitigation, REDD+, Ethiopia.

3.1. Introduction

Forests sustain life by providing habitats for a wide array of species and promote environmental, land, and economic sustainability. They provide products that serve our needs, such as: food, medicine, timber, and they are an incredibly important source of carbon sequestration to mitigate global warming and climate change (Yasin et al., 2024; Bonan, 2008; Nunes et al., 2020). Forests enhance soil fertility, promote biodiversity, and offer ecosystem services like shade, recreation, and environmental protection that are basic for attaining the global carbon balance and constructing resilience against natural disasters (Robledo and Forner, 2005). Forests also support trillions of livelihoods and facilitate sustainable development (Shahi et al., 2022).

However, despite being these key ecosystems, forests are besieged by deforestation and land use change, particularly in tropical developing countries, where deforestation is also a key issue (Assa, 2020; Kafy et al., 2023; Kan et al., 2023). The problem to be solved in these threats is improved governance to curb overuse, enhance awareness, restrict disturbance, and introduce afforestation and reforestation programs (Plugge et al., 2011; Kumeh and Ramcilovic, 2023; Choksi, 2022). Climate change, which is primarily caused by greenhouse gases like CO_2, CH_4, and N_2O, has a two-way relationship with forests through driving mitigation and being affected by climate change (Vitasse et al., 2017; Shivanna, 2022). Global warming is promoted by deforestation through higher atmospheric concentrations of the said greenhouse gases, which increase temperatures and cause climate change.

On the other hand, forests play an extremely important function in the mitigation of global warming since trees can capture and store greenhouse gases in their biomass, and they maintain species diversity despite global warming forces (Dagar et al., 2024). Forests sequester 1.2 to 5.8 gigatons of CO_2 annually but release 4.8 billion tons of CO_2 annually from the tropics (Daigneault et al., 2022; Harris et al., 2021). Global warming accelerates forest fires, threatens plant and animal biodiversity, and destabilizes local climate systems (Bonan, 2008; Sutton et al., 2018; Ellison et al., 2017). Aboveground and belowground biomass are crucial to carbon sequestration and climate regulation (Chapin et al., 2006; Pan et al., 2011; Yusuf et al., 2019; Chen et al., 2023; ; Dada et al., 2024; Psistaki et al., 2024). The accurate estimation of biomass is, therefore, a prerequisite for understanding the potential of forests to mitigate climate change.

The impacts of global warming on Ethiopia are more severe because the country relies greatly on rain-fed agriculture and has weak adaptive capacity, such that the droughts have become more frequent, changing the rainfalls, and an increase in temperatures (UNDP, 2021; World Bank, 2008; Bryan et al., 2009). It adapts by recovering 22 million hectares of degraded land by 2030 and increasing forest cover to 30% by 2025 from 15.7%. Its Nationally Determined Contribution (NDC) plans to reduce emissions by 255 $MtCO_2e$ by the year 2030, of which 130 million tons are projected to be from forestry (MEFCC, 2018). Conversely, deforestation, forest degradation, and policy limitations limit the contribution capacity of the forest sector towards a green economy in Ethiopia. Without any intervention, greenhouse gases would increase from 150 $MtCO_2e$ in 2010 to 400 $MtCO_2e$ by 2030 (Grieg-Gran et al., 2015; FDRE, 2011).

Various studies that have been conducted in Ethiopia have indicated biomass estimation and computation of carbon sequestration in various forest ecosystems. For example, Taragedam forest aboveground biomass was 306.37 tons/ha (Gedefaw et al., 2014) and Egdu forest at a value of 278.08 tons/ha (Feyissa et al., 2014). The second site within Gesha and Sayilem districts of 362.4 tons/ha (Addi et al., 2019) and Kubayo forest of 370.34 tons/ha (Asfaw et al., 2019). These studies unveil the heterogeneity of Ethiopian forest biomass distribution under environmental conditions and management regulations.

Church forests are especially famous for carbon storage as well as sequestration potential of carbon. Religious communities preserve Ethiopian church forests and are important both ecologically and culturally (Wassie et al., 2010). Church forests are home to various plant and animal species, and most of them are threatened or endangered (Mekonen et al., 2019; Baez et al., 2022). Church forests preserve carbon; hence assist in climate change mitigation. Others have also tried to estimate church forest biomass and carbon stock in northern Ethiopia. For example, Sewagegn and Abate (2024) and Sewagegn et al. (2022) have studied church forests of Dangila District, while Mengistu et al. (2021) have analyzed sample church forests of northern Ethiopia. These studies are highlighting the imperative ecological functions of church forests, not only in conserving biodiversity but also in sequestering carbon and thereby facilitating activities to mitigate climate change.

Church forests in West Gojjam zone of Northwestern Ethiopia are a crucial sanctuary for biodiversity as well as a pivotal player in the upkeep of healthy ecosystems (Woldemedhin and Teketay, 2016). However, their contribution to sequestration and utilization of carbon to mitigate climate change remains unexplored. With the growing global focus on forests as carbon sinks, there is little empirical evidence on the productivity of biomass and the ability of woody vegetation species to sequester carbon in church forests despite the growing global focus on forests as carbon sinks, data on biomass production and carbon storage capacity of woody plant species in church forests are scarce. This lack of data hinders efforts to quantify their contributions to climate change mitigation and to develop effective conservation strategies. Given the increasing pressures from human disturbances and the ongoing degradation of these forests, there is an urgent need to evaluate the carbon stocks of these ecosystems. Therefore, this study was aimed to address this gap by estimating the aboveground and belowground biomass and carbon storage potential of woody plant species within selected church forests in West Gojjam Zone.

3. 2. Materials and Methods

3.2.1. Description of study area

The study area was well described in chapter 1, General methodology, Section 1.4.1 of the general methodology, including a map of the study area.

3.2.2. Site selection and sample size determination

A total of 26 church forests were selected using stratified sampling methods based on forest size, elevation, the presence or absence of stone wall, and distance from population centers. In addition, the sample size was determined. These were briefly described in chapter 1, General methodology, section 1.4.3 and Table 1.2.

3.2.3. Methods in vegetation data collection

Vegetation data was collected from 26 church forests by laid down a plot along gentry transects lines. Three gentry transect lines were laid down at three cardinal directions in each church forest with 120^o interval at 60^o, 180^o and 300^o (Fig. 3.1). Each woody species that have DBH $\geq$ 2.5 cm and height $\geq$ 2.5 were measured for estimation of biomass in each church forests. The detailed was described in Chapter 1, General methodology, section 1.4.4.

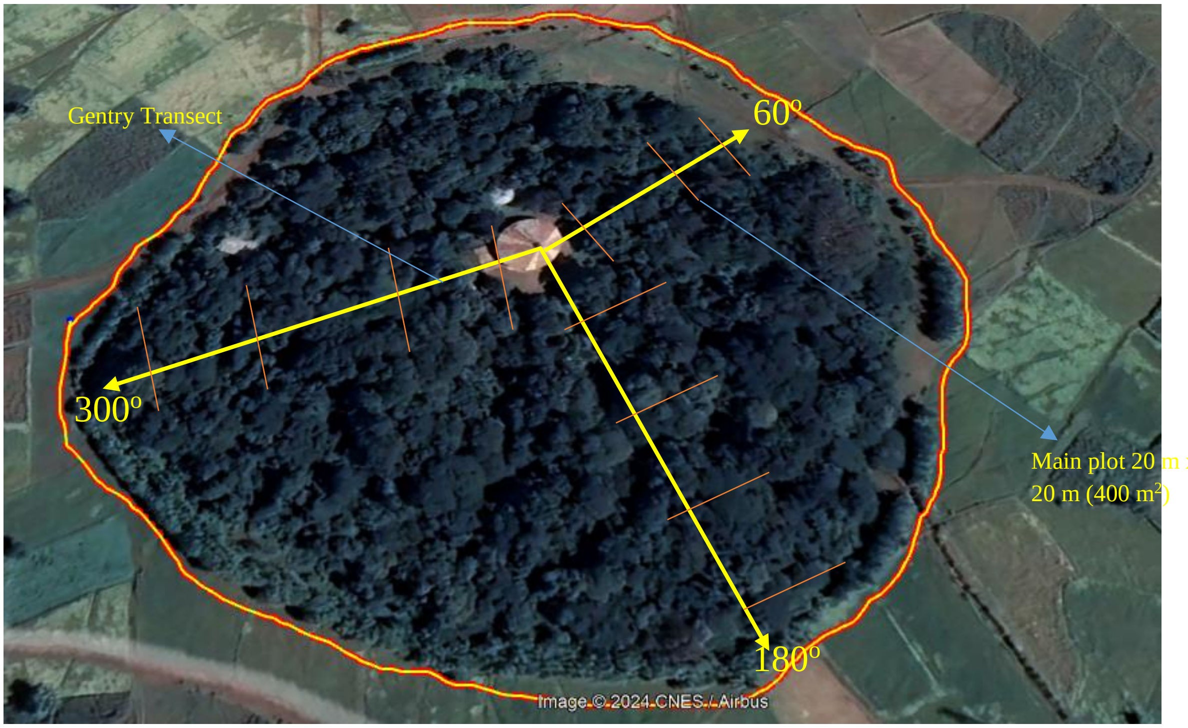


Figure 3.1. Plot layout for vegetation and disturbance data collection (Image of Gombat Mikael church forest, Bahir Dar Zuria district: Google Earth Pro, 2024)

Figure 3.2. Measurement of woody species biomass in the study area (Photo by Abebe Ayele Haile, 2023).

3.2.4. Aboveground and belowground estimation of biomass

3.2.3.1. Aboveground biomass estimation

Numerous allometric equations have been developed for various species and forest ecosystems. The model proposed by Chave et al. (2014) was employed to estimate the aboveground biomass of woody plant species. This equation is widely recommended and extensively applied for biomass estimation in tropical forests, including those in Africa. It is considered robust and adaptable, particularly when used with locally derived relationships between diameter at breast height (DBH) and tree height. The reliability of the Chave et al. (2014) model stems from its incorporation of key variables that influence biomass such as, DBH, tree height, and wood density. Hence, for present study we used the following allometric equation to estimate biomass. The equation is as follows:

$$AGB = 0.0673 * (\rho D^2 H)\text{^}0.976$$

Where, H=Height of tree (m), ρ = Wood density (t/m3), D =Diameter (cm) at breast height (1.3m), AGB = aboveground biomass (kg). For ρ calculation we used a mean value of wood density for African trees is 0.58 ton/m3 (Sewagegn et al., 2022). Wood density values by species exist for most of the species in Ethiopia (MEFCC, 2017). In the absence of such special data, a mean value of wood density of 0.58 t/m³ for African trees, as presented by Sewagegn et al. (2022), was employed.

Aboveground carbon (AGC) was estimated based on (Meragiaw et al., 2021) through the following formula:

$$\mathrm{AGC} = \mathrm{AGB} * 0.5$$

3.2.3.2. Belowground biomass

Due to uncertainty in root biomass measurement, estimation of belowground biomass is much more difficult. Therefore, root biomass is commonly estimated with the help of root-shoot ratios (R/S) by calculating 25% of aboveground biomass (Adame et al., 2017). Therefore, the BGB depends upon AGB and is calculated as given below:

$\mathrm{BGB} = \mathrm{AGB} * 0.25$ $\mathrm{BGC} = \mathrm{BGB} * 0.5$;

Where, BGB = belowground biomass, BGC = belowground carbonn

3.2.3.3. Estimation of soil organic carbon

To estimate soil organic carbon, we used a mathematical equation described by Mengistu et al. (2021) as below:

$$\mathrm{SOC} = \mathrm{BD} * \mathrm{d} * \%\mathrm{C}$$

Where, SOC = soil organic carbon (t ha^{-1}), BD = Soil bulk density (g /cm^{-3}), D = auger depth (10 cm), % C = Carbon concentration.

While we calculated the bulk density (BD) by using the following equation:

$$\mathrm{BD} = \frac{\mathrm{W\ oven\ dry}}{\mathrm{V}}$$

$$\mathrm{V} = \pi r^2$$

Where: - BD = bulk density of the soil sample, W dry oven = dry oven weight of soil sample, V= volume of soil sample in the auger in cm^3, H = the height of the core sampler augur in cm (10 cm), r = radius of the core sampler augur in cm

3.2.3.4. Estimation of total carbon stock

To know the total caron stocks of the church forests we are adding all carbon pools as follows calculation:

$$\mathrm{TC} = \mathrm{AGC} + \mathrm{BGC} + \mathrm{SOC}$$

Where, TC = Total Carbon stock (ton/ha) and AGC = aboveground carbon (ton/ha), BGC = belowground carbon (ton/ha), and SOC = Soil organic carbon.

The total carbon stock was then converted to tons of equivalent CO_2 by multiplying it by 3.67 (Pearson et al., 2007).

CO_2 equivalence = TC*3.67

The percentage of area covered by each human disturbance category was then calculated within the main plots along each gentry transect following the methodology of Cardelus et al. (2019).

$$\%\ \text{area covered by disturbance} = \frac{\text{area covered by disturbance category in a plot}}{\text{Area of plot}} * 100$$

3.2.5. Statistical analysis

To identify plant species contributing most to aboveground biomass (AGB) across church forests, individual species biomass was calculated. One-way ANOVA was used to assess the effects of altitude, forest size, distance from population centers, and human disturbance on AGB. Linear regression analysis examined the relationships between species richness, density, diversity, and AGB. All statistical analyses were performed using JMP 17 (SAS Institute).

3.3. Results

3.3.1. Woody species composition in the study areas

A total of 111 woody species were recorded in the studied church forests, of which 82.88%, 1.8 and 15.32% were indigenous, endemic and exotic, respectively. The Fabaceae family exhibited the highest diversity, comprising (12) species. Rosaceae, Euphorbiaceae, and Myrtaceae, each was represented by (6) species. Rutaceae included (5) species, while Moraceae, Rubiaceae, and Asteraceae were each represented by (4) species. Families such as Capparidaceae, Acanthaceae, Celastraceae, Myrsinaceae, and Oleaceae contained (3) species each. Additionally, Cupressaceae, Ebenaceae, Flacourtiaceae, Lamiaceae, Malvaceae, Meliaceae, Poaceae, Rhamnaceae, Salicaceae, and Sapindaceae were represented by (2) species apiece. The remaining (29) families were each represented by a single species.

The highest Shannon diversity index (3.47) was initially recorded at Tiemt Batalemaryam Church Forest, while the lowest (0.99) was observed at Debre Mihret Mesk Kidanemihret Church Forest. However, due to differences in the number of plots among sites, the raw Shannon diversity values were rarefied, after which Tiemt Batalemaryam exhibited the lowest diversity (Appendix 5). The species richness in all church forests was ranged from 7 to 45, with an averaged of 23.08.

3.3.2. Estimation of biomass and carbon stocks in each church forest

The study found that the carbon sequestration was an average aboveground biomass (AGB) of 31.97 ± 3.31 tons ha^{-1} and an average aboveground carbon (AGC) of 15.98 ± 1.65 tons in 26 church forests. The average belowground biomass (BGB) and belowground carbon (BGC) were 7.99 ± 0.83 tons and 3.99 ± 0.41 tons, respectively. Soil organic carbon (SOC) averaged 6.21 ± 0.43 tons, contributing to a total carbon stock (TC) of 26.48 ± 2.83 tons. The total CO2 equivalence for these forests averaged 97.15 ± 10.47 tons ha^{-1}. The study showed visible differences in carbon storage among church forests (Fig. 3.3). The Debre MK stored the highest amount of carbon, while Korch S stored the lowest.

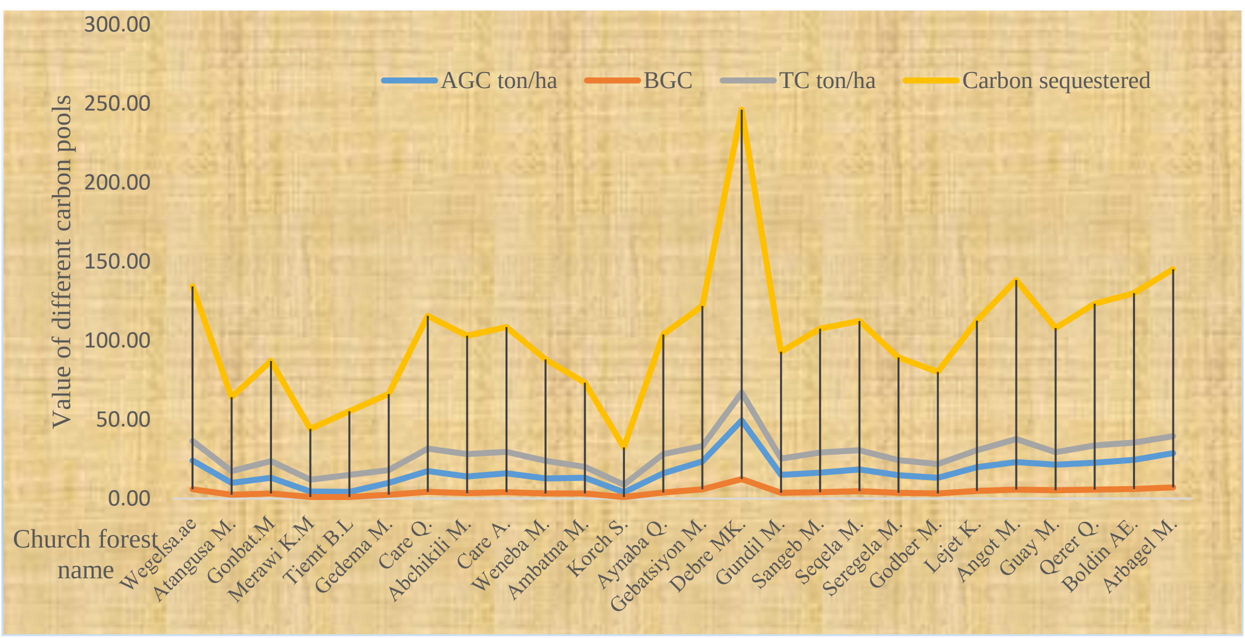


Figure 3.3. Estimation of biomass and carbon stocks of the study church forests

Note: Wegelsa.ae=Wegelsa atangusa arbayitu ensesa, Atangusa M.= Atangusa bata lemariam, Gonbat.M = Gonbat Mikael, Merawi K.M= Merawi kidenemihret, Tiemt B.L= Tiemt bata lemariam, Gedema M.= Gedema Mariam, Care Q.= Care Qusquam, Abchikili M.= Abichikili Mariam, Care A.=Care Aregawi, Weneba M.=Weneba Mariam, Ambatna M.= Ambatna Mariam, Korch S.=Korch Silassie, Aynaba Q.=Aynaba Qusquam, Gebatsiyon M.=Gebatsiyon Mariam, Debre MK.=Debre Mesk Kidanemihret, Gundil M.=Gundil Mariam, Sangeb M.=Sangeb Mariam, Seqela M.=Seqela Mariam, Seregela M.= Seregela Mariam, Godber M.=Go dber Medihaniyalem, Lejet K.= Lejet Kidanemihret, Angot M. = Angot Mikael, Guay M.= Guay Mikael, Qerer Q.=Qerer Qusquam, Boldin AE.= Boldin Arbayitu Ensesa, Arbagel M.= Arbagel Mikael.

3.3.3. Estimation of biomass and carbon stocks in dominant species

In the present study areas, the dominant species contributing to high carbon storage were investigated and showed a notable difference in carbon sequestration capability among the six plant species (Fig. 3.4). *Ficus vasta* had stored higher carbon stocks ((AGC (65.79), BGC (6.57), TC (72.36)), and CO2 equivalence (144.8 tons ha^{-1}) when compared to *Podocarpus falcatus* ((AGC (0.46), BGC (0.093), TC (0.55)), and CO_2 equivalence (2.05 tons ha^{-1}).

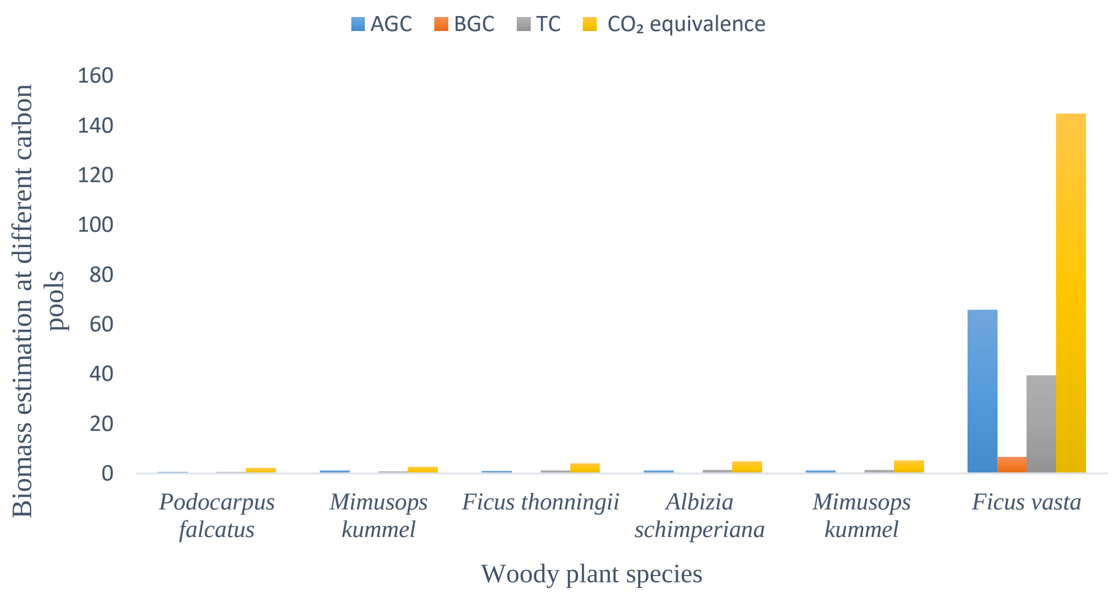


Figure 3.4. Top six woody species with high biomass estimation in church forest

3.3.4. Investigating the impact of species richness, diversity, and density on woody biomass among church forests

We assessed the relationships among species richness, diversity, and density to understand their influence on the carbon sequestration potential of church forests. The results revealed that the species richness, diversity, and density of sequestered carbon in thee studied forest showed negative linear correlation (Fig. 3.5 and Fig. 3.6). However, the coefficient of determination (R^2=0.267) indicates that the linear relationship between CO2 equivalence quantity and diversity of woody species was only explained by about 26.7% of variability in diversity (Fig. 3.5). The statistically significant p- value (P=0.0069) indicated that the observed correlation is not likely to occur by chance. Therefore, there is evidence for the argument that diversity might influence the level of CO2 equivalence, where the regression equation shows a negative relationship, indicating that with the increament of diversity, CO2 equivalence reduces.

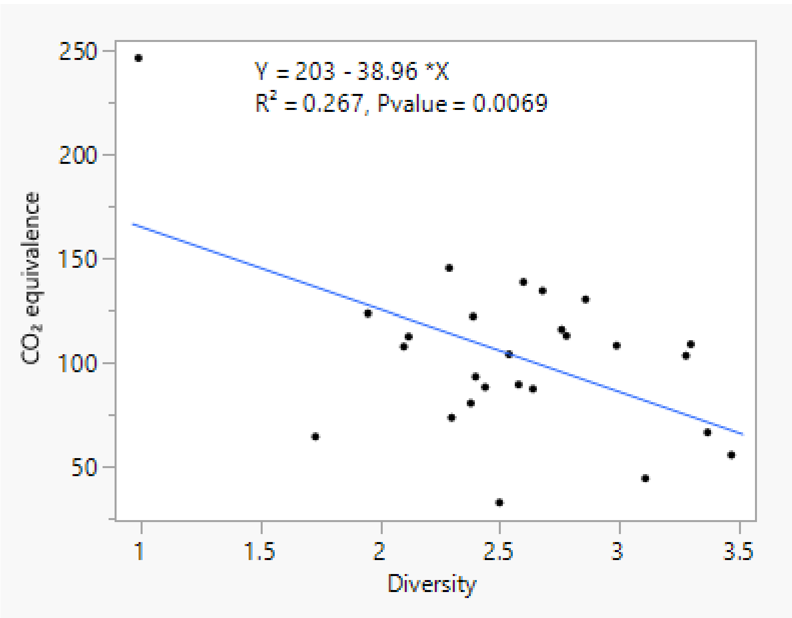


Figure 3.5. The relationships between diversity versus CO2 equivalence in 26 church forests of West Gojjam zone

The relationship between species diversity and aboveground biomass (AGB) among the 26 church forests of the West Gojjam Zone also followed a unimodal (hump-shaped) pattern, with diversity reaching its maximum at intermediate AGB levels. Diversity decreased at low biomass due to limited resources and at high biomass due to competitive exclusion, consistent with the model of Grime (1973) and findings of Mittelbach et al. (2001).

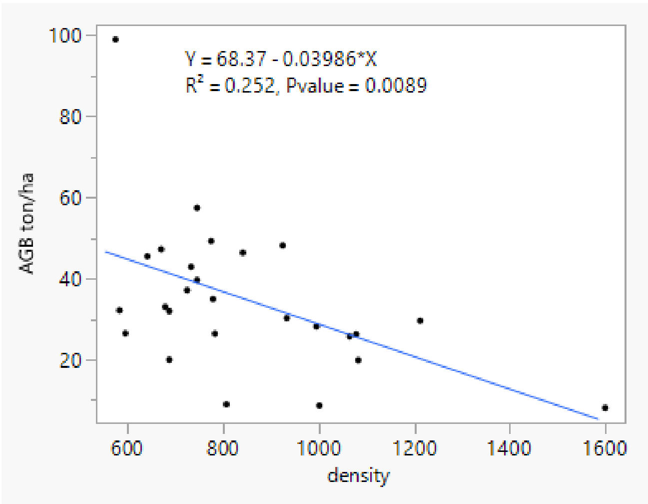
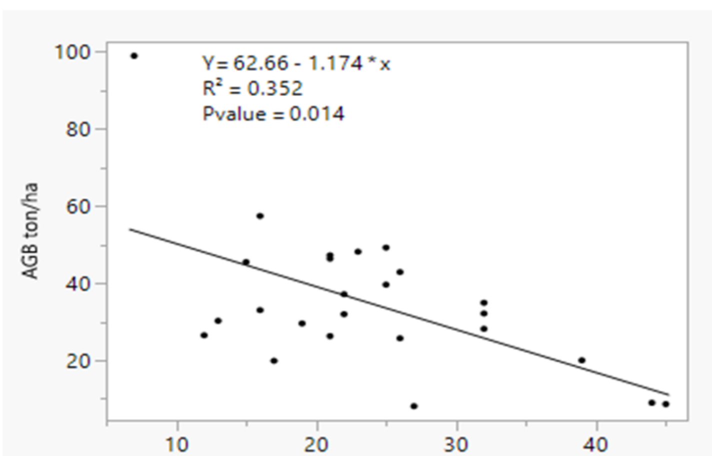


Figure 3.6. The relationships between density versus AGB among 26 church forest

Species density in the 26 church forests showed a unimodal relationship with aboveground biomass (AGB), peaking at intermediate biomass levels. At low biomass, density was constrained by resource availability, while at high biomass, competitive interactions likely reduced species density, in line with the unimodal model described by Grime (1973) and supported by Mittelbach et al. (2001).



Species richness across 26 church forests

Figure 3.7. Relationship between species richness and aboveground biomass (AGB) among 26 church forests of West Gojjam zone exhibited a unimodal (hump-shaped) pattern, with species richness peaking at intermediate AGB levels. This pattern aligns with the unimodal model proposed by Grime (1973) and supported by Mittelbach et al. (2001), suggesting that species richness declines at both low and high biomass levels due to resource limitation and competitive exclusion, respectively.

3.3.5. Aboveground and belowground biomass and carbon stocks across plots in 26 church forest

In the present study area, in the 26 church forests we had laid down a total of 175 plots. In these plots, we calculated biomass and carbon stocks, and the averaged aboveground biomass (AGB) was 44.25 ± 3.711 ton ha^{-1}, and the belowground biomass (BGB) of 11.06 ± 0.92 ton ha^{-1}. The total carbon stock averaged was 34.49±2.32 tons ha^{-1}, with a range from 5.47 to 166.28 tons ha^{-1}, while the average of CO_2 equivalence was 126.61 ± 8.53 ton ha^{-1} sequestered from 175 plots. We conducted correlation analysis to ensure consistency among AGB and its mathematically derived variables, such as AGC, BGB, BGC, TC, and CO_2 equivalence. The correlation analysis demonstrated notable positive relationships between the plot size and all biomass and carbon storage variables.

Specially, larger plot categories moderately associated with increased aboveground biomass (AGB ton ha^{-1}; r = 0.338), aboveground carbon (AGC; r = 0.338), belowground biomass (BGB; r = 0.338), and belowground carbon (BGC; r = 0.338) (Table 3.2). AGB ton ha^{-1}, AGC, BGB and BGC showed perfect correlations with each other (r = 1.000), reflecting their direct proportionality. The total carbon (TC) and CO2 had perfect correlated (r = 1.000) (Table 3. 1). The correlations were a significant at the $p < 0.01$ that means strong relationship across the variables. The negative correlation between Soil Organic Carbon (SOC) and other carbon storage variables may reflect differences in carbon sequestration processes, with higher biomass areas potentially having faster turnover and less SOC accumulation. Additionally, factors such as soil depth, disturbance, and decomposition rates likely contribute to the weak negative relationship between SOC and biomass or carbon pools.

Table 3.1. Pearson correlation coefficients among biomass and carbon storage variables in church forests from 175 plots (Note: 175 plots were derived from the sum of plots laid out in 26 church forests).

Variables	Plot	AGB ton ha^{-1}	AGC	BGB	BGC	SOC	TC	CO_2 equivalence
Plot	1	0.338**	0.338**	0.338**	0.338**	-.221**	0.317**	0.317**
AGB $tonha^{-1}$	0.338**	1	1.000**	1.000**	1.000**	-.019	0.996**	0.996**
AGC	0.338**	1.000**	1	1.000**	1.000**	-.019	0.996**	0.996**
BGB	0.338**	1.000**	1.000**	1	1.000**	-.019	0.996**	0.996**
BGC	0.338**	1.000**	1.000**	1.000**	1	-.019	0.996**	0.996**
SOC	-.221**	-.019	-.019	-.019	-.019	1	.073	.073
TC	0.317**	0.996**	0.996**	0.996**	0.996**	.073	1	1.000**
CO_2 equivalence	0.317**	0.996**	0.996**	0.996**	0.996**	.073	1.000**	1

Note: Correlation coefficients with ** are significant at the 0.01 level (2-tailed). r= Pearson correlation coefficient

3.3.6. Factors influencing biomass in the study area

The one-way ANOVA result showed that disturbance was the only factors influencing carbon stocks in the study areas while others had no effect on it (Table 3.2). This study revealed that managing disturbance level is crucial for influencing carbon stocks.

Table 3.2. One-way ANOVA results for the effect of various factors on biomass in church forests

Factor	Sum of Squares	Mean values	df	F-Ratio	p-value
Elevation Zone	8201.304	341.721	(1, 24)	0.687	0.415
Distance	8219.691	342.487	(1, 24)	0.632	0.435
Size	7762.442	337.497	(2, 23)	0.998	0.384
Wall	8406.141	350.256	(1, 24)	0.085	0.773
Disturbance	6308.422	274.279	(2, 23)	3.879	0.035

3.4. Discussion

3.4.1. Woody species composition in the study areas

The present study revealed that a total of 111 woody species were identified from 26 church forests. When compared to other church forests (Mekonnen et al., 2023; Mekonnen and Wubetie, 2023), our findings were higher. This implied that higher species richness was recorded in 26 church forests. Furthermore, the present study finding showed good species richness when compared to other forest ecosystems. For instance, in the Hangadi Watershed, which recorded 61 woody species (Tamiru et al., 2021), in the afromontane dry forest of Harego recorded 50 species (Bogale et al., 2022), and in the dry afromontane forests of northern Ethiopia documented 80 woody species (Muluneh et al., 2021). These implications showed that church forests had good biodiversity.

3.4.2. Estimation of biomass and carbon stocks in each church forest

Aboveground biomass (AGB) and carbon stock were estimated in each church forest. Then, we summed each church forest biomass to get 31.97 ± 3.31 tons ha^{-1} of AGB, and the total carbon stock (TC) was 26.48 ± 2.83 tons ha^{-1}. However, The values in this study were lower than those reported by Sewagegn et al. (2022, 2024) and Yilma and Derero (2020), this inconsistency may be the result of the influence of forest management, species composition, and microclimatic conditions on carbon stocks. The present study also showed a mean value of CO_2 equivalence at 97.15 ± 10.47 tons ha^{-1}. The present finding emphasized the dynamism of church forests in reducing climate change. The current research had higher AGB than reported by other studies in northern Ethiopia, with 24.73 tons ha^{-1} church forest aboveground biomass carbon (Mengistu et al., 2021). However, the current research had lower AGC than Sekele-Mariam Forest (37.54 tons ha^{-1}) (Mekonnen et al. 2019) and Zequala Monastery Forest (237.20 ton ha^{-1}) studied by Girma et al. (2014). When we compared among church forests, Debre Mihret Mesk Kidane Mihret had potential carbon storage and sequestration even though the species richness is lower than Korch Silassie church forest (see Appendix 6 in detail). The reason for the difference was that the Debre Mihret Mesk Kidane Mihret church forest contained high-aged *Juniperus procera* species with large DBH when compared to Korch Silassie, which had a high number of species with low

DBH. This variability showed that the biomass depends on factors like plant diversity and tree size (DBH) (Wolde, 2023).

3.4.3. Estimation of biomass and carbon stocks in dominant species

In the 26 church forests, we assessed the potential woody plant species that stored high biomass. Hence, the present study revealed that *Ficus vasta* had the highest biomass when compared to other identified species. These results were consistent with other studies (Gibbs et al. 2007; Aiba and Kitayama 1999) that show the massive root network of *Ficus vasta* increases its ability to store carbon. In addition, Chave et al. (2009) found that *Ficus vasta* had the highest carbon accumulation determined by wood density due to its high-density wood structure. Conversely, inconsistent to the present study the highest biomass accumulated species were *Juniperus procera* and *Eucalyptus globulus* recorded from Addis Ababa church forests (Yilma and Derero, 2020).

Native vegetation in and around EOTC plays a significant carbon sequestration role by stocking carbon in their biomass, litter, and soil that reduces atmospheric CO2 level (Wolde, 2023). Native trees of the church forest have promising carbon storage capacity because of high accumulation potential, rate, and intrinsic contribution to the forest ecosystem (Yilma and Derero, 2020; Sewagegen et al., 2022). These species were important in mitigating climate change since they utilize carbon dioxide. Study indicated that soil carbon is more closely associated with native species richness than with exotic species richness (Meunpong et al., 2010; Van and Alonso, 2023). This is because native species are well adapted to the environment, hence their high efficiency in carbon sequestration (He et al., 2020). Native trees, with well-developed root systems and adaptation to local climates, sequester more soil carbon and add organic matter, enhancing sequestration and ecosystem health, unlike exotics (Rodríguez-Loinaz et al., 2013).

3.4.4. Investigating the impact of species richness, diversity, and density on woody biomass

We analyzed the relationship between woody species composition of the community and biomass of 26 church forests. The value of linear regression showed that the density, diversity, and richness of species were negatively correlated. This meant the estimation of biomass varies from church to church. Negative associations of density and diversity of species richness and aboveground biomass in this study may be due to reasons such as increased resource competition and dominance of small, fast-growing species in more diverse sites. In denser species-rich sites, very high intraspecific competition for water, light, and nutrients may suppress the growth of trees, thus leading to lower biomass accumulation (Wirabuana et al., 2022). This can also explain the trend towards lower values of DBH in areas that are more species-rich, where smaller, younger trees will reign supreme. In the present study older, larger trees with higher DBH values will be dominant in areas with less species richness. These have greater biomass, but there is fewer total species diversity. The presence of old-aged species with high repetition in such stands, always with high DBH, should be causing the negative correlation between biomass and species richness among different church forest.

In Tiemt bata lemariam church forest, the species richness is quite high, with approximately 45 species contributing to approximately 8.6 tons ha^{-1} aboveground biomass (AGB). In contrast to this, Debre Mihret Mesk Kidane Mihret church forest that has a relatively low number of just approximately 7 species has a much higher AGB of 99 tons ha^{-1}. The immense difference is largely made by the dominance of *Juniperus procera*, a species with high DBH and individual abundance that contributes considerably towards biomass even at less diverse species. Whereas Tiemt Bata Lemariam church forest has more species richness, its role in biomass contribution is comparatively weaker. Species richness tends to positively correlate with biomass, but such a positive association was not reported here. Maybe it was influenced by the standing condition of regeneration, dominance with big individuals holding large DBH values, and age structure classes.

DBH is a critical biomass determinant in trees since it is directly proportional to tree size, volume, and carbon storage capacity. Large DBH values are equivalent to large biomass since trunk diameter growth is in an exponential function with wood, branch, and leaf weight that make up the AGB. Church forests dominated by large-diameter trees will be denser in biomass, albeit with low species richness, since DBH is highly correlated with tree mass and carbon sequestration. DBH is therefore a good indicator of the forest's potential biomass. It must be highlighted that species richness plays a critical role in promoting biomass buildup and carbon storage in church forests, showing the ecological value of biodiversity upkeep. This aligns with the findings of Dada et al. (2024) and Sewagegn et al. (2022), who cited that higher species diversity yields higher biomass and carbon accumulation. Overall, Baul et al. (2021) found that inland and hillside forests with higher tree species richness and diversity contained more aboveground, and belowground biomass carbon (C) stocks. Thus, it is important to preserve biodiversity in church forests as they provide the most ecological services and best contribute to carbon sequestration and climate change mitigation

In this study, tree density did not show a clear effect on carbon storage or biomass accumulation. We compared biomass across different church forests with varying tree densities, but not within the same forest. Although higher tree density might lead to greater biomass, competition for resources such as light, water, and nutrients may limit growth in very dense areas. This suggests a trade-off, while having more species can improve how resources are used, it does not always result in more biomass when trees are too crowded. The nature of trees that store carbon and ability to tolerate higher tree density could also be perceived as influences on some trees have reputed carbon-storing capabilities, whereas some trees tolerate greater density better than others. For example, in a dense church forest, there were many small trees but few large trees, and since the larger trees are associated with most biomass and carbon stored while the smallest had lower biomass. These combined factors showed species richness- tree density -forest structure characteristics that limit biomass and carbon storage dynamics and hold critical support to the importance of biodiversity conservation in these church forests. In general, in 26 church forests, aboveground biomass was lower in diverse stands but higher in forests with fewer, large-diameter trees, making DBH and species composition better predictors of carbon storage than richness or density.

3.4.5. Aboveground and belowground biomass and carbon stocks across plots

The present study showed an average belowground biomass (BGB) of 11.06 ± 0.92-ton ha^{-1}, varying from 0.30 to 65.25-ton ha^{-1} across 175 plots. This is smaller than the average BGB value (16.9 ton ha^{-1}) of the Chilimo-Gaji forest ecosystem (Siraji, 2019). Nonetheless, the BGB of the present result was higher than that of studied in northern Ethiopia church forests (Mengistu et al., 2021). These authors document a mean belowground carbon biomass (BGB) of 5.53 ± 0.46 ton ha^{-1} with a range of 0.15 to 32.62 ton ha^{-1}. Belowground biomass and carbon stocks that characterize health, carbon sequestration potential, biodiversity, and productivity vary among church forests. Higher values indicate healthier, carbon-rich ecosystems of value for sequestering carbon and climate change mitigation (Kothandaraman et al., 2020). Total carbon stock was lower than the 49.9 tons ha^{-1} of Sewagegn et al. (2022), and Sewagegn and Abate (2024) in Dangila church forest and far lower than 156 ± 92 tons ha^{-1} for Addis Ababa church forests (Yilma and Derero, 2020). Plot-to-plot variability in carbon stocks will likely be due to differences in plant density, tree species, and age as well as plot size (Siraji, 2019).

3.4.6. Factors influencing biomass in the study area

The result of one-way ANOVA showed that disturbance had a significant influence on biomass. Elevation, size, walls and distance had no influence on biomass. This is in line with the observations of Gedefaw et al. (2014) and Simegn et al. (2014), who also observed that altitude, had no significant influence on aboveground and belowground carbon stock. On the other hand, Chimdessa (2023), Körner (2007), and Kassaye et al. (2024) found the impact of elevation on trees' aboveground and belowground biomass. The difference may be attributed to the fact that elevation is not the only determinant of variation in spatial forest biomass and carbon stock variation.

Moreover, forest size did not significantly affect biomass ($p = 0.384$), contrary to findings in literature research. As it is argued by Stephenson et al. (2014), biomass growth rises consistently with tree size, suggesting that more forested areas with larger trees have greater biomass. However, the present study showed the larger forests had smaller DBH, and one small forest had larger DBH, but not all small forests had higher biomass.

The DBH variation may be one of the reasons for the non-significant effect of forest size on biomass, which indicates that forest size will have lesser impact on the correlation between forest size and biomass than the trees' diameter distribution. Thus, despite a forest potentially being larger, if it consists primarily of trees with smaller DBH, then it could potentially not represent higher biomass than a smaller-sized forest with larger DBH trees.

The present study noted that human disturbance significantly decreased the carbon sequestration. This observation supported Wassie et al. (2010), revealed that more human activities like grazing, logging, and agricultural encroachment decrease church forest potential for carbon storage by directly destroying vegetation and soil. Likewise, Cardelus et al. (2013) noted that decreased carbon sequestration may result from deforestation by decreasing forest biomass. Habitat fragmentation of forests because of deforestation for agriculture is an outcome of agricultural encroachment, while forest loss and accessibility are direct consequences of the development of infrastructure, i.e., road and building constructions resulting n decrease biomass (Aerts et al., 2016).

Similarly, deforestation, fragmentation, and land cover change in other forest systems also reduce carbon sequestration capacity by reorganizing forest structure and composition (DeFries et al., 2002; Imhoff et al., 2004). All these effects emphasized the vulnerability of church forests and forest systems in general to human processes and have important implications for their potential as carbon sequestration and climate change mitigation.

The presence of walls did not significantly affect biomass accumulation ($p = 0.773$), contrasting with other studies that highlight the importance of physical barriers in protecting forests from disturbances and increasing seedling richness, which in turn promotes biomass growth (Cardelus et al., 2019). This suggests that walls alone may be insufficient to mitigate disturbances without additional management strategies, indicating that other factors, such as the enforcement of protective regulations or active forest management are needed to enhance the effectiveness of walls in supporting biomass and forest conservation.

Likewise, distance to population centers was not a significant effect of biomass ($p = 0.435$), counter to studies that suggest diminishing woody biomass in nearby regions adds pressure for wood gathering in church forests (Scull et al., 2017). In our study, other contextual factors, such as the amount of human disturbance and particular management choices, moderate the relationship between proximity to human settlements and biomass, thus challenging our assumption that church forests farther away from population centers would contain more biomass.

3.5. Conclusion

The study identified 111 woody species, mainly indigenous, with a significant presence of the Fabaceae family. Across the 26 aggregated church forests studied, the average aboveground biomass measured 31.97 ± 3.31 tons/ha, and total carbon was 26.48 ± 2.83 tons/ha. Among the sites, Debre Mihret Mesk Kidanemihret demonstrated the highest carbon sequestration, whereas Korch Silassie exhibited the lowest. Key species, such as *Ficus vasta*, were crucial for carbon storage. Species richness significantly affected carbon metrics, whereas tree density did not. Enhancing the richness of species is essential for maximizing carbon storage and support global climate change mitigation efforts. The study found that elevation, proximity to population centers, forest size, and the presence of walls did not significantly influence carbon storage, with the exception of disturbance, which emerged as a significant factor. These findings underscore the importance of conservation strategies to protect and restore church forests, thus enhancing their role as carbon sinks and providing a valuable baseline for future research and management. Furthermore, church forests in Northwestern Ethiopia should be recognized in initiatives like REDD+ due to their significant role in carbon sequestration. Future study should explore carbon sequestration by species level by permanent plot, the influence of forest structure, and the role of soil organic carbon, understory vegetation, and litter in total carbon stocks, using remote sensing and GIS for large-scale monitoring

CHAPTER 4: Human Disturbances and Their Impact on Woody Species Diversity in Sacred Church Forests in West Gojjam Zone, Northwestern Ethiopia

Abebe Ayele Haile[1, 2,*], Ali Seid[1], Amare Bitew Mekonnen[1], Wubetie Adnew Wassie[1], Getahun Yemata[1], Endalamaw Yihune [1], Animut Mekuriaw[1]

[1]Department of Biology, College of Science, Bahir Dar University, P.O. Box 79 Bahir Dar, Ethiopia

[2]College of Natural Sciences, Department of Biology, Debre Berhan University, P.O. Box 445, Debre Berhan, Ethiopia

* **abebeayele230@dbu.edu.et**

This chapter is published in Trees, Forests and People, 19 (2025), 100776

https://doi.org/10.1016/j.tfp.2025.100776

ABSTRACT

Although church forests are valuable biodiversity refuges and have significant ecological functions, they are in danger due to human impacts in Ethiopia. Therefore, to make meaningful conservation actions, it is important to understand the richness of woody species and the effects of disturbances. The purpose of this study was to assess human disturbance extent and how it affects woody species diversity in 26 church forests located in the West Gojjam Zone. Human disturbance and vegetation data were collected from 26 church forests. The main plots measuring 20m × 20m ($400m^2$), were used to record all trees with DBH $\geq$ 2.5 cm and height $\geq$ 2.5m. In addition to main plots, 5m × 5m ($25m^2$) sub-plots and 1m × 1m ($1m^2$) plots for saplings and seedlings were laid down within the main plots. Durng data analysis, we used statistical methods such as one-way ANOVA and linear regression. In a study area the average disturbance level was 24.35%. The most notable human disturbances identified were grave construction, clearings, and livestock grazing, and they affect forests overall. Larger forests and those at higher elevations experienced fewer disturbances, while lower elevation forests closer to population centers were more vulnerable. The edge effect significantly influenced ecological degradation by promoting the introductions of exotic species and modification of native species, which decreased biodiversity. Woody species abundance varied across forest zones, with 38.9% in inner, 39.0% in middle, and only 22.1% in edge plots, indicating higher regeneration and stability in the interior zones of the church forests. The smallest species was recorded at the end of plot in the church forests. This is due to human disturbances impact on the edges of the forest. In conclusion, to preserve the sustainability of these church forests, community involvement, ecological restoration, and long-term monitoring, especially where potential for human disturbance existed are recommended to mitigate disturbances and enhance ecological integrity of the forest.

Keywords: Church forests, woody species diversity, human disturbance, biodiversity conservation, exotic species, edge effects, West Gojjam

4.1. Introduction

Sacred church forests of Northwestern Ethiopia, which are predominantly associated with EOTC, are unique ecosystems with deep cultural, ecological, and historical significance (Wassie et al., 2010). Forests that are found predominantly surrounding churches are sacred places, which express the extremely deep spiritual and cultural significance of local communities (Klepeis et al., 2016; Cardelús et al., 2017). They are ecologically important because they are sources of biodiversity, habitat for a diverse variety of indigenous species, and providers of ecosystem services, for example: seeds, water conservation, and climate regulation (Cardelús et al., 2017; Baez et al., 2022; Mekonnen, 2019; Cardelús et al., 2019). The church forests historically existed as traditional conservation measures for hundreds of years, preserving not just their ecological function, but the cultural value as well (Aerts et al., 2016; Wolde, 2023). Thus, religious church forests form the centre of the nation's cultural heritage, ecological resilience, and continuity.

Woody richness constitutes an extremely crucial element of ecological stability and provision of ecosystem services (Mori et al., 2016). It is also extremely crucial in Northwestern Ethiopian sacred church forests (Ayele et al., 2024). The church forest contains high native plant richness, which is the cornerstone of ecological stability and resilience (Aerts et al., 2007). Higher species diversity of woody vegetation enhances the structural organization of the forest as habitat variation creates niches for various wildlife to live in and enhance ecological processes (Cherinet and Lemi, 2023). Diversity is not replaceable in ecosystem service: it stabilizes soil against erosion, facilitates water regulation and cleansing, and increases carbon sequestration, thus averting climate change. In religiously meaningful church forests, religion-cultural importance taps into ecological process; therefore, woody species diversity should be preserved to ensure preservation of the integrity of the systems in addition to provision of fundamental services they provide (Cardelüs et al., 2017; Wolde, 2023).

Human disturbances within the church forest disrupting the stability of the overall ecosystem balance of the forest (Cardelús et al., 2017; Klepeis et al., 2016). Agricultural expansion played notable effects of deforestation induced by human being on vegetation, and creating fragmentation of the forest (Wassie, 2020).

Hence, these deforestations directly reduce the canopy cover of trees and alter the forest structure, which can lead to the reduction of woody species diversity through the destruction of key habitats and interference with ecological processes erosion (Iordăchescu and Vasile, 2023). Grazing by livestock leads to vegetation destruction, soil compaction and emergence bare soil surfaces, which inhibit plant regrowth, leading to loss of biodiversity, and soil erosion (Orlowska and Klepeis, 2018). Infrastructure development, including roads and trails, introduces pollutants and alters hydrological patterns, fragmenting habitats and increasing human access in these sacred church forests (Mekonnen, 2019). The collection of non-timber forest products, while vital for local livelihoods, can lead to overharvesting and impact forest regeneration (Cardelús et al., 2017). Additionally, cultural practices such as grave construction and ceremonial clearings disturb soil and forest dynamics, impacting ecosystem stability (Ayele et al., 2024). These combined disturbances threaten the ecological balance and cultural significance of these sacred forests, highlighting the need for sustainable management practices.

Ritual removals and grave digging are some of the processes that interfere with the processes of forest and soil and will harm the growth and structure of woody species by impacting nutrient flow and microhabitats (Ayele et al., 2024). In general, church forest integrity and woody species decline were strongly affected by disturbance (Baez et al., 2022). The various levels of disturbance inside church forests were affected by several factors such as distance to the population center, elevation and presence of a wall (Klepeis et al., 2016; Woldemhedin and Tekaty, 2016). Elevation and distance to urban settlements rise with higher biodiversity due to the least disturbance by human activities (Aerts et al., 2016; Klepeis et al., 2016). Physical structures like walls also deter direct human activities within forests (Woods et al., 2017).

Human disturbances in forest such as logging, land conversion, urbanization, and infrastructure development significantly influence forest structure and biodiversity, leading to habitat loss, reduced species diversity, and altered ecosystem functions (Turner, 2010; IPCC, 2021). Studies have highlighted that logging and agricultural expansion simplify ecosystems and disrupt ecological balance, while urbanization and infrastructure create fragmented landscapes that exacerbate edge effects and alter species dynamics. Grazing and other agricultural activities further degrade soil quality and hinder plant regeneration (Gebrelibanos and Assen, 2013).

Ethiopian church forest studies recognize the significance of the forests both culturally and ecologically, and they vary in their reaction to human disturbance in the form of grazing, clearing, and grave digging with edge effects playing a critical role in their ecological integrity (Klepeis et al., 2016; Aerts et al., 2016). In view of the foregoing, there are significant gaps in quantitative data on the assssment of various disturbance types and their cumulative impacts on biodiversity and ecosystem function, particularly in ecologically significant forests like those in West Gojjam zone. Furthermore, long-term studies are needed to achieve the effect of such disturbance on forest regeneration and ecosystem processes in the future for effective conservation strategies (Woldemedhin and Tekaty, 2016).

Church forests in West Gojjam zone are crucial ecosystems for biodiversity and local culture preservation. However, they are increasingly threatened by human disturbnaces like logging, grazing, agricultural encroachment, and urbanization. Quantitative studies on the cumulative effects of disturbances on church forest biodiversity are limited, and knowledge gaps exist on interactions of disturbances, and edge effects. This showed that investigation of human distrubance types and impact on the church forests is crucial to ensure its sustainability. Therefore, the present study was aimed to investigate human disturbance and its effect on woody species in 26 church forests in the West Gojjam Zone, northwestern Ethiopia.

4.2. Material and Methods

4.2.1. Description of study area

The study area was well described in chapter 1, General methodology, Section 1.4.1 of the general methodology, including a map of the study area.

4.2.2. Site selection and sample size determination

A total of 26 church forests were selected using stratified sampling methods based on forest size, elevation, the presence or absence of stone wall, and distance from population centers. In addition, the sample size was determined. These were briefly described in chapter 1, General methodology, section 1.4.3 and Table 1.2.

4.2.3. Methods in vegetation data collection

Vegetation data was collected from 26 church forests by laid down a plot along gentry transects lines. Three gentry transect lines were laid down at three cardinal directions in each church forest with 120o interval at 60°, 180° and 300° (Fig. 4.1). Each woody species that have DBH $\geq$ 2.5 cm and height $\geq$ 2.5 were measured for estimation of biomass in each church forests. The detailed was described in Chapter 1, General methodology, section 1.4.4.

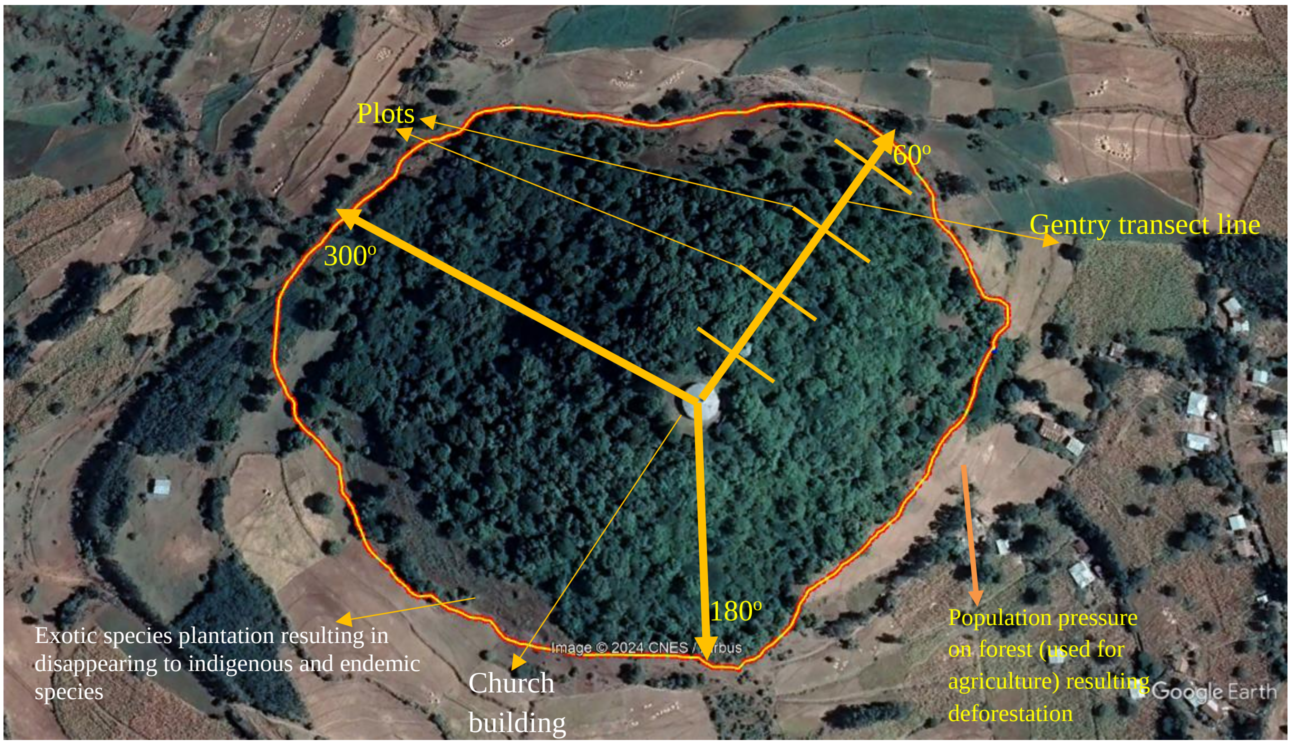


Figure 4.1. Gentry transects lines and layout of main plots for vegetation and disturbance data collection (Korch Silassie church forest in Yilmana Densa district; Source: Google Earth Pro 2024

4.2.4. Disturbance, species richness, density and biomass

To examine the effects of disturbances, there were different types of disturbances wre collected from each church forest. Natural disturbances such as gaps and wind tree falls, and human disturbances such as graves, clearings, trails, grazing, gathering, construction, plantation activities and cut stamps were documented. The percentage of area affected by each of the types of disturbances on each transect was calculated. The human disturbance was more prone than natural disturbance. Hence, natural disturbances were thus excluded from further analysis.

The estimated proportion of area covered by each type of disturbance in the main plots along each transect was calculated following Cardelús et al. (2019).

$$\%\text{area covered by disturbance} = \frac{\text{area covered by disturbance category in a plot}}{\text{Area of plot}} * 100$$

Estimation of biomass

The estimation of aboveground biomass is used to determine the contribution of church forests act as carbon sinks, by absorbing massive amount of CO2 through photosynthesis and then stored in their biomass. To estimate the biomass, we used Chave et al. (2014) allometric equations, which are robust and widely used in tropical rainforests. This equation incorporates DBH, height of the tree and wood density. Hence, their accuracy and precision demonstrate them to be functional and easy to use. The equation is as follows:

$$\text{AGB} = 0.0673 * (\rho D^2 H)^\wedge 0.976$$

Where, AGB = aboveground biomass (kg), H=Height of tree (m), D=Diameter (cm) at breast height (1.3m), and ρ= Wood density (t/m3), the African trees average wood density values (0.58 ton/m^3) (Sewagegn et al., 2022).

4.2.4. Statistical analysis

We used a one-way ANOVA to determine if there is a significant relationship between elevation, distance, wall presence, and size with the dependent variables: disturbance, tree species density, tree species richness, tree biomass, seedling density, seedling richness, and seedling density by usig SPSS software. Linear regression analyses were conducted to assess the relationships between vegetation parameter and disturbance types with SAS using JMP 17 statistical software at $P<0.05$.

4.3. Results

4.3.1. Diversity of woody species in different church forests

A total of 111 woody species belongs to 95 genera and 51 families were identified from 175 plots in the church forests surveyed (see Supplementary File). Of these, 72 species were trees, 23 were shrubs, 8 were shrub/tree hybrids, and 8 were lianas. The woody species composition at the study sites was 82.88% indigenous, 15.32% exotic, and 1.8% endemic. Similarly, a total of 5923 saplings and 6136 seedlings were recorded from 26 church forests in west Gojjam zone. Fabaceae was the mos dominant family with comprising (12) species followed by Rosaceae, Euphorbiaceae, and Myrtaceae, each represented by (6) species, followed. Rutaceae included (5) species, while Moraceae, Rubiaceae, and Asteraceae were each represented by (4) species. Families such as Capparidaceae, Acanthaceae, Celastraceae, Myrsinaceae, and Oleaceae contained (3) species each. Additionally, Cupressaceae, Ebenaceae, Flacourtiaceae, Lamiaceae, Malvaceae, Meliaceae, Poaceae, Rhamnaceae, Salicaceae, and Sapindaceae were represented by (2) species apiece. The remaining (29) families were each represented by a single species.

4.3.2. Disturbances

In a study area the average disturbance level was 24.35%. However, human disturbances, which are more severe than natural disturbances, were targeted in the study for data analysis. The human disturbance categories and descriptions are briefly presented (Table 4.1). Boxplot revealed noteworthy percent area coverage disturbance variations in four disturbance types (Fig. 4.2): extreme median (~25%) and dispersion (IQR: ~20–28%, range: ~15–35%) reflect extensive disturbance due to the synergistic natural and human drivers, and a single outlier reflects extreme disturbance in the forests. Weedy disturbance showed a moderate median (~6%, IQR: ~4–9%, range: ~3–11%), reflecting but lower level of ecological stress from aliens. Exotics under plantation have a low median disturbance (~3%, IQR: ~2–4.5%), but outliers (~10%) exhibit localized threats from aliens. Planted natives, however, have the lowest median (~0.5%, IQR: ~0.3–0.8%), indicating low disturbance and stressing their ecological value.

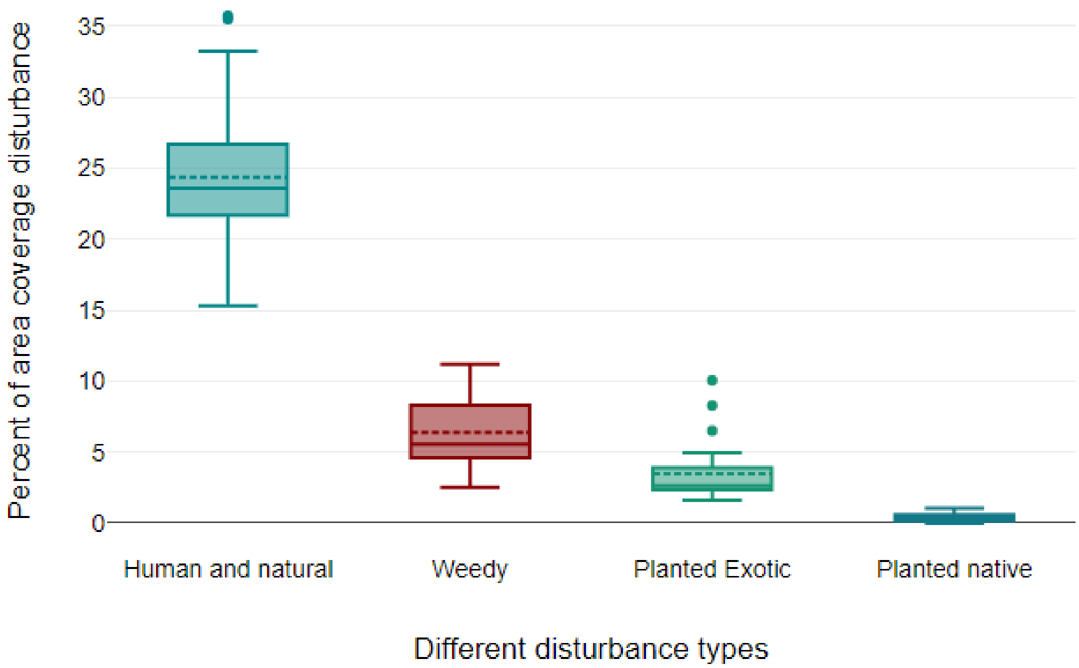


Figure 4.2. Human disturbance types in each church forests at $p < 0.05$.

Table 4.1. Types of human disturbances recoreded in each church forest

Category	Types of Disturbance	Description
Physical Alterations to Forest Structure	Clearings	Involves tree removal for other reasons, producing extreme disturbances and changing forest patterns.
	Plantation	Conversion of forest into farmed trees and agricultural crops, disrupting native forests and exposing them to invasive plants.
Soil and Vegetation Impact	Trails	Damages seedling vegetation, leading to soil compaction and erosion.
	Grazing	Alters vegetation species and damages seedling plants.
Specific Activities Causing Disturbance	Graves	Includes cemented graves and grave houses causing localized disturbances, altering plant structure, nutrient processes, and soil organization.
	Gathering (Mahiber)	Collection of church communities for particular tasks that involve tree clearing and lead to forest destruction and degradation.
	Cut Stump	Selective logging process.

4.3.3. Cumulative percent disturbance

The cumulative percentage disturbance approximates the cumulative impact of all various human-induced disturbances in the church forest by summing the percentage of area covered by each type of disturbance. The measure provides a summary assessment of the extent to which church forest has been disturbed by clearings, grazing, trails, and other human disturbances (Fig. 4.3). Cumulative percent disturbance is a great way to provide an overall assessment of potential impact of many disturbances, given that it quantifies the combined impact of several disturbances, making it a reliable measure of ecosystem health, an indicator to direct immediate conservation action and a useful tool for informing land management actions to minimize further environmental degradation. Church forest was faced with a complicated challenge considering the high extent of disturbance by a great variety of human activities. The church forests were assigned their levels of disturbance and per square meter scores were collected for the variable’s clearings and graves, grazing and waste, trails son on. They are grouped as having a high, moderate, or low level of disturbance, depending on their overall score: high disturbance (>500 m^2), moderate disturbance (300–500 m^2) and low disturbance (<300 m^2). Calculation of the cumulative percent disturbance provides a measure of the threat to the church forest, allowing the conservation efforts.

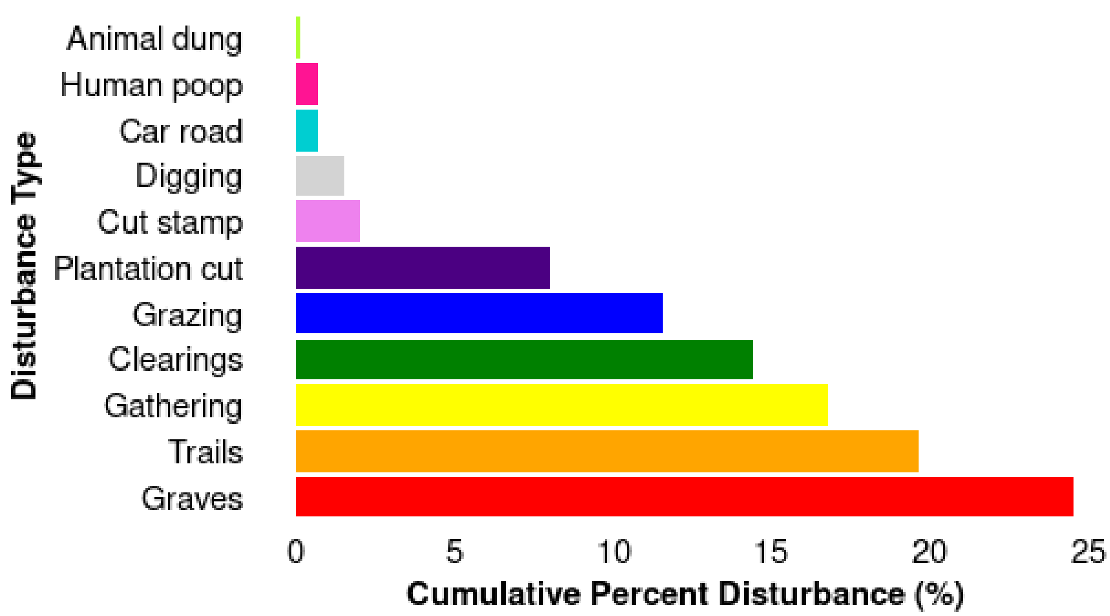


Figure 4.3. Cumulative percent disturbance for each type of human disturbance

4.3.4. Factors affecting the rate of disturbances on the parameters of woody plant species

Species richness

Disturbance and elevation were significantly influencing species richess in church forest. Elevation significantly influences species richness ($F (1, 24) = 2$, $p < 0.0001$), which means that species richness was alter with an alteration in elevation. Disturbance also had a significant effect on species richness ($F (2, 23) = 0.945$, $p < 0.0001$), with different types of human disturbance impacting species diversity (Table 4.2). However, neither distance to the population, nor walls, nor forest size significantly impact species richness, as their respective corresponding p-values showed no strong evidence of such an effect in this study.

Density

Density in the church forests is significantly affected by elevation and forest size. Elevation had a strong impact on density ($F (1, 24) = 28.8$, $p < 0.001$), with higher elevations generally associated with varying density levels. The size also influences density ($F (2, 23) = 3.65$, $p = 0.042$), indicating that the extent of the forest area affects the density of species (Table 4.2). However, distance from population centers, presence of walls, and types of disturbance do not show significant effects on density, as evidenced by their no significant p-values in the analysis.

Sapling density

Sapling density in the church forests is influenced considerably by elevation. The effect of elevation on sapling density is substantial ($F (1, 24) = 4.87$, $p = 0.037$), which means that changes in elevation are connected to changes in sapling density (Table 4.2). Other factors, such as distance from population, walls, forest cover, and disturbances, had no substantial influence on sapling density because their p-values indicate no substantial effect in this study.

Seedling density

Disturbance had a siginificant influence on sedling density ($F (2, 23) = 3.67$, $p = 0.041$) (Table 4.2). However, elevation, distance from population, presence of wall and forest size had not significantly influence on seedling density as their p-values are not significant.

Table 4.2. ANOVA results of the effects of elevation, distance from the centre of the population, wall, size of forests, and disturbance on woody species parameters (species richness ha^{-1}, density ha^{-1}, sapling density ha^{-1}, seedling density ha^{-1}, and biomass ton ha^{-1}) in church forests.

	Species richness (ha^{-1})			Density ha^{-1}			Sapling densityha^{-1}			seedling densityha^{-1}		
Model	Df	F	P	Df	F	P	Df	F	P	Df	F	p
Elevation	1,24	2	<0.0001	1,24	28.8	<0.001	1,24	4.87	0.037	1,24	0.003	0.961
Distance	1,24	0.012	0.915	1,24	0.56	0.459	1,24	0.18	0.675	1,24	1.022	0.322
Wall	1,24	0.015	0.905	1,24	1.59	0.219	1,24	0.51	0.482	1,24	0.757	0.393
Size	2,23	0.05	0.952	2,23	3.65	0.042	2,23	0.65	0.531	2,23	0.659	0.527
Disturbance	2,23	0.945	<0.0001	2,23	1.17	<0.0001	2,23	2.17	0.137	2,23	3.67	0.041

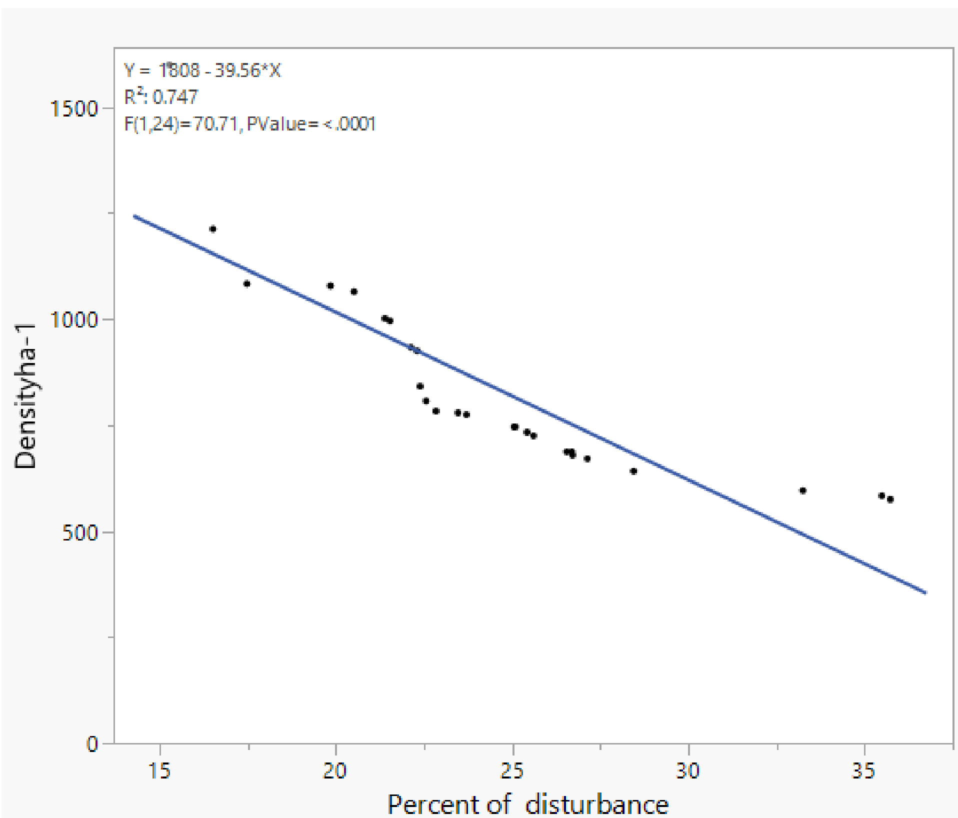


Figure 4.4. The relationships between density versus percent of disturbance

Density decreased significantly with increasing disturbance. Thus, human disturbance increased by one unit, the density per hectare dropped by around 39.56 units.

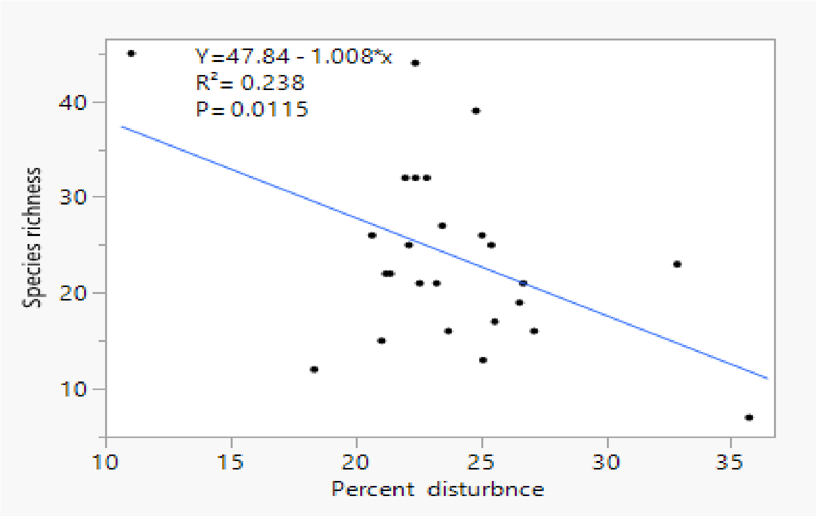


Figure 4.5. The relationships between species richness versus percent disturbance.

The relationships between species richness versus percent disturbance. Regression analysis shows that as percent disturbance in church forests increases, the species richness decreases. This relationship is statistically significant (p = 0.0115).

4.3.5. Edge effects on church forests

The abundance of woody species showed clear spatial variation among the inner, middle, and edge plots of the 26 church forests (Fig. 4.6). Out of a total of 5,880 individual trees and shrubs, the inner plots contributed 38.9% (2,288 individuals), the middle plots 39.0% (2,292 individuals), and the edge plots only 22.1% (1,300 individuals). The highest total abundance was recorded in Tiemt Bata Lemariam (621 individuals, 10.6% of the total), followed by Korch Silassie (501 individuals, 8.5%), whereas the lowest was found in Debre Mihret Mesk Kidanemihret (126 individuals, 2.1%). Approximately 30.8% (8 out of 26) of the church forests had no woody species at their edges, indicating higher degradation or disturbance at the forest margins. Overall, woody species abundance was substantially higher in the inner and middle zones (together 77.9%) than at the edges (22.1%), suggesting that the central forest zones provide more favorable conditions for regeneration, moisture retention, and protection from anthropogenic pressures. This pattern aligns with previous studies (e.g., Wassie et al., 2010; Aerts et al., 2016), which reported that inner forest areas maintain higher ecological stability and structural integrity than edges affected by grazing and fuelwood collection.

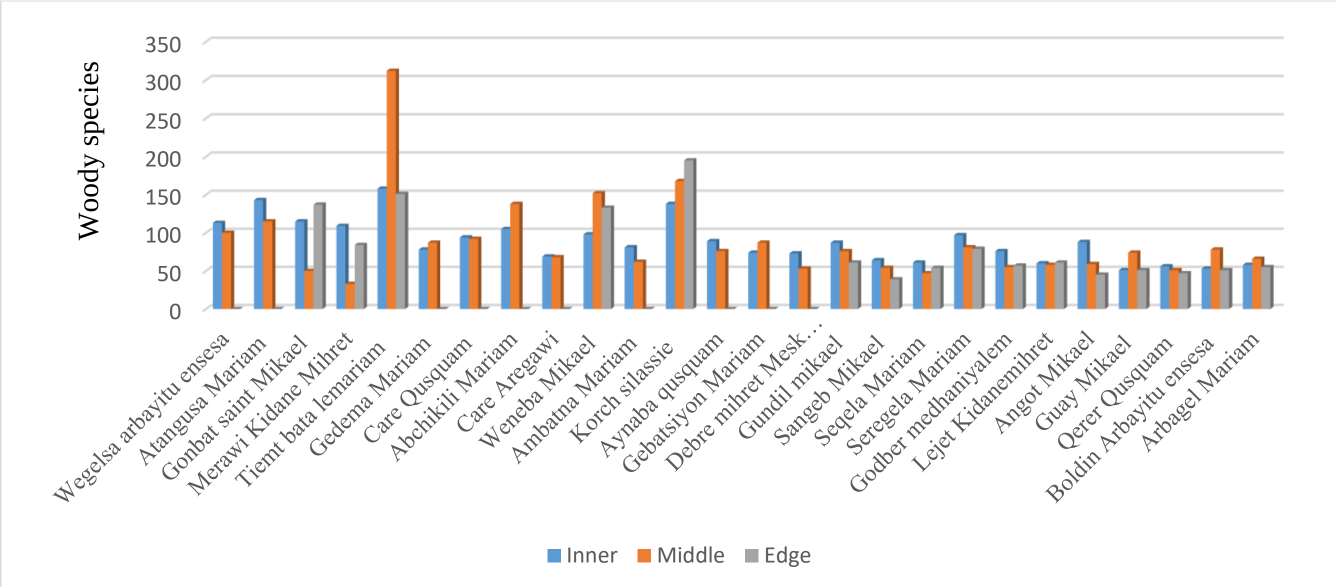


Figure 4.6. Distributions of woody species along the location of the plot from the inner to the edge

There are several human disturbances in the research area, including gathering points, trails, graves, clearings, and plantations, all of which were photographed and documented. The photographs demonstrate graphically the impact of these disturbances on the environment of the area.

Figure 4.7. Grave construction (photo taken by Abebe Ayele and Dr. Amare Bitew, 2023)

Figure 4.8. Clearing of church forests for various purposes, mainly to gather (photo taken by Abebe Ayele, 2023). Description: Clearing of church forest leads to lowered biodiversity, impairment of ecosystem functioning such as carbon sequestration and water management, intensified soil erosion, altered regional climatic regimes, and possible loss of cultural and spiritual values.

Figure 4.9. Plantation of exotic species (photo taken by Abebe Ayele, 2023). Description: Exotic species plantation has the ability to disrupt the native ecosystem, reduce bio-diversity, and alter soil structure and water retention capacity, which eventually compromise the ecological balance of the area.

4.4. Discussion

A total of 111 woody species were documented from 26 church forests, and it was more diversity than Birhanu et al. (2021) recorded 73 species in Dangila church forest, but fewer than the 174 species documented by Mekonnen (2019) from 46 church forests in South Gonder. These comparisons yet again emphasize church forests as points of high biodiversity.

In the West Gojjam zone, the church forests are disturbed by both human and natural factors, but this study focusses on human disturbances, as natural disturbances were found to be insignificant. The present study showed a lower percentage of human disturbances (24.35%) when compared to South Gonder (56.5%) (Cardelús et al., 2019). The result of these variations might be intensity of local people's pressure, traditional practice, or conservation policy in the church forests of West Gojjam zone. The study identified important variations among different types of human disturbances, including graves, clearings, trails, grazing areas, gathering sites, plantations, and areas with cut stumps, digging, human waste, animal dung, and car roads. These disturbances reflected the relative environmental impact of various human activities around churches.

Although the church forests are smaller in area, activities such as cut stumping, digging, and waste deposition collectively contributed to the overall cumulative impact, emphasizing the significant human effect on these forests. Grave construction and clearings indicated visible physical alterations of forest sites, and trails alo impacted habitat fragmentation in resulting biodiversity loss. Grave construction within church forests can have both positive and negative impacts. On the positive side, it may enhance the sacredness of the site and raise local awareness about conservation, thereby contributing to improved protection efforts. However, it can also lead to soil disturbance, habitat fragmentation, and the introduction of invasive species, all of which may negatively affect plant diversity (Ayele et al., 2024). To mitigate these adverse effects, sustainable management practices and increased public awareness of the ecological implications are essential. Effective strategies to preserve plant diversity in church forests containing graves include careful site selection, restricted access, reforestation efforts, invasive species control (Wolde, 2023), active community involvement, and collaborative management among religious institutions and conservation organizations (Mekonnen et al., 2022).

Grazing and gathering activities threaten vegetation cover and crucial ecological processes. Similar trends have been observed in other regions, such as forest grazing in Bhutan and coniferous forests in the Himalayas, as noted by Walter et al. (2002). Laurance et al. (2009) also quantified the prevalent consequence of clearings and roads in tropical forest loss. According to FAO (2015), 80% of the forest removal was due to agriculture, then road and dam construction, and urbanization and mining. Adequate information of these disturbances should be acquired to prepare an effective conservation plan.

In the study area, introduction of exotic species was achallenge for native species. These activities are reducing biodiversity, consistent with Mekonnen (2019), who noted that exotic species like eucalyptus compete with native flora and diminish biodiversity. Plantation changes the forest structure (Heilmayr et al., 2016). Exotics such as eucalyptus introductions into natural forests have significant ecological impacts (Bogale et al., 2023). Eucalyptus plantations are also harmful to biodiversity through the monoculture and eucalyptus surrounding environment modification, which chases off local flora and fauna. Eucalyptus is a recognized water consumer, and as a result, this will sap water from the surrounding environment of the plantation site and intrude on neighboring plants (White et al., 2022). Allelopathic compounds vaporized by eucalyptus could control soil chemistry and inhibit native vegetation growth (Song et al., 2018). In addition, Poore and Fries (1985), Paritsis and Aizen (2008), emphasized that invasive plantations reduce species richness as well as alter assemblage structure. These findings align with global reports of human disturbance impact on forests, such as Brazilian Amazonian clearing for timber and agriculture (Andersen, 2002), and human induced disturbance in northern New England wetland forest (Bell et al., 2017).

The study found that species richness and density of woody species were influenced by elevation. The result agreed with Yasuhiro et al. (2004) and Ni et al. (2003) elevation had impact on density and richness, which affects temperature, precipitation, and soil quality. Elevation affects sapling density and seedling recruitment, and human disturbances playing a critical role in forest regeneration. Species richness at higher elevations were good, due to restricted accessibility, experience fewer disturbances related to graves and cut stumps, while lower elevations were more vulnerable to grazing, gathering, and trafficked trails due to proximity to population centers.

Larger habitat areas support greater species density, while anthropogenic disturbances reduce seedling and sapling abundance (Bogale et al., 2023; Cardelús et al., 2019). Walled church forests faced fewer disturbances, and larger forests experience less disturbance than smaller ones. Distances from population and wall presence had no notable effect on seedling density or species richness. Integrating field data on species composition, soil, and elevation offers insights for effective conservation and management strategies (Haugo et al., 2010; Simin et al., 2022). Developing successful conservation and management strategies requires a better understanding of ecological circumstances, which can be obtained by combining data on elevation gradients, field observations, soil properties, and species richness (Haugo et al., 2010; Simin et al., 2022).

Ecologically, edge disturbances in church forests lead to microclimatic changes, including increased light and wind speed, which alter temperature and humidity levels vital for flora and fauna adapted to sheltered, cooler conditions (Sandewall & Gebrehiwot, 2015; Yirsaw & Nigussie, 2024). These changes, coupled with human and animal activities, cause soil degradation through compaction, erosion, and loss of organic matter, affecting nutrient cycling and plant health (Cardelús et al., 2020; Mekuria et al., 2021). Fragmentation isolates forest remnants, reducing habitat for interior species, and increasing ecological instability (Fahrig, 2017). Edge effects also facilitate the invasion of non-native species, displacing indigenous vegetation and impacting the biodiversity of woody plants (Ribeiro et al., 2009; Mekonnen et al., 2022). This degradation diminishes the cultural and spiritual value of church forests, disrupting religious practices and the use of traditional resources such as medicinal plants, while also threatening the transmission of ecological knowledge and cultural identity (Scotton & Andreatta, 2021; Yahya et al., 2022). Effective conservation of these forests requires protecting core areas, restoring buffer zones, and implementing sustainable land management practices.

Forest dynamics in church forests are shaped by the interaction between native and exotic plant species, particularly during management activities. While certain exotic species with extensive root systems, such as *Eucalyptus camaldulensis*, *Schinus molle*, *Casuarina equisetifolia*, and *Grevillea robusta*, are capable of stabilizing soil in degraded forest edges (Yahya et al., 2022), they often overshadow indigenous species. This creates increased competition for resources and leads to lower biodiversity (Magnago et al., 2015). Attention is needed when introducing exotic species into church forest study areas to prevent disrupting the ecological balance and undermining the stability of native species. Prioritizing the conservation of indigenous species and maintaining biodiversity is essential to ensure the long-term ecological integrity and function of church forests.

4.5. Conclusion

This study revealed that sacred church forests in the West Gojjam Zone experience an average human disturbance level of 24.35%, primarily from grave constraction, clearings, trails, grazing, and exotic species plantations, which collectively threaten their ecological integrity and biodiversity. Elevation and disturbance intensity significantly influenced woody species richness, density, and regeneration, with higher-elevation and larger forests exhibiting lower disturbance and greater diversity, while forests near human settlements and at lower elevations were more degraded. Edge effects further intensified these impacts by encouraging exotic species invasion and reducing native species abundance near forest boundaries. The traditional stonewalls surrounding many church forests played a protective role by minimizing human intrusion, highlighting the importance of cultural and spiritual stewardship in conservation. Therefore, urgent, community-based management interventions are needed focusing on restoring degraded areas with native species, regulating grazing and plantation activities, and promoting continuous monitoring to preserve the ecological and cultural heritage of Ethiopia's sacred church forests for future generations.

CHAPTER 5: Soil Fertility and Ecosystem Integrity in Wst Gojjam Zone Selected Church Forests: Effects of Eucalyptus Plantation and Edge Disturbance

Abebe Ayele Haile [a, b, *], Ali Seid [a], Amare Bitew Mekonnen [a], Wubetie Adnew [a], Getahun Yemata [a], Endalamaw Yihune [a], Animut Mekuriaw [a]

[a]Department of Biology, College of Science, Bahir Dar University, P.O. Box 79, Bahir Dar, Ethiopia

[b]Department of Biology, College of Natural and Computational Sciences, Debre Berhan University, P. O. Box 445, Debre Berhan, Ethiopia

ABSTRACT

Soil is important for biodiversity, climate regulation, and keeping ecosystem stability, but human disturbances are a threat to its quality. Therefore, the present study was aimed to assess the soil's physical and chemical properties by comparing the church forests with outside church forests and eucalyptus-planted area. Soil data was collected from three land cover types (church forests, outside and eucalyptus plantations). The soil physical and chemical properties were analyzed. The present study showed that church forests had the highest moisture content (42.98%), porosity (16.08%) along with the highest carbon (57.22%), phosphorus (0.0445 ppm) and nitrogen (0.56%) levels. Church forsts had good soil when compared to outside forests, and eucalyptus plantations had lower more acidic soil (pH 4.95), water content (28.34%), and more acidic soil (pH 4.95). In contrast, soils at the outside of church forest, especially near agricultural lands, had lower nutrient levels, indicating reduced fertility. Eucalyptus plantations had a high impact on nutrient depletion and soil quality compared to both the church forest and areas outside the forest. In addition, the soil nutrient levels decline from the interior of the church forest to the edges of church forests. Edge Effects revealed minor changes in soil properties near the forest edge. Bulk density was slightly higher at the edge (0.58 g/cm^3) compared to the interior (0.57 g/cm^3), reflecting slight compaction from human activity. Water content was consistent in the interior but showed greater variability at the edges, suggesting higher stress on plant regeneration. Porosity was marginally higher in the interior (16.58%) than at the edge (15.88%), indicating edge effects may hinder root development and water retention. Overall, church forests support better soil health, while eucalyptus plantations and edges negatively affect soil properties, emphasizing the need for conservation strategies like buffer zones and reforestation.

Keywords: Human disturbance, Eucalyptus plantation, Church Forest, Climate regulation, Soil Physicochemical Properties

5.1. Introduction

Soil is vital in supporting global food production through its unique role in agriculture (Bagnall et al., 2021). Soil health for the long term is required not only to raise the crops that feed billions, but to preserve biodiversity itself. Similarly, it is equally important for forest biodiversity because it provides nutrients, water, and support for biomass. This, in turn, affects vegetation health and composition and supports diverse communities of microorganisms and animals that help to enhance ecosystem resilience and stability (Telo, 2023). Soil is one of the main carbon sinks, with CO_2 sequestered through photosynthesis and organic matter decomposition, mitigating climate change (IPCC, 2022). Intensive agriculture, however, is driven by growing global food demand, undermining soil, reducing biodiversity, and disturbing ecosystem processes. Excessive use of chemical fertilizers and pesticides, in addition to unsustainable land use like deforestation and overgrazing, is causing further depletion of soil carbon reserves and higher greenhouse gas emissions that cause a process of degradation and lower yield (Li, 2008).

Forest ecosystem sustainability and health can be described definitively through some of the soil physical and chemical characteristics. These characteristics affect processes resulting in vegetation growth, nutrient cycling, water allocations, and forest productivity more generally (Lal, 2015). Most physical characteristics such as; bulk density (BD), porosity, water content, and available water-holding capacity can be associated with soil structure and retention of vegetation better than other characteristics (Vitousek and Howarth, 1991). For example, BD affects root penetration and water movement - porosity affects both aeration and drainage. Available water-holding capacity and moisture content are also especially important to plant support during dry periods (Hatten and Liles, 2019). Both cationic and anionic contributions to soil chemistry, including organic carbon (SOC), total nitrogen (TN), total phosphorus (TP), and soil pH, play a crucial role in regulating nutrient availability and, consequently, influence a wide range of microbial processes (Brady & Weil, 2008; Joshi & Garkoti, 2023). Soil organic matter, which mostly is SOC, also helps improve soil structure, water retention, and soil fertility.

Nutrient-rich forests shield the atmosphere from climate change by sequestering carbon content through uptake (Luo et al., 2006; Fernández-Martínez et al., 2015; Terefe and Feyera, 2018; Zhao et al., 2023; Du, 2023). In addition to the conservation of forest richness and diversity, knowledge of the state of soil is essential (Vitousek and Howarth, 1991; Hatten and Liles, 2019). Therefore, a deep understanding of soil physical and chemical properties is fundamental to forest ecosystem health, which will further improve tree growth, forest productivity, and maintaining ecological balance.

Forest soils, known for their rich organic matter content, play a significant role in carbon sequestration. Carbon, nitrogen, and phosphorus are the three essential nutrients in forest ecosystems (Marschner, 2011). Plants get nearly all of their carbon directly from the atmosphere specifically, carbon dioxide (CO2) through photosynthesis. According to one analysis of global data from 1981-2010, forests are estimated to sequester 2.4 ± 0.4 pentagrams of carbon each year (Pugh et al., 2019). Nitrogen is often limiting in temperate and boreal forests affecting the carbon sequestration process via its role in synthesis of protein, nucleic acids and chlorophyll (Schulte-Uebbing and de Vries, 2018). Phosphorus also plays a vital role in the flow of energy and the composition of nucleic acids, which affects biomass production in tropical forests (Du et al., 2020). The role of major nutrients with respect to limitation and availability differs with forest type and age, with the principal limiting factor in young forests being nitrogen (N) (due to low organic matter, minimal nitrogen fixation, and high demand for rapid growth), but phosphorus (P) in older systems (because of phosphorus immobilization in soils, depletion from weathering, and accumulation of nitrogen over time) (Capek et al., 2016). Moreover, stoichiometric carbon to nitrogen (C : N) and nitrogen to phosphorus (N : P) ratios play a pivotal role in governing soil microbial communities and nutrient cycling processes that are central to explaining forest responses to global change (Zechmeister-Boltenstern et al., 2015).

Ethiopia has remarkable ecological diversity: a range of ecoregions and several forest biomes which contain a multitude of tree species of great ecological, recreational, and scientific value (Fashing et al. 2022; Dagne & Birhanu, 2023). The introduction and proliferation of the exotic vegetation such as Eucalyptus result in acidification of the soil, depletion of nutrients, more likelihood of fires with their volatile flammable oils, and the limitation of reformative native vegetation and soil fertility (Liang et al., 2016; Tadesse & Tafere, 2017; Younes et al., 2024).

The significant increase in the amount of land used for crop and animal agriculture due to population growth and demand for forest products has increased areas of deforestation and fragmentation which has drastically changed large swathes of unbroken forests into small, fragmented sites (Hussein, 2023; Kasu, 2022; Seta et al., 2018). In addition, the fragmentation allowed grazing, wood collection, and agriculture all occurring on the edge of the forest. The edge effect on the forest resulted in changed forest soil and species composition (Cubides & Cardona, 2011; Harper et al., 2005; Willmer et al., 2022). Edge effect also occurs in Ethiopia's church forests, which have had their soil properties affected due to human intervention (Cardelus et al., 2020).

However, clearings, logging, grave and road construction, and agriculture are among the human activities that have tremendously destroyed soils in forests through physical integrity break-up and increased erosion susceptibility. The removal of vegetation opens soil to erosive energy and the construction of infrastructure alters natural hydrology and allows less water to infiltrate (FAO, 2015; Houghton et al., 2015). Church forests in Ethiopia are locations the only remaining unique and culturally important remnants of ecosystems with significant biodiversity and ecosystem services. Historically, sacred groves for religious importance are now under pressure from increasing human disturbance such selective logging, grazing, clearings for agricultural purpose, and the use as burial sites (Wassie et al., 2010; Aerts et al., 2016; Ayele et al., 2024). Such land cover threatens plant diversity and reduces vegetal and structural soil resources, which influence the stability of the ecosystem (Endalew et al., 2020).

Church forests are hotspots of biodiversity and havens for endemic species, and soil health maintenance forms part of ecological resilience and cultural heritage (Aerts et al., 2016; Endalew et al., 2020). A recent study showed that in the West Gojjam Zone, deforestation, burial in the traditional way, and exotic plantations have impacted soil and vegetation structure in the church forests (Ayele et al., 2024). Boundaries by surrounding agriculture or human habitation impact microclimates and soil conditions, leading to soil compaction, nutrient decline, and decreased biodiversity (Cardelus et al., 2020).

In different parts of Ethiopia, there were undertaken different research on soil physical and chemical properties (Getachew et al., 2012; Molla et al., 2022; Cardelus et al., 2020; Tadesse, 2020). These studies focused on the impact of human disturbance on forest soils, including those in church forests. Furthermore, assessing the impacts of human disturbance, and edge effects on soils in areas like church forests, outside forest and near eucalyptus plantation is crucial for understanding soil health. However, in West Gojja zone there was no study undertaken in church forests about soil physico-chemical properties. Therefore, the present study was aimed to assess the soil physical (moisture content and bulk density) and chemical (carbon, nitrogen, and phosphorus) properties in church forests, outside forests and near eucalyptus plantations in the West Gojjam Zone, Amhara Region, Ethiopia.

5.2. Materials and Methods

5.2.1. Description of the study area

The study area was well described in chapter 1, General methodology, Section 1.4.1 of the general methodology, including a map of the study area.

5.2.2. Soil sample collection

At each church forest site, a total of six soil samples were collected, with two samples taken along each of the three gentry transect angles (60°, 180°, and 300°) extending from the forest center. This includes two samples along each of transect angles inside the church forest (n = 6), three samples from plots just outside the forest boundary aligned with the interior plots (n = 3), and, where present, three additional samples from adjacent Eucalyptus plantations (n=3).

A. Soil samples collection inside the church forest

Soil samples were collected from two plots along three gentry transects (at 60°, 180°, and 300°) extending from the forest center to the edge, with one plot in the inner zone and the other at the forest edge (Fig. 5.1). From each plot, three subsamples were taken from two subsamples from corners and one at the middle and then mixed to form a single composite sample (Fig. 5.1). A soil auger was inserted vertically, twisted, and pushed down to a depth of 10 cm.

According to Du et al. (2015), soil carbon is most concentrated in the upper 10 centimeters and declines with depth. Once the auger reached this depth, it was carefully twisted and lifted to collect the sample. This method produced six composite samples at each site, adding up to 156 samples from all the forests studied. By using this sampling design, the study achieved broad spatial coverage and captured soil variability, which improved the reliability of comparisons between different sites (Fig. 5.1). All soil samples across the 26 church forests were collected using this standardized layout of six 20 m × 20 m plots per site, arranged along three transect angles (60°, 180°, and 300°), with two plots at different distances from the forest center per transect (Table 5.1).

Table 5.1. Layout of soil sampling plots in church forests

Forest Site	**Transect Angle**	**Plot**	**Plot Size (m × m)**	**Forest zone**	**Descriptions**
Site 1	60°	T60-A	20 × 20	Inner zone	Composite of 3 subsamples =1
	60°	T60-B	20 × 20	Edge zone	Composite of 3 subsamples =1
	180°	T180-A	20 × 20	Inner zone	Composite of 3 subsamples = 1
	180°	T180-B	20 × 20	Edge zone	Composite of 3 subsamples =1
	300°	T300-A	20 × 20	Inner zone	Composite of 3 subsamples = 1
	300°	T300-B	20 × 20	Edge zone	Composite of 3 subsamples = 1

Note: T60-A, T180-B, etc. refer to sampling plots along transects extending from the forest center at 60°, 180°, and 300°, respectively. The letter "A" denotes the inner forest zone; the letter "B" denotes the edge zone. Done in similar way for all sites.

Total soil samples: 26 forest sites × 6 plots/site = 156 soil samples

Each plot includes one composite sample, created from three auger subsamples taken within the 20 × 20 m area.

B. Soil samples collection inside Eucalyptus Forest near the church forest

A total of 3 soil samples were collected using 3 plots inside of eucalyptus forest near the church forest. The samples were taken by soil auger with the same size and amount of other soil samples with 4m gap between each soil samples (Fig. 2). The samples from eucalyptus forest were collected with separate soil bags then labeled by site number as Euc-1, Euc-2 and Euc-3 respectively (Fig. 5.1).

C. Soil samples collection outside the church forest

The same methods were used for the collection of soil samples from outside the forest in non-cultivated land parallel to the church forest. A total of 3 soil samples were collected using 3 plots. Each soil samples in a plot were collected with 4m gap between samples of outside of each church forest. The samples were taken by soil auger with the same size and amount of soil as in the forest samples. The 3 outside soil samples were collected in each church forest with separate soil bags then labeled by site number as Out-1, Out-2 and Out-3 respectively (Fig. 5.1).

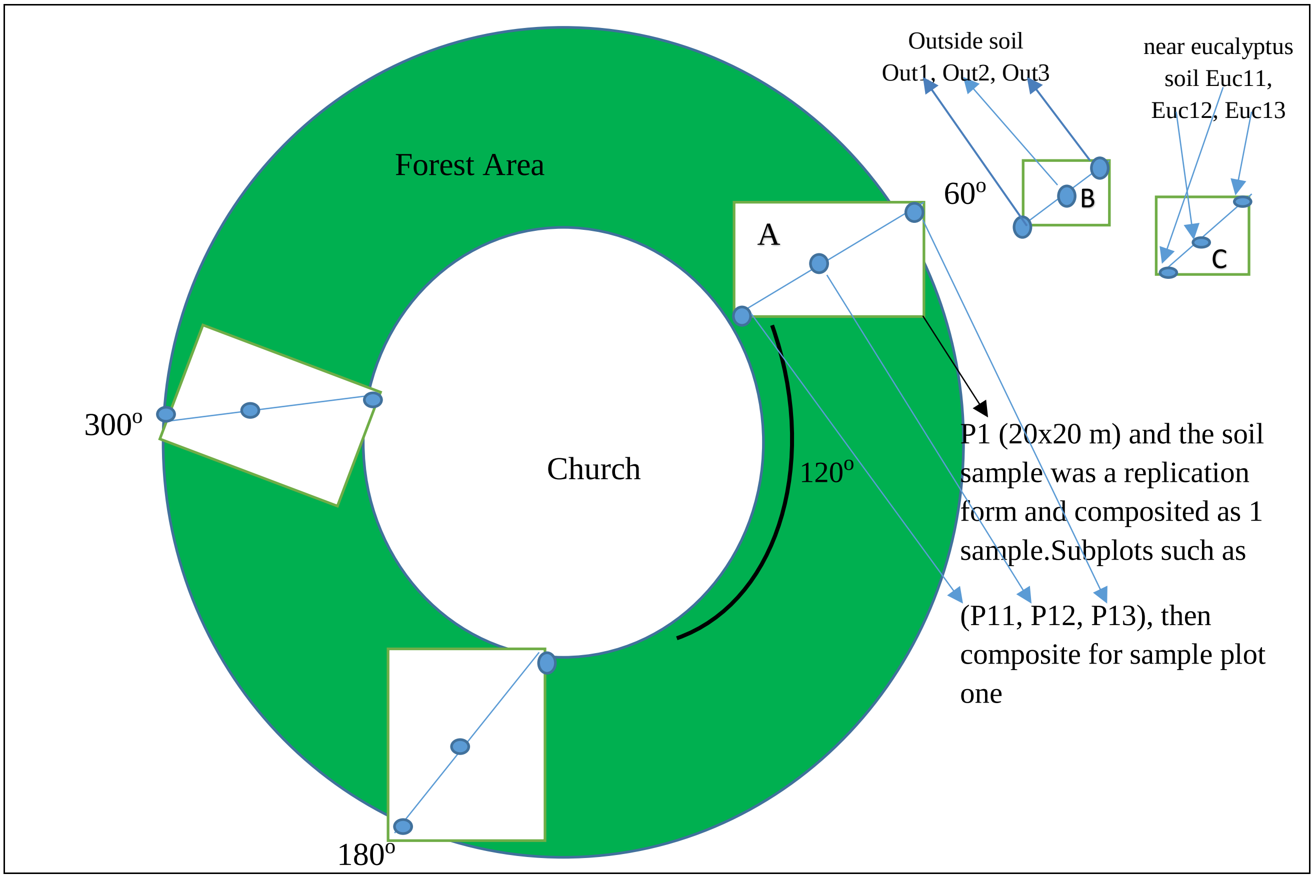


Figure 5.1. Plot arrangement during soil sample collection. (Soil samples were collected in multiple replicates to ensure accuracy and consistency). Soil sampling Plots layout for collecting soil from inside church forest (**A**), soils outside the church forest (**B**), and soils inside Eucalyptus plantation (**C**)

Figure 5.2. Photo of the researcher while collecting soil sample collection (photo taken by Abebe Ayele, 2023). A. Soil collected near eucalyptus B. Soil sample collected inside church forest

5.2.3. Soil sample preparation and nutrient analysis

The soil samples were collected from three distinct locations: inside church forests (6 samples/church forest), outside church forests (3 samples), and near eucalyptus stands (3 samples), each with three replications. Therefore, a total of 303 soil samples were collected from the study areas. The collected soil samples were air-dried and sieved through a 2 mm mesh.

to remove larger debris and aggregates while retaining the fine soil particles that are critical for accurate nutrient assessment) (Fig. 5.3). Finally, the sieved soil samples were put at Bahir Dar University, Botany graduate soil science laboratory for further nutrient analysis. The physical properties of the soil samples were determined using different methods. The bulk density of the soil sample was determined by the auger method and weighing a known volume of oven-dry soil (Fig. 5.4 A, B, C). Soil bulk density was calculated as the mass of soil per unit volume and was expressed in grams per cubic centimeter (g/cm^3).

Figure 5.3. Physical properties of the soil sample in the laboratory (determining the bulk density). A. Soil sieving. B. Measuring the weight of oven-dried soil C. Result of oven-dried soil sample measured for bulk density

Procedure for determining soil chemical properties

pH: Approximately, 10 grams of each site soil sample were weighed and shaken with 25 ml deionized water. Then, the electronic pH meter was calibrated by employing a standard buffer solution, by immersing the glass electrode in the solution and taking readings subsequently.

Organic carbon content was estimated using the wet oxidation method developed by Walkley and Black (1934). In this procedure, concentrated sulfuric acid and potassium dichromate were mixed to oxidize the soil's organic matter. The remaining (excess) dichromate was quantified through titration with ferrous sulfate, using barium diphenylamine sulfonate and orthophosphoric acid as indicators. The endpoint of the reaction was signaled by a color change to pale green. The carbon content was then calculated as a percentage of the total sample, based on the amount of dichromate consumed, which is directly proportional to the soil's organic carbon.

The percentage of soil organic carbon is calculated as follow:

$$\%\mathbf{C} = \frac{\text{N x v1} - \text{v2x0.39x Mcf}}{\text{S}}$$

Where, N = Normality of ferrous sulfate solution (from blank titration), v1 = volume of ferrous sulfate solution used for blank, ml, V2 = volume of ferrous sulfate solution used for sample, ml

S= weight of air-dry sample in gram, 0.39 = 3 x 10-3 x 100%x1.3 (3 = equivalent weight of carbon), Mcf = moisture correction factor.

Soil organic matter contains 58% C. Conversion of % carbon to % organic matter is, therefore, done with the empirical factor of 1.724, which is obtained by dividing 100 by 58 (100/58).

% Soil organic matter = 1.724 x % Carbon

The total nitrogen content of soil samples was determined using the Kjeldahl digestion and distillation method (Bremner and Mulvaney, 1982). The soil sample was air-dried, ground into a fine powder, and approximately 0.5 gram was used for analysis. It was digested with 7 ml of concentrated sulfuric acid (H_2SO_4) along with a catalytic mixture of copper sulfate and selenium powder in a Kjeldahl flask until the mixture became colorless, indicating completion of the oxidation reaction. Concentrated sulfuric acid is essential as it hydrolyzes organic matter and converts nitrogen into ammonium sulfate. After digestion, the mixture was cooled, and diluted with 50 ml of distilled water, and alkalized by adding 75 ml of 40% sodium hydroxide (NaOH). Then, Ammonia was distilled into a receiver flask containing boric acid solution (up to 100 ml).

Finally, the distillate was titrated with 0.1N sulfuric acid (H_2SO_4) using a mixed indicator (methyl red–bromocresol green). The endpoint was identified by a color change from green to pink (Fig. 5.4). The nitrogen content was calculated based on the volume of acid consumed and expressed as a percentage of total nitrogen. The percentage of the total Nitrogen was calculated as follow;

$\%\mathbf{N} = \frac{(a-b) x\ n\ x\ 0.014\ x\ 100\ x\ mcf}{s}$ Where, a = volume of H_2SO4 required for titration of sample, ml; b= volume of H_2SO4 required for titration of blank, ml; s= air dry sample weight in gram; n= Normality of H_2SO4 (0.1N)

Figure 5.4. Determination of percent total nitrogen by the Kjeldahl method. **A**. Digestion. **B**. Distillation. **C**. Result of distillation. **D**. Titration. **E**. Pink colour after titration

Available phosphorus was determined using the Bray II method. A dilute acid-fluoride solution was used to effectively extract phosphorus from the soil sample (Wuenscher et al., 2015). The Bray II extraction method is recommended for acidic soils with pH less than 7. Since the soil sample in this study had a pH below 7, this method was appropriate for determining available phosphorus. In the first step, 0.5 grams of soil was mixed with the Bray II extractant and shaken for one minute. Then, the resulting suspension was filtered using Whatman grade 1 filter paper to obtain a clear extract. The filtration was essential to separate solid particles from the liquid extract, to obtain a clean sample for analysis. The extracted samples were analyzed by using a spectrophotometer at approximately 882 nm, the wavelength of maximum absorbance for the molybdenum blue complex. These complex forms when extractable phosphorus reacts with ammonium molybdate, ascorbic acid, and sulfuric acid. Finally, the available concentration of phosphorus was calculated based on sample absorbance relative to a blank and a calibration curve prepared from known phosphorus standards.

Disturbance

Disturbance was quantified following the method described by Cardelús et al. (2019). Disturbance data were collected through systematic sampling along three Gentry transects oriented at 60°, 180°, and 300°, radiating from the center of the church toward the forest edge. Measurements were taken within 20 m × 20 m (400 m^2) plots established along these transects. Various types of disturbances were identified and recorded in these plots, including clearing, logging, trails, graves, and grazing grounds within the church forest (Ayele et al., 2024). The percentage of disturbance was then calculated for each church forest as follows:

$$\%\ \text{area covered by disturbance} = \frac{\text{Area covered by category inside plot}}{\text{Area of plot}} * 100$$

5.2.4. Statistical analysis

ANOVA was used to compare three different land cover types (within church forest, outside church forest, and eucalyptus plantations) at each site of church forest to determine whether there were statistically significant differences in soil physical and chemical properties. Linear regression analysis was used to examine the influence of church forest variables (disturbance, elevation, population size, and proximity) on soil chemical and physical properties. Tukey's HSD post hoc test was also used to separate means at a significance level of $p = 0.05$. In addition, C : N and N:P ratios were calculated, as these soil nutrient ratios provide insights into nutrient balance and cycling, as well as broader ecological processes and interactions (Ma et al., 2020). Ratios such as C: N, C: P and N: P were used to assess nutrient availability, organic matter decomposition rates, and potential nutrient limitations among different land cover categories.

The following nutrient ratios were calculated:

$$\mathbf{C:N\ Ratio} = \frac{\mathbf{\%Carbon}}{\mathbf{\%Nitrogen}}$$

$$\mathbf{N:C\ Ratio} = \frac{\mathbf{\%Nitrogen}}{\mathbf{\%Carbon}}$$

$$\mathbf{C:P\ (ppm)\ Ratio} = \frac{\mathbf{\%Carbon}}{\mathbf{P\ (ppm)}}$$

$$\mathbf{N:P\ (ppm)\ Ratio} = \frac{\mathbf{\%Nitrogen}}{\mathbf{P\ (ppm)}}$$

5.3. Results and Discussion

5.3.1. Soil physical properties across land cover types and edges

5.3.1.1. Soil Physical Properties across land cover types

The present study showed a notable difference in soil porosity, bulk density, and soil moisture among different land cover types. Church forest had highest water content (42.98 ± 4.43%) compared to outside the church forest (31.47 ± 2.56%). The eucalyptus plantation had the lowest water content (28.34 ± 3.011%) when compared to church forest and outside. The highest value in church forest might be a canopy cover and organic matter content in the forest, which allow for maximum infiltration of moisture and minimum evaporation. These results were consistent with other findings confirmed that forests are better, and able to maintain moisture levels, hence sustaining plant organisms and microorganisms in the long term (Ozkan and Gokbulak, 2017; Ni et al., 2019). In addition, forest areas receive more relative humidity than outside forest areas because trees capture rain, slow down water runoff and mainatin soil moisture by their root structure (Ren et al., 2020). The higher soil moisture level of the forest ecosystem implies a higher relative humidity level when compared to non-forested area. This concept was aligh with Alavi (2022), soil moisture is a common influential factor, especially during hot and dry weather, and is a forest growth and productivity limiter.

The church forest had highest porosity (16.08 ± 1.09%) than other cover types. This is ability of forest canopy cover, and well-defined root structures that resist soil compaction and contributing pore space (Pagliai et al., 2004; Briliawan et al., 2022). On the other hand, the lower porosity was recoded at the outside of the forest (10.79 ± 4.25%). This is also due to a notable level of various human disturbances. This result is consistent with Admasu et al. (2020) and Hu et al. (2021), who revealed that a large proportion of human activities, such as grazing and agriculture, contribute to soil compaction and expose elements of the landscape to rain erosion. Similarly, the porosity of soil under eucalyptus planation showed lower (10.97 ± 6.29%) due potentially to inhibitory allelochemicals from eucalyptus that limit the understory vegetation, restricting the levels of organic matter, and restricting root growth, both of which are important for the development of deeper, structured, and porous soil (Alem et al., 2010; Leite et al., 2010).

Church forests had highest bulk density (0.59 ± 0.16 g/cm³) than other cover types. This result aligned with healthier and less compact soil, developed by more effective vegetation cover and minimal human disturbance conducive to organic matter deposition and enhancing soil aggregation (Bhandari and Bam, 2014). Higher bulk density can imply soil compaction, which is not beneficial for aeration and water infiltration, and lower bulk density typically implies a perfect structure of the soil. Human activities on soil may affect soil structure, and leading to reduce bulk density (Kumar et al., 2020). The highest bulk density was recorded from outside the church forest (0.72 ± 0.11 g/cm³). This is due to outside the forest; human disturbances such as grazing and agriculture disrupt the structure of soil, resulting in reduced pore space. This agreed with Tadesse (2020), revealed that church forests had a lower bulk density compared to outside forest. However, the BD in eucalyptus plantations were an intermediate value (0.60 ± 0.25 g/cm³). This is a a result of low decomposition rate of eucalyptus litter and low understory plant cover, both of which discourage soil aeration and disruption of organic matter (Gil et al., 2010). In general, church forest soils are less compact, with lower bulk density and better water retention, while eucalyptus plantations and lands outside church forests show higher soil compaction and degraded conditions due to greater bulk density and lower porosity (Yitaferu et al., 2013; Getachew et al., 2012; Yimam et al., 2024; Vigo et al., 2024; Salazar et al., 2024).

Pearson correlation analysis revealed that there was a high degree of correlation between bulk density (BD), water content (WC), and soil porosity (Table 5.2). There was an extremely high correlation between WC and porosity ($r = 0.818$, $p < 0.01$), while BD was negatively correlated with WC ($r = -0.246$, $p < 0.05$) and porosity ($r = -0.322$, $p < 0.01$). These findings consistent with Shaheb et al. (2021) and Fattani et al. (2021), confirm that increased porosity increases the water retention and, conversely, decreased pore space decreases maximum bulk density.

Table 5.2. Pearson correlation matrix for Water Content (WC), soil porosity, and Bulk Density (BD) among different land cover types

Correlations		Different soil physical properties		
		GWC (%)	Soil porosity (%)	Bulk denity (BD)
GWC (%)	Pearson Correlation	1	.818**	-.246*
	Sig. (2-tailed)		0.000	0.030
Soil porosity (%)	Pearson Correlation	.818**	1	-.322**
	Sig. (2-tailed)	0.000		0.004
Bulk density (BD)	Pearson Correlation	-.246*	-.322**	1
	Sig. (2-tailed)	0.030	0.004	

Note: ** correlation is significant at 0.01 level (2-tailed); *correlation is significant at 0.05 level (2-tailed)

5.3.1.2. Edge effects on soil physical properties

Bulk density

The bulk density at the forest edge (0.58 ± 0.027 g/cm³) was slightly higher than in the interior (0.57 ± 0.038 g/cm³), indicating a minor increase in soil compaction at the edges (Table 5.3; Fig. 5.5A). The variation in standard deviations reflects differences in land use and site management. These differences in bulk densities may a result of human disturbance that existed in these areas (Mariotti et al., 2020). Even slight increases in bulk density can reduce water infiltration and aeration in the soil, limiting root growth and negatively affecting plant health (Lyu et al., 2021). To reduce edge-related compaction, conservation measures like establishing buffer zones should be prioritized Alignier & Deconchat, 2013; Razafindratsima et al., 2017; Hending et al., 2023).

Water Content

The water content in the church forest and its edges was nearly comparable, with values close to those retained in the forest interior (41.35% ± 3.6%) and at the boundary (41.38% ± 3.8%) (Table 5.3; Fig. 5.5B). However, at the forest edge, the water content does not fully resemble that of the inner church forest, which can affect plant regeneration and biomass accumulation due to climate-induced stress (Zhu et al., 2023). Ni et al. (2019) observed that during summer, soils under vegetation may retain up to 50% less water because of high evapotranspiration, whereas in autumn, moisture content can increase by up to 70% due to reduced transpiration and lower root water uptake. Reforestation and afforestation enhance soil water retention, mitigate edge effects, and promote sustained church forest growth and resilience.

Soil Porosity

Church interior had highest porosity (16.58% ± 1.14%) than at the edge (15.88% ± 1.07%) (Table 5.3; Fig. 5.5C). This result consistent with (Sekucia et al., 2020), better root development and water-retaining conditions at interior of the church forest. Reduced porosity at the edge may affect plant competition and diversity (Ruwanza, 2019). Encouragement of soil porosity by reforestation and reduced edge exposure can support ecosystem resilience (Fahad et al., 2022; Takele et al., 2022).

Table 5.3. Descriptive statistics of soil physical properties in the forest interior and edge of 26 church forests

Soil Property	Edge effects	Mean ± Std.Error	95% CI for Mean	Range	IQR
Bulk Density (%)	Forest Interior	0.57 ± 0.038	0.49 – 0.65	0.19 – 0.96	0.31
	Edge	0.58 ± 0.027	0.52 – 0.63	0.30 – 0.84	0.22
Water Content (%)	Forest Interior	41.35 ± 3.6	33.93 – 48.78	14.60 – 74.60	36.21
	Edge	41.38 ± 3.8	33.59 – 49.16	6.60 – 73.00	33.6
Soil Porosity (%)	Forest Interior	16.58 ± 1.14	14.21 – 18.94	7.47 – 25.80	11.56
	Edge	15.88 ± 1.07	13.67 – 18.09	5.6 – 26.5	7.79

Note: SD = standard deviation, CI = Confidence Interval, IQR = interquartile range

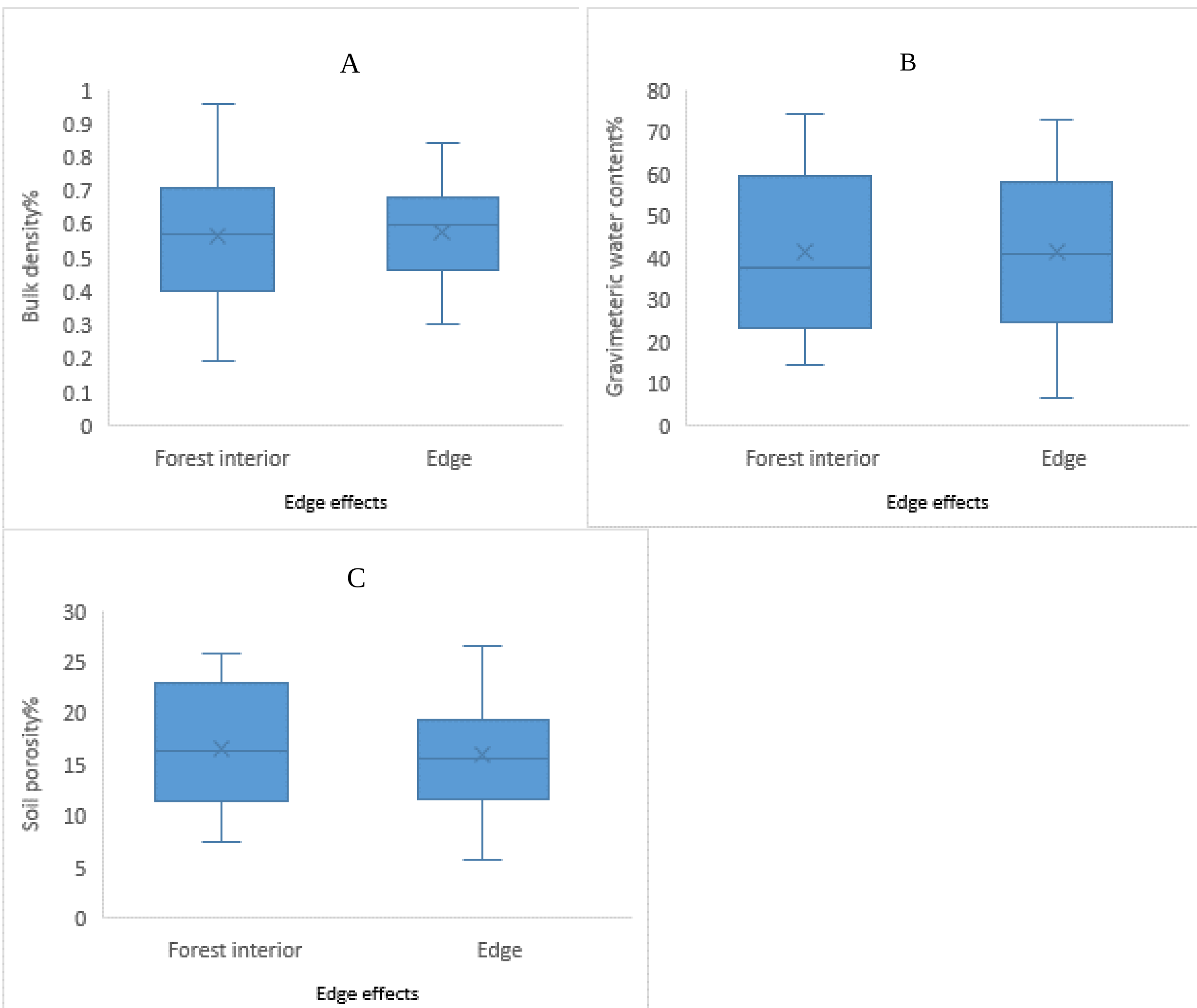


Figure 5.5. Box plots of soil physical properties in forest interiors and edges

5.3.2. Soil chemical properties across different land cover types and edges

5.3.2.1. Soil chemical properties across land cover types

The chemical properties of soil nutrients varied across different land cover types. The present study showed that church forests had the highest soil organic carbon (SOC) averaging (57.22% ± 3.94%) (Tables 5.4 and 5.5), reflecting greater organic matter accumulation due to dense vegetation and minimal disturbance. In contrast, soils outside church forests had notably lower carbon content, averaging (40.61% ± 3.5%). However, eucalyptus plantations had the lowest SOC levels (36.27% ± 27.26%). This result align with (Demessie et al., 2012; Yitaferu et al., 2013; Kabir et al., 2023; Garrett et al., 2024), revealed that that high nutrient and water uptake of eucalyptus trees and slower decomposition of their leaf litter, which limits organic matter return to the soil. In addition, the the statistical analysis of ANOVA confirmed these differences as significant ($F = 6.512$, $p = 0.002$), with church forests having significantly higher carbon content compared to both outside areas (mean difference = 16.61, $p = 0.022$) and eucalyptus plantations (mean difference = 20.95, $p = 0.003$). Similarly, soil organic matter (SOM) was highest in church forests (0.99 ± 0.07), intermediate outside forest areas (0.70 ± 0.06), and lowest in eucalyptus plantations (0.63 ± 0.09) (Fig. 5.6). Therefore, church forests are playing an important role in preserving soil quality through stable microclimatic conditions and reduced biomass removal, supporting previous findings on the superior nutrient content and carbon sequestration capacity of natural forests (Mengistu and Dereje, 2021; Asmare et al., 2023; Molla et al., 2022; Tebkew et al., 2024).

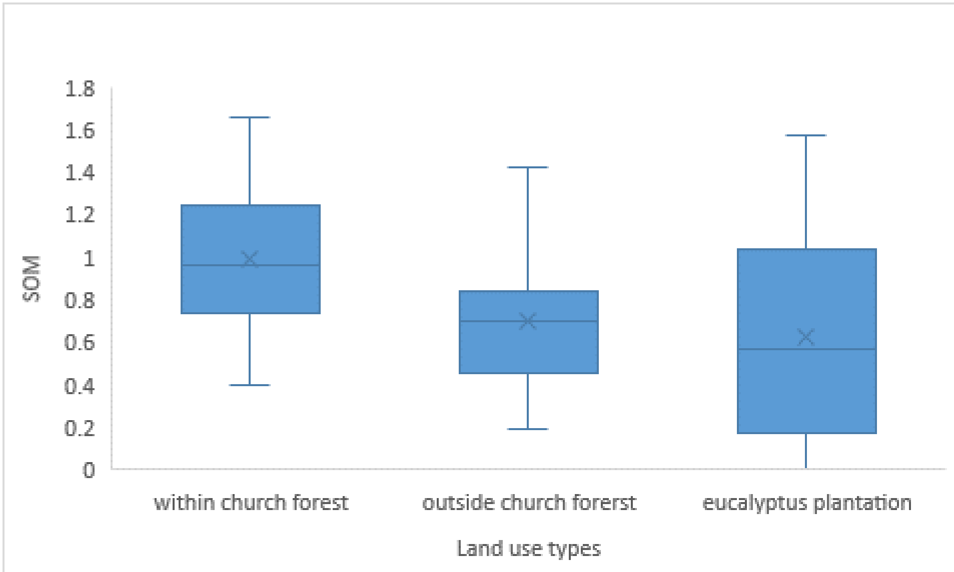


Figure 5.6. Distribution of soil organic matter (SOM) across land cover types (church forests, outside forests, and eucalyptus plantations). Description: The boxplot illustrated distinct Soil Organic Matter (SOM) distributions in three land cover types: church forestshad highest and most consistent SOM values (narrow IQR, few outliers), outside church forests had low values with narrow variability, and eucalyptus plantations lowest and most variable SOM concentrations (wide IQR).

PH

ANOVA results ($F = 7.240$, $p = 0.001$) indicated that soil pH differed significantly in eucalyptus plantations and the adjacent landscapes (Tables 5.4 and 5.5). In contrast, there was no significant difference of pH inside church forests (mean difference = 0.10, $p = 0.948$), and it suggests that forest cover has a buffer effect on soil chemistry. Soils around eucalyptus plantations were lowest in mean pH (4.95 ± 1.86) and significantly more acidic than outside church forests (mean difference = 1.09, $p = 0.003$) and inside church forests (mean difference = 1.00, $p = 0.007$). The quick nutrient removal, slow litter decomposition, acidic root exudates, and high base cation uptake such as calcium and magnesium, which increases H^{+} and Al^{3+} ion concentrations, can be a reason for the sudden pH drop in eucalyptus (Zhang and Fu, 2009; Soumare et al., 2014; Molla et al., 2022; Yimam et al., 2024; Vigo et al., 2024). This confirms earlier studies in northern Ethiopia where soil under eucalyptus was more acidic than soil in or outside church forests (Liang et al., 2016; Yitaferu, 2011). Eucalyptus litter decomposition acidifies the soil through the release of organic acids during decay (Yitaferu et al., 2013).

Total Nitrogen

The present study showed a notable difference in soil nitrogen levels across different cover types ($P < 0.001$) (Tables 5.4 and 5.5). Church forests (0.56%) and areas outside the church forests (0.55%) had similar nitrogen content. However, eucalyptus plantations revealed notably lower nitrogen levels (0.30%). This variation is a result of eucalyptus-dominated land covers taking high nitrogen depletion when compared to other land cover types. These findings are consistent with Liang et al. (2016), who reported higher nitrogen levels in natural sacred forests than in eucalyptus plantations in northern Ethiopia. Reduced soil fertility under eucalyptus is attributed to allelopathic compounds such as phenolic acids, flavonoids, and tannins that suppress plant growth, microbial activity, and litter decomposition (Chapuis et al., 2002). This disruption of nutrient flow allows nitrogen and phosphorus to become limiting factors. Moreover, the eucalyptus tree needs more water, resulting in depleting soil resources. Their N-poor, lignin-rich litter decomposes at a slow rate, further reducing nitrogen return to the soil (Demessie et al., 2012). Higher nitrogen levels in church forest soils reflect greater fertility, whereas lower nitrogen under eucalyptus plantations suggests reduced soil quality, potentially limiting native plant diversity. This aligns with Gaya and Aldrich (2017) and Abebe et al. (2020), who found that native forests and fertilized plantations generally exhibit higher nitrogen due to complex plant–microbe interactions and nutrient inputs. Restoring native vegetation may therefore improve soil health and support ecosystem balance.

Available Phosphorus

The availability of phosphorus (ppm) was examined across three land cover types: within church forests, outside church forests, and eucalyptus plantations. ANOVA revealed a highly significant effect on phosphorus content (Tables 5.4 and 5.5). The F-statistic of 17.461 and a p-value of < 0.001 showed that phosphorus availability varied significantly among the three land cover types: church forest, outside forest, and eucalyptus. Descriptive statistics indicated that the highest mean concentration of phosphorus was found inside the church forest (0.0445 ppm) and outside the church forest (0.0148 ppm), while the lowest concentration was near the eucalyptus plantation (0.0055 ppm) (Tables 5.4 and 5.5).

The highest phosphorus concentration was recorded inside the church forest, while eucalyptus plantations exhibited extremely low concentrations. These findings suggest that different land cover types and vegetation influence phosphorus availability in the soil by altering soil properties, organic matter composition, and nutrient cycling. Consistent with the present results, higher phosphorus levels have been reported in church forests compared to eucalyptus plantations and outside forests (Liang et al., 2016). This is likely due to the efficient root systems of eucalyptus trees, which are capable of rapidly absorbing large quantities of phosphorus from the soil, thereby depleting the nutrient and making it less available to other vegetation (Foltran et al., 2019). As a result, eucalyptus plantations tend to have lower phosphorus levels compared to native forests. Moreover, the more diverse and fertile soils beneath natural forests facilitate greater phosphorus sequestration, which further increases the gradient of phosphorus concentration between the two cover types (Yu et al., 2021).

Table 5.4. Results of a one-way analysis of variance (ANOVA) of soil chemical properties in the 26 church forests in west Gojjam zone

Variable	Source of variation	Sum of Squares	Df	Mean Square	F	Pvalue
Carbon	Between Groups	6359.008	2	3179.504	6.512	.002
	Within Groups	36618.544	75	488.247		
	Total	42977.552	77			
SOM	Between Groups	1.89	2	.945	6.512	.002
	Within Groups	10.8	75	.145		
	Total	12.7	77			
PH	Between Groups	19.043	2	9.521	7.240	.001
	Within Groups	98.636	75	1.315		
	Total	117.678	77			
Nitrogen	Between Groups	4.992	2	2.496	22.431	<.001
	Within Groups	8.123	73	.111		
	Total	13.114	75			
P (Ppm)	Between Groups	.022	2	.011	17.461	<.001
	Within Groups	.046	75	.001		
	Total	.068	77			

Table 5.5. Tukey HSD Post-Hoc test results showing mean differences (± SE), p-values, and significance levels for soil chemical properties across different land cover types

Variable	Land cover types	Mean ± SE	SignificantMean Differences of land cover types ± SE	P Valu	Sig.
Carbon (%C)	Within Church Forest	57.22 ± 3.94	Inside vs. Outside Forest: 16.61 ± 6.13	0.022	Sig.
	Outside Forest	40.61 ± 3.50	Inside vs. Near Eucalyptus: 20.95 ± 6.13	0.003	Sig.
	Eucalyptus Plantation	36.27 ± 5.35	Outside vs. Near Eucalyptus: 4.34 ± 6.13	0.759	Not Sig.
SOM (%SOM)	Within Church Forest	0.99 ± 0.07	Inside vs. Outside Forest: 0.28 ± 0.10	0.022	Sig.
	Outside Forest	0.70 ± 0.06	Inside vs. Near Eucalyptus: 0.28 ± 0.10	0.759	Not Sig.
	Eucalyptus Plantation	0.63 ± 0.09	Outside vs. Near Eucalyptus: 0.36 ± 0.10	0.759	Not Sig.
pH	Within Church Forest	6.04 ± 0.10	Inside vs. Outside Forest: 0.10 ± 0.32	0.948	Not Sig.
	Outside Forest	5.94 ± 0.10	Inside vs. Near Eucalyptus: 1.09 ± 0.32	0.003	Sig.
	Eucalyptus Plantation	4.95 ± 0.36	Outside vs. Near Eucalyptus: 0.99 ± 0.32	0.007	Sig.
Nitrogen (%N)	Within Church Forest	0.56 ± 0.05	Inside vs. Outside Forest: 0.33 ± 0.09	0.002	Sig.
	Outside Forest	0.55 ± 0.07	Inside vs. Near Eucalyptus: 0.63 ± 0.09	<0.001	Sig.
	Eucalyptus Plantation	0.30 ± 0.04	Outside vs. Near Eucalyptus: 0.31 ± 0.09	0.005	Sig.
Phosphorus (P ppm)	Within Church Forest	0.0445 ± 0.007	Inside vs. Outside Forest: 0.03 ± 0.007	<0.001	Sig.
	Outside Forest	0.0148 ± 0.003	Inside vs. Near Eucalyptus: 0.039 ± 0.007	<0.001	Sig.
	Eucalyptus Plantation	0.0055 ± 0.001	Outside vs. Near Eucalyptus: 0.009 ± 0.007	0.37	Not Sig.

Notes: Mean differences are reported as Mean ± SE (Standard Error). A p-value < 0.05 indicates statistical significance. Sig. = Significant. Not Sig. = Not Significant. The mean difference is significant at the 0.05 level.

The PCA biplot (Fig. 5.7) provides a detailed overview of the physical and chemical properties of soil across 26 church forests with three land cover types: within church forests, outside church forests, and eucalyptus plantations. The first principal component (PC1) accounts for 45.9% of the variance and is primarily influenced by pH, carbon, and phosphorus levels, which are more concentrated in church forest soils.

These soils are thus richer and more fertile compared to those in eucalyptus plantations and outside areas. Bulk density and soil porosity show an inverse correlation with PC1, indicating that they are more prevalent in eucalyptus and external areas. This is likely due to soil compaction and lower organic matter in these locations. PC2, which explains 21.1% of the variance, is associated with soil water content and porosity. Church forest soils are wetter and more porous, conditions that promote nutrient cycling and microbial diversity.

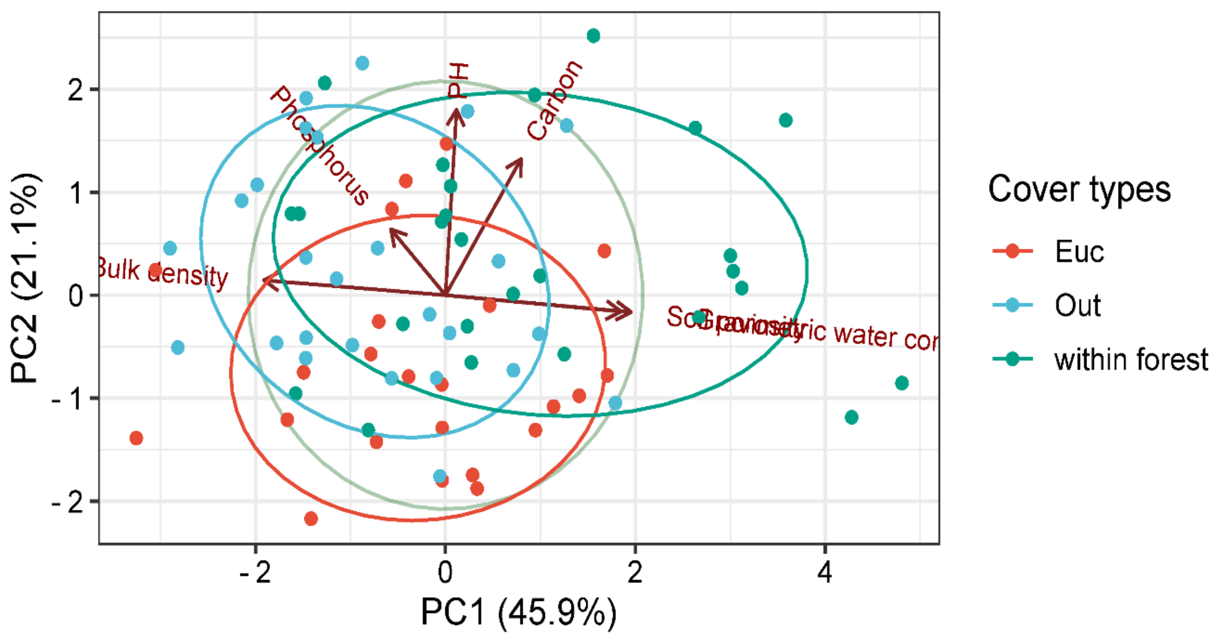


Figure 5.7. Principal Component Analysis (PCA) of soil properties across different land cover types

Edge effects on soil chemical properties

The present study showed that edges had effects on forest soil's chemical properties when compared to the interior of the church forest. At the edge, the soil chemical properties, such as total nitrogen, available phosphorus, and organic carbon, were decreased. This result is consistent with other findings (Tolessa and Senbeta, 2018; Cardelus et al., 2019; Song et al., 2019). Moreover, understory shrub density in the interior of the forest deposits continuous organic matter into the ground, which supports the structure of the soil and sequesters nutrients, while the reliable microclimate promotes microbial activity and nutrient cycling (Chen et al., 2024). Soil carbon, pH, and nitrogen levels exhibit equivalent patterns at the edge and interior, the edge is more variable, particularly in carbon and phosphorus concentration (Fig. 5.8A, 5.8D).

Nitrogen and pH levels are relatively constant with equivalent distribution in each zone (Fig. 5.8B, 5.8C). These edge effects are a source of nutrient loss, low microbial activity, erosion, and vegetation changes with drastic threats to forest health and biodiversity. In extreme cases, they lead to habitat fragmentation. Mitigation strategies such as the establishment of buffer zones, afforestation of degraded edges, utilization of sustainable agriculture, and involving local communities in forest management are central to preserving the ecological integrity of such sacred forests (Cardelus et al., 2019; Tolessa and Senbeta, 2018; Song et al., 2019; Chen et al., 2024).

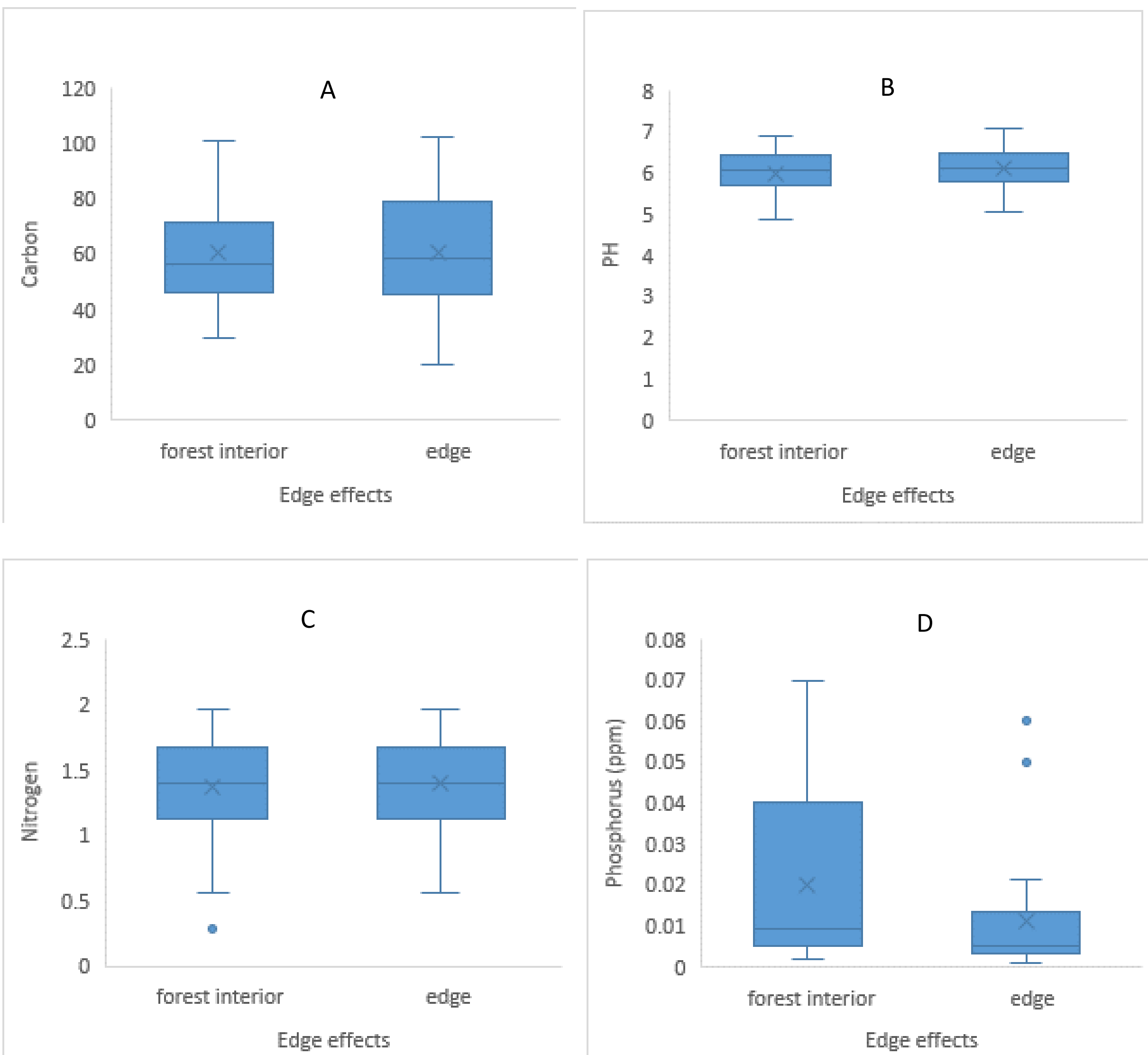


Figure 5.8. Boxplots of soil chemical properties of edge effects in the church forest interior and edges

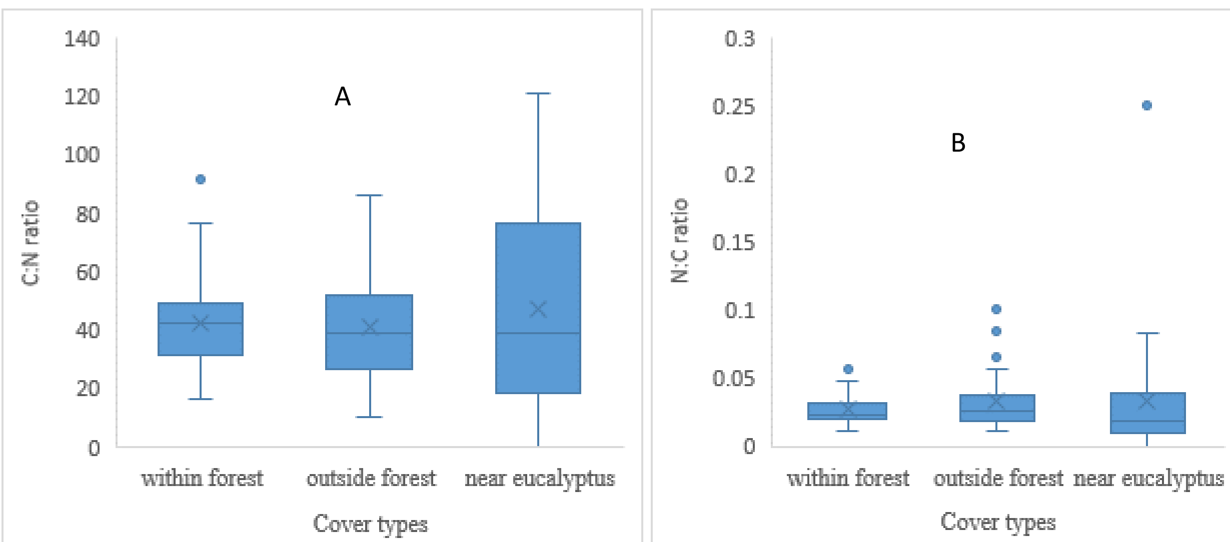
Soil Carbon, Nitrogen, and Phosphorus Ratios

The study concerning soil carbon, nitrogen, and phosphorus ratios (C: N: P ratio) in forest soils is necessary to assess nutrient cycling, productivity of the ecosystems, and fertilizers. These ratios also indicate microbial activity and limitations, guiding sustainable forest management and conservation practices. The descriptive statistics for ratios of soil nutrients C: N, N: C, C: P and N: P were compared among three land cover types: church forest, outside forest, and eucalyptus plantations. Although the C: N and N: C ratios among sites are not significantly different (ANOVA: $p = 0.666$ and $p = 0.806$, respectively (Table 5.6; Fig. 5.9 B), boxplot also revealed that church forest had low and uniform variability, whereas along eucalyptus sites had high variability. This is likely because litter of eucalyptus has a higher C: N ratio (Fig. 5.9 A) and more lignin, which slows down decomposition and alters nutrient availability (Castro-Díez et al., 2011; Briones and Ineson, 1996; Ostrowska and Porębska, 2015).

On the other hand, post hoc analysis indicated C:P and N:P ratios significantly varied between land cover types (ANOVA: $p = 0.020$ and $p = 0.002$, respectively), with the highest values recorded near eucalyptus plants, which reflect disturbed nutrient dynamics influenced by the presence of eucalyptus (Vigo et al., 2024; Cui et al., 2023). These are a consequence of low pH and limited nutrient supply caused by reduced litter quality and unequal decomposition patterns. Boxplot comparisons (Fig. 5.9 C) also showed that C:P is lowest and most uniform in forest stands, while it is highest and most variable outside the forest and under eucalypts, perhaps due to outliers or exceptional soil conditions. Alternatively, N: P ratios are considerably lower within the forest but higher outside the forest and near eucalyptus (Fig, 5.9 D); this may be due to high phosphorus requirements of eucalyptus trees and extensive root systems that drain nearby pools of nutrients (Cui et al., 2023). Eucalyptus plantations significantly affect native forests by reducing understory plant species richness, altering nutrient cycling, and disrupting nitrogen-to-phosphorus (N:P) ratios. These plantations deplete soil nitrogen and phosphorus levels, leading to ecosystem imbalances (Maquere et al., 2008; Pulrolnik et al., 2009; Gougoulias et al., 2014; McMahon et al., 2019). Such nutrient shifts underscore the ecological impact of invasive eucalyptus species on soil fertility and the health and diversity of adjacent native forest ecosystems.

Table 5.6. One-way ANOVA results for soil chemical properties of nutrient ratios in 26 church forests of West Gojjam Zone

Nutrient ratio		Sum of Squares	Df	Mean Square	F	Sig. (p value)
C:N ratio	Between Groups	570.172	2	285.086	.409	.666
	Within Groups	52247.774	75	696.637		
	Total	52817.945	77			
N:C ratio	Between Groups	.000	2	.000	.216	.806
	Within Groups	.075	75	.001		
	Total	.075	77			
C:P ratio	Between Groups	1014202619.44	2	507101309.	4.11	.020
	Within Groups	9249433776.50	75	123325783.		
	Total	10263636395.9	77			
N:P ratio	Between Groups	317628.232	2	158814.116	6.663	.002
	Within Groups	1787522.721	75	23833.636		
	Total	2105150.953	77			



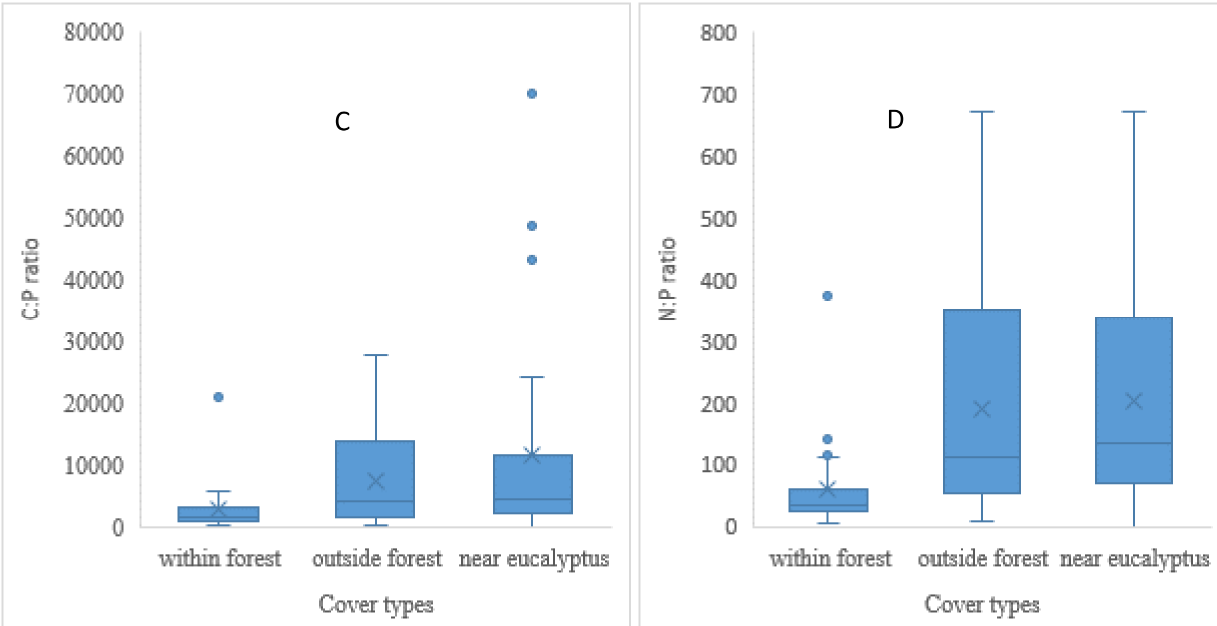


Figure 5.9. Soil nutrient ratio influences across different cover types

Factors affecting soil nutrient status

The disturbance data was gathered from church forests during vegetation surveys to assess its impact on these unique ecosystems. The overall mean disturbance in the study church forests was 24.35%. The chemical properties of the soil are also substantially influenced by disturbance, particularly phosphate concentration. This is evidenced by the regression model Y = 0.4319 - 0.04736X, indicating a negative association between disturbance and phosphorus, since the greater the disturbance, the less the availability of phosphorus (Fig. 5.10). Several factors play a role in this connection, including soil erosion, nutrient leaching, altered microbial activity, and nutrient immobilization, which together account for approximately 30.1% of the variation in phosphorus levels, as reflected in R^2 value of 0.301. Additionally, the statistically significant p-value of 0.0037 indicated that the observed correlation is unlikely to be a result of random chance. Although disturbance can alter soil structure and microbial communities for nutrient cycling, other factors such as elevation, temperature, distance, plot size, and physical barriers appear to have a limited impact on phosphorus dynamics and other nutrients in this scenario. The present findings contrast from those of Cardelús et al. (2019), who concluded that the disturbance had no significant effect on the physical and chemical properties.

It means if disturbances do not significantly affect the properties, the implication is that the effects of disturbance on forest dynamics could vary, suggesting that factors such as forest type and stand density exibit greater control on soil processes than disturbances alone (Cardelus et al. 2019). However, the present study showed disturbances notably affected the physical and chemical properties, while the size, wall, and distance of the forest did not show an impact. Ultimately, the effects of disturbance on phosphorus showed its importance for ecosystem health and nutrient cycling, highlighting the importance of effective land management strategies to prevent further loss and uphold soil fertility.

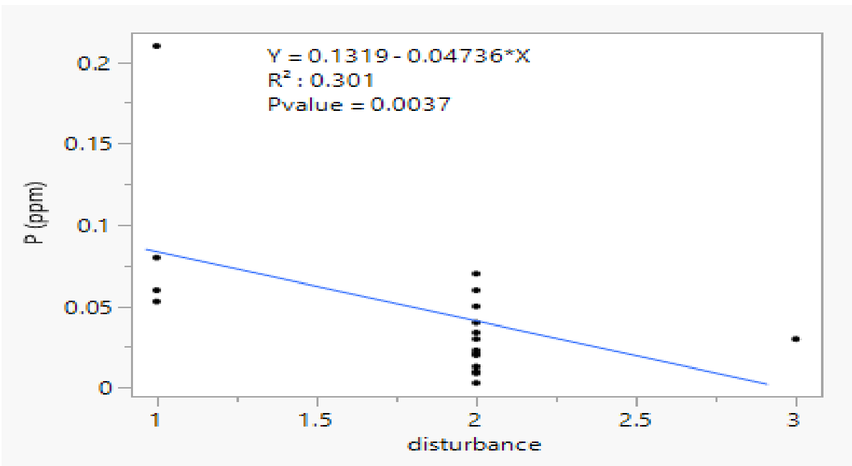


Figure 5.10. The relationship of disturbance versus phosphorus level inside church forest

5.4. Conclusion

This study revealed that church forests maintain superior soil physical and chemical properties compared to adjacent areas and eucalyptus plantations. Higher moisture content, porosity, organic carbon, nitrogen, and phosphorus levels in church forests highlight their ecological role in preserving soil fertility and ecosystem health. Conversely, soils outside forests and under eucalyptus plantations showed higher bulk density, lower nutrient availability, and increased acidity, reflecting degradation from human disturbance and exotic species. Edge effects further reduced nutrient levels and soil structure quality. Therefore, conservation and restoration of church forests are vital for sustaining soil productivity, biodiversity, and carbon sequestration. Management strategies such as buffer-zone establishment, community-based protection, and replacement of exotic plantations with indigenous species are recommended to ensure long-term ecological stability.

CHAPTER 6. Ethnobotanical study of the traditional use of medicinal plants used for treating human diseases in selected districts of West Gojjam zone, Amhara Region, Ethiopia

Abebe Ayele[1and2]*, Ali seid[1], Amare B. Mekonnen[1], Wubetie Adnew[1], Getahun Yemata[1]

[1]Department of Biology, Science College, Bahir Dar University, P.O. Box 79, Bahir Dar, Ethiopia

[2]Department of Biology, College of Natural and Computational Sciences, Debre Birhan University, P. O. Box 445, Debre Birhan, Ethiopia

*Corresponding author: Abebe Ayele, a PhD student at Bahir Dar University, Department of Biology, Science College, Bahir Dar, Ethiopia. Tel: +251928383044, email: abebeayele230@dbu.edu.et

*** abebeayele230@dbu.edu.et**

This chapter is published in Phytomedicine Plus, 4(3), 100776

https://doi.org/10.1016/j.phyplu.2024.100620

ABSTRACT

Historically, Ethiopians have relied on medicinal plants to heal a wide range of human diseases. However, indigenous knowledge associated with medicinal plants has been lost due to the secrecy of the knowledge transfer system and several anthropogenic factors. Therefore, documentation is crucial before this knowledge disappears entirely. In this context, the present study aimed to document the ethnobotanical knowledge of medicinal plants in three districts (Sekela, Dembecha, and South Achefer) in the West Gojjam Zone, Amhara Regional State. Ethnobotanical data were collected between November 28, 2021, to December 22, 2022 using a semi-structured questionnaire, a focus group discussion, and field observations. Data were gathered from 30 key informants and 399 general informants. Key informants and general informants were selected by purposively and random sampling method, respectively. Descriptive statistics and ranking analyzing methods was used to analyze the data. During the process of data analysis, we pooled data from three districts into a single dataset.Combining data from three districts into one analysis gives a broader view of the traditional knowledge and practices in the districts. A total of 97 medicinal plants were documented from the study areas. Fabaceae was the dominat family followed by the Asteraceae. Herb was the most frequent plant habit. Leaves were the most used plant parts for preparation of remedies. The most common method of preparation for remedies was crushing. Most of the remdies were taken orally. *Calpurnia aurea* was the most highly ranked plant for treating diarrhea, followed by *Rumex nepalensis*. *Olea europaea subsp. cuspidata* was the most important multipurpose plant species and found under high pressure. The decline of medicinal plants in the study areas was mainly caused by agricultural expansion and charcoal production. As a result, herbalists now must gather remedies from forests and remote places. This study highlights the important role of local knowledge and biodiversity by documenting the use of medicinal plants in the Sekela, Dembecha, and South Achefer districts. To keep the sustainability of these medicnal plants conservation efforts are needed and support traditional medicine.

Keywords: Ethnobotany, Key informants, Medicinal plants, indigenous knowledge, West Gojjam Zone

6.1. Introduction

The connection between humanity and nature in the pursuit of healing is deep-rooted, tracing the journey of medicinal plant usage from ancient times to modern pharmacotherapy (Petrovska, 2012). It traces the evolution of our understanding of these natural remedies over the years, highlighting the rich history and enduring significance of plant-based medicines that have been utilized for millennia. Ethiopia, a country with an abundance of cultural past and diverse plant life, has a long history of using traditional medicine to treat numerous health issues (Abera, 2014). Ethiopia is one of the most plant-rich countries in Africa where about 60% of the plants are said to be indigenous and most with healing potential (Dest et al., 1996). This technique has deep roots throughout the country's numerous ethnic groups, who hold a wealth of knowledge regarding ancient healing procedures (Alemu et al., 2024). Ethiopian folk medicinal plants are *Hagenia abyssinica* in the management of parasitic worms (Tesfaye et al., 2022), *Moringa stenopetala* in nutrition (Tesfaye et al., 2022) and *Allium sativum* for cold (Moges and Moges, 2020). Therefore, ethnobotanical studies on medicinal plants are crucial in addressing contemporary challenges such as emerging diseases as well as concerns about the safety and effectiveness of man-made drugs (Fabricant et al., 2001). In addition, the search for new molecules has progressed such that ethnopharmacognosy and ethnobotany are now leading chemists to explore various sources and classes of compounds (Gurib-Fakim, 2006). Because of this, ethnobotanical studies of medicinal plants are very important for tackling current issues like new diseases and concerns about the safety and effectiveness of synthetic drugs (Fabricant et al., 2001). Also, the search for new compounds has changed, with ethnobotany and ethnopharmacognosy now guiding chemists to explore different sources and types of compounds (Gurib-Fakim, 2006).

Ethiopia, with its high biodiversity and long tradition of traditional medicine, offers good soil for different ethnobotanical research (Ayalew et al., 2022). Ethnobotanical research on medicinal plants in different districts of Ethiopia has been carried out, such as in Abaya (Bekele and Reddy, 2015), Ada'a (Kefalew et al., 2015), Chilga (Mekuanent et al., 2015), Ganta Afeshum (Kidane et al., 2018), Gera (Gonfa et al., 2020), Sheka (Kassa et al., 2020), and Seharti Samre (Araya et al., 2015). The findings contribute to the understanding of medicinal plants in Ethiopia.

Giday et al. (2009) conducted integrated ethnobotanical and scientific investigations among the Bench Maji people to bridge the gap between traditional knowledge and modern research on antioxidant activity. These interesting approaches characterized the immense scope and complexity of the Ethiopian ethnobotany that preserves cultural heritage, facilitates better comprehension of traditional medicine/medicine consumption, and potentially, the discovery of new sources of therapeutic resources. Ayalew et al. (2022) also carried out a detailed review of the multipurpose traditional uses, pharmacology, and phytochemistry of the Ethiopian endemic medicinal plants. Their report captured 412 species of plants, with 44 shown to have massive value in being used medicinally. They also isolated 74 compounds, with the majority being phenolics, and recorded a range of biological activities such as antimalarial, antimicrobial, and anticancer activity. However, the majority of these medicinal applications have not been scientifically established, and this reinforces the pressing need for evidence-based research and stringent conservation measures, particularly for the nine species found to be endangered, in order to ensure their future availability and assist pharmaceutical developments.

According to WHO reports, 80% of the population in developing countries relies on medicinal plants for health care (Hazrat et al., 2020; Van Wyk and Gorelik, 2017). It is crucial that this potential is not limited to a single group, so everyone does their part to pass indigenous knowledge on to the next generation through documentation and serves as a starting point to find new medicines (Weckmüller et al., 2019). However, the plant resources have been lost due to an alarming increase in population, urbanization, agricultural expansion, forest fires, and drought (Tefera and Kim, 2019; Agize et al., 2022).

Besides, most of the traditional knowledge related to medicinal plants is secret and passed on orally to a relative (Yebirzaf et al., 2019; Kindie et al., 2021). This has led to loss of traditional knowledge due to lack of adequate documentation, wise use, and control (Gonfa et al., 2020; Gimay et al., 2021; Woldemariam et al., 2021). Despite the numerous roles medicinal plants play in the treatment of human diseases in Ethiopia, very little has been done to investigate record and promote these widely used medicinal plants (Lulekal et al., 2013).

Medicinal plants have long been essential for treating human diseases, especially in traditional healthcare systems. However, many of these valuable plant species are now increasingly threatened due to habitat loss, overharvesting, and environmental changes, making documentation of their uses urgent and critical. Moreover, no prior ethnobotanical studies have been conducted in selected districts of West Gojjam zone (Dembecha, Sekela, and South Achefer) despite the rich traditional knowledge present. Therefore, present study was aimed to document medicinal plants used to treat human diseases in these selected districts of West Gojjam zone to support their conservation and sustainable utilization.

6.2. Materials and Methods

6.2.1. Description of study area

The study area was well described in chapter 1, General methodology, Section 1.4.1 of the general methodology, including a map of the study area.

6.2.2. Research methods for Ethnobotanical data collection

6.2.2.1. Reconnaissance survey

The reconnaissance survey was briefly described in Section 1.4.2.1 under Chapter 1, General Methodology.

6.2.2.2. Selection of study sites, sampling method and informants’ selection

The selection of study sites, sampling methods, and informant selection procedures were briefly described in Section 1.4.2.2 under Chapter 1, General Methodology.

6.2.2.3. Ethnobotanical data collection and semi-structured interviews

Ethnobotanical data collection and semi-structured interviews were briefly described in Section 1.4.2.3 under Chapter 1, General Methodology

6.2.3. Plant specimen’s identification and preservation

Preliminary identification of plant species was conducted in the field based on observable morphological characteristics. Subsequently, the species were further verified and documented by recording their local names, scientific names, and botanical families. This verification process involved a detailed comparison with existing botanical literature and, in many cases, cross-referencing with authoritative sources such as the Flora of Ethiopia and Eritrea (Volumes 1–7) to ensure accurate classification and nomenclature.

6.2.4. Ethical considerations

Ethical consideration is important before starting any research. Ethical approval for this study was obtained from the Biology Department, as evidenced by the official approval letter. I presented this written letter to the district authorities, who then forwarded it to the administrators of each kebele. After this, by showing the official letter to kebele leaders and the community, the objective of the research was briefly explained in their local language, ‘Amharic’, in that the data will be used only for academic purposes. After providing this information, I obtained verbal consent from each participant. Following their consent, ethnobotanical data was collected.

6.2.5. Ethnobotanical Data Analysis

During the process of data analysis, we pooled data from three districts into a single dataset. Combining data from three districts into one analysis allows for a broader understanding of the traditional knowledge and practices within the zone. The information gathered from local people, such as methods of preparation, routes of administration, diseases treated, parts used and growth form of medicinal plants, and other associated indigenous knowledge was summarized using descriptive statistics. The summary calculations, bar graphs, and pie charts were drawn using MS Excel 2016 spreadsheet ans SPSS software.

Informant Consensus Factor (ICF). The ICF was employed to assess the level of agreement among plant users regarding the use of medicinal plants for treating specific disease categories in the study area. This method evaluates the homogeneity of informants’ knowledge following the approach outlined by Trotter and Logan (2019).

ICF is calculated to determine the most important categories of human disease in the district and identify potentially effective medicinal plant species in the respective disease categories (Heinrich et al., 1998). The ICF was calculated using the following formula:

$\mathbf{ICF} = \frac{\text{nur}-\text{nt}}{\text{nur}-1}$ Where nur = number of use citations for each disease, nt= number of species used

According to Abe and Ohtani (2013), the Informant Consensus Factor (ICF) measures the agreement among informants regarding the use of species to treat specific ailments. ICF values range from 0 to 1, with values closer to 1 indicating greater consensus on the importance of particular species in disease treatment. In the current study, different human diseases were pooled into 14 categories of 48 diseases that were reported by informants. The diseases reported at the study sites were grouped into the following categories. These are respiratory problems (nose bleeding, asthma, common colds, cough, and tonsillitis); dermatological diseases (wounds, skin rashes, skin burns, acne, swelling, dandruff); gastrointestinal diseases (stomachache, ascaris, gastric problems, vomiting, diarrhea, constipation); sexual problems (Dysuria, gonorrhea, syphilis); internal medical diseases (heart disease, jaundice, hypertension, cancer, rabies, diabetes, kidney problems, and lung disease) spiritual problems (Evil eye, spiritual illness); and snake bites, headache, fever, malaria, warts, bronchitis, arthritis, anemia (Table 6.4).

Preference ranking followed the methods of Martin (1995) and Cotton (1996) to identify the most important medicinal plants for treating specific illnesses. Since diarrhea was the most common ailment reported, purposively selected key informants ranked the medicinal plants used to treat it in the study area. Twelve key informants were asked to assign values from 1 to 8 to eight medicinal plants used to treat diarrhea, where 8 indicated the highest healing potential and 1 the lowest. The assigned values were then summed and ranked (Table 6.5).

Direct matrix ranking: Direct matrix ranking, following Martin (1995), was used to assess the multipurpose uses of selected medicinal plant species and identify the most threatened ones. Ten purposively selected key informants assigned scores from 0 to 5 for each use category (5 = best, 4 = very good, 3 = good, 2 = less used, 1 = least used, 0 = not used). The scores were then summed and ranked (Table 6.6).

6.3. Results

6.3.1. Sociodemographic characteristics of the informants

The sociodemographic profile of informants in the ethnobotanical study reflects a diverse distribution across three age categories: 20-41, 42-62, and over 62 years old, with a notable concentration within the 42-62 age range (Table 6.1). Surprisingly, a significant percentage of informants were literate, highlighting the need for education to improve their comprehension and documentation of medicinal plants, thus extending the ethnobotanical knowledge archive.

Table 6.1. Demographic information of informants. Note: M=Male, F=Female

Category		Total	Gender		Local healer	Farmer	Teacher	Church servant	Shop keeper	Trader
			M	F	10	65	10	13	5	7
Age	20-41	110	88	22						
	42-62	243	154	89	15	165	19	28	10	6
	>62	76	49	27	5	45	3	16	4	3
	Total	429	291	138	30	275	32	57	19	16
Education status	Literate	377								
	Illiterate	52								

6.3.2. Human diseases in the study sites

According to the informants, 48 human diseases/problems were reported at the study sites (Table 6.2). For each disease/problem, different numbers of plants were used. The highest numbers of medicinal plants were reported for toothache (12.4%) followed by wounds (10.3%), and tonsillitis, stomachache and diarrhea have (7.2%) in each. The responses of informants indicated that most of the human diseases were treated by only one medicinal plant species (37.11%). Based on this, 48 human diseases reported by key informants and general informants were treated by one medicinal plant (Table 6.2).

Table 6.2. List of human diseases/problems identified at the study sites and the respective numberof plant species used for treating human disease.Note: Spp=Species

No.	Diseases/problems	No of Spp	%	No.	Diseases/problem	No of plant spp	%
1.	Syphilis	1	1	25.	Kidney problem	1	1
2.	Nose bleeding	5	5.1	26.	Headache	2	2
3.	Cough	6	6.2	27.	Rabies	4	4.1
4.	Tonsillitis	7	7.2	28.	Bronchitis	1	1
5.	Dandruff	5	5.1	29.	Ascaris	4	4.1
6.	Liver Problem	1	1	30.	Swelling	4	4.1
7.	Toothache	12	12.4	31.	Arthritis	3	3.1
8.	Fever	3	3.1	32.	Stomachache	7	7.2
9.	Common cold	4	4.1	33.	Tapeworm	5	5.15
10.	Evil eye	3	3.1	34.	Eczema	1	1
11.	Warts	3	3.1	35.	Sudden illness	1	1
12.	Cancer	3	3.1	36.	Dysuria	1	1
13.	Fire burn	1	1	37.	Acne	1	1
14.	Skin rash	3	3.1	38.	Leprosy	1	1
15.	Eye problem	2	2	39.	Spiritual illness	1	1
16.	Skin burn	1	1	40.	Hypertension	2	2
17.	Wound	10	10.3	41.	Diabetes	2	2
18.	Asthma	3	3.1	42.	Vomiting	1	1
19.	Diarrhea	7	7.2	43.	Lung diseases	1	1
20.	Snake preventation	1	1	44.	Anemia	1	1
21.	Skin cancer	1	1	45.	Gonorrhea	1	1
22.	Snake bite	2	2	46.	Gastritis	1	1
23.	Jaundice	6	6.2	47.	Constipation	1	1
24.	Heart burn	1	1	48.	Malaria	1	1

6.3.3. Diversity of medicinal plants

A total of 97 medicinal plants belonging to 92 genera and 52 families were documented from the study sites used to treat human diseases. Among the families, Fabaceae was represented by 8 species (15.3%) and ranked first, followed by the Asteraceae family represented by 7 species (13.5 %). Similarly, Lamiaceae were represented by 6 species (11.5%). The remaining 36 species were represented by one species. The local names, family names, scientific names, plant parts and methods of preparation of medicinal plants were summarized (Appendix 7).

Sources of medicinal plants collected by traditional healers

Traditional healers in the study area utilize a strongly diverse set of natural environments from which medicinal plants are collected, reflecting ecological diversity and long-term cultural tradition (Fig. 6.1). Of these environments, church forests are most critical, yielding approximately 45% of the medicinal plant species. These church forests, typically preserved for religious and spiritual purposes, are important sources of biodiversity and sanctuaries for rare and endemic flora. Medicinal species are primarily sourced by indigenous healers from forests surrounding church sites, where plant richness is considerably greater and more concentrated (Fitsumbirhan, 2018). Partial integrity of such forests, based on local protection and religious taboos regarding forest clearance, allows for high diversity of medicinal plants. Natural forests provide about 25% of the medicinal plants, despite growing human pressures. Home gardens provide about 20% as sustainable and knowledge-based resources. Farmland and disturbed areas provide the remaining 10%, albeit less diverse and more vulnerable to degradation. This emphasizes the need for maintaining church forests and natural ecosystems for the sake of sustaining medicinal plant resources.

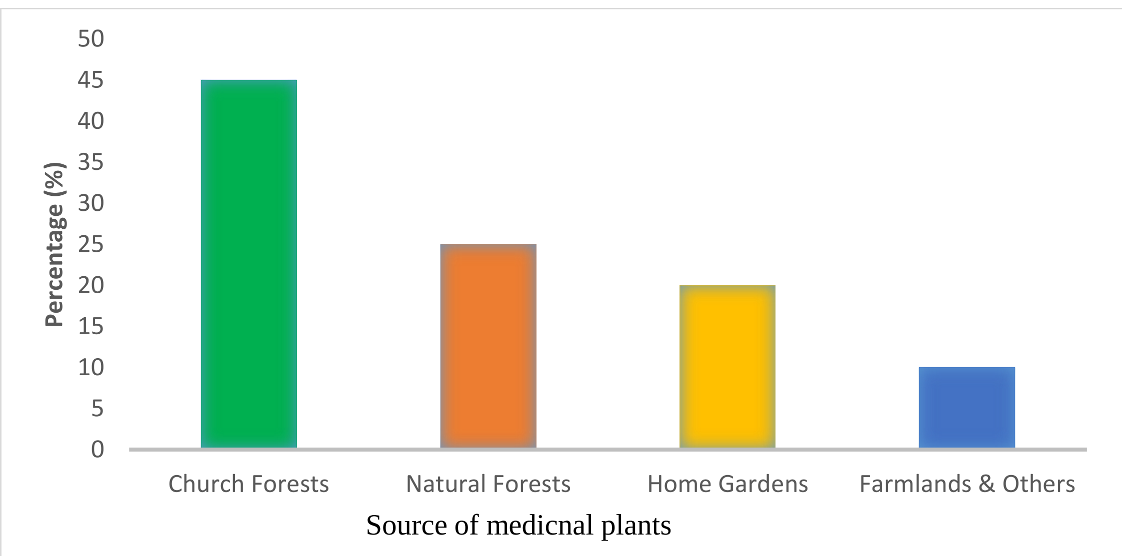


Figure 6.1. Distribution of medicinal plant sources in the study area

6.3.4. Growth habits of medicinal plants

At the study sites, the growth habit of most medicinal plants was found to be herbs represented by 47 species, followed by shrubs, 26 species (Fig. 6.2). From the total medicinal plants, herbs and shrubs constituted 75% of the current study.

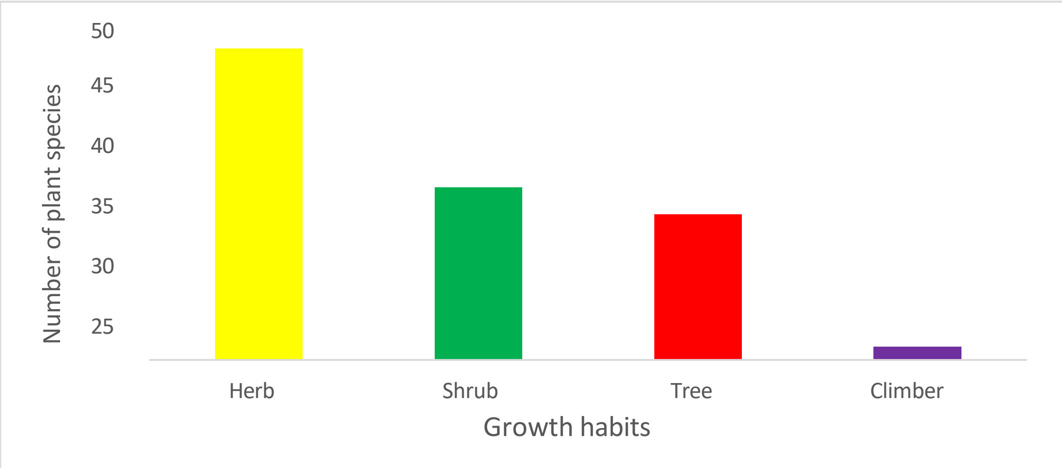


Figure 6.2. Growth habits of medicinal plants in the study sites

6.3.5. Plant parts used for the preparation of remedies

In the studied area, diverse plant parts played crucial roles in the preparation of traditional remedies for various human diseases. The study revealed that different plant parts served as the primary ingredients for preparing remedies to treat various human diseases. The most cited plant parts for the preparation of remedies were leaves represented by 37 species (26.5%), followed by seeds represented by 22 species (15.7%) and roots represented by 19 species (13.6%) (Fig. 6.3).

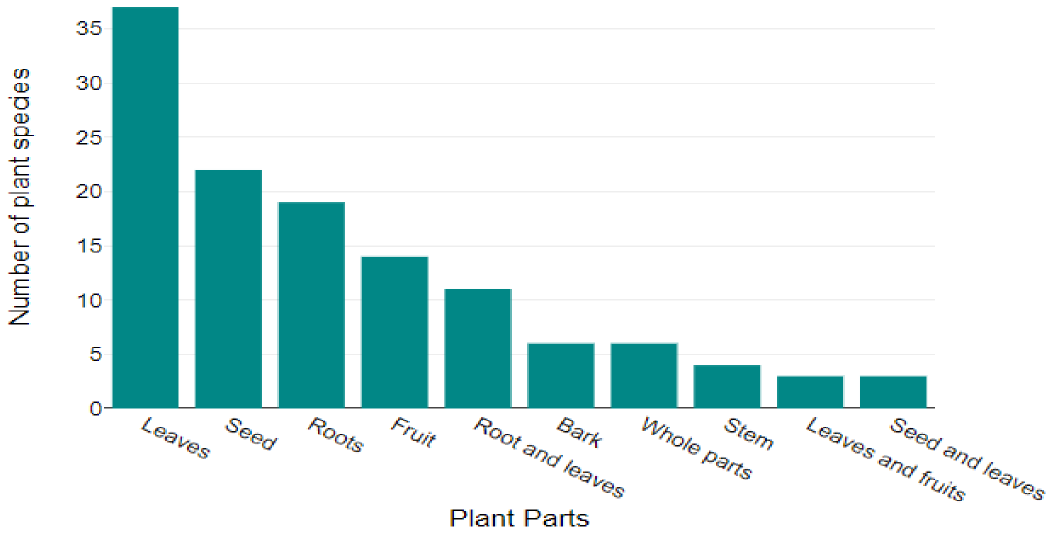


Figure 6.3. Parts of medicinal plants used to prepare remedies for the treatment of human diseases

6.3.6. Mode of preparation of remedies

The main methods for the preparation of herbal medicine were crushing (22%), followed by pounding (17%), powdering (10%), and others (Fig. 6.4).

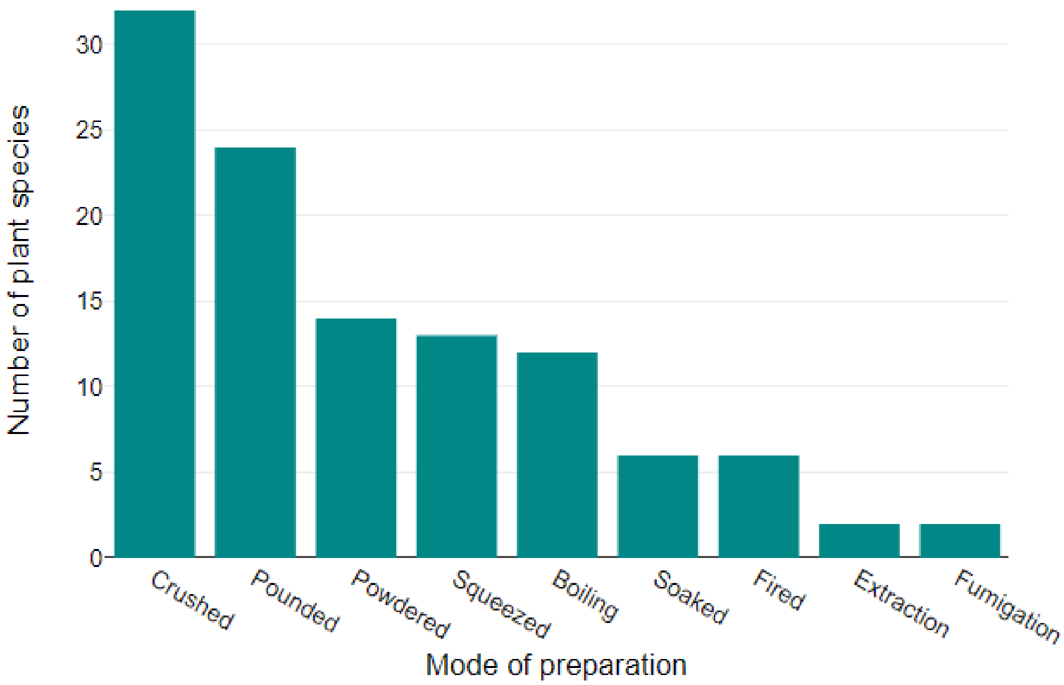


Figure 6.4. Mode of preparation of remedies to treat human diseases

6.3.7. Route of administration and dosage

The routes of administration of remedies reported at the study sites were oral, dermal, and nasal (Fig. 6.5).

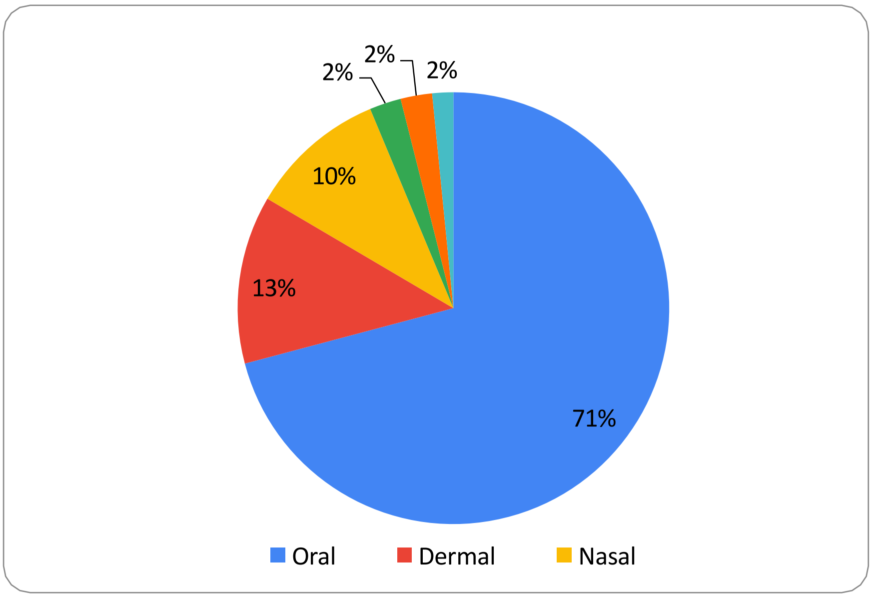


Figure 6.5. Route of administration of medicinal plants used to treat human diseases

6.4. Healing potential and multipurpose use of medicinal plants in study sites

6.4.1. Informant Consensus Factor (ICF)

In the current study, a total of 48 human diseases reported by the informants were grouped into14 categories (Table 6.4). ICF was calculated and ranked for each disease category. These categories include respiratory problems (nose bleeding, asthma, common colds, cough, and tonsillitis); dermatological diseases (wounds, skin rashes, skin burns, acne, swelling, dandruff); gastrointestinal diseases (stomachache, ascariasis, gastric problems, vomiting, diarrhea, constipation); sexual problems (dysuria, gonorrhea, syphilis); internal medical diseases (heart disease, jaundice, hypertension, cancer, rabies, diabetes, kidney problems, and lung disease); spiritual problems (Evil eye, spiritual illness) and snake bites, headache, fever, malaria, warts, bronchitis, arthritis, anemia (Table 6.3).

Table 6.3. Informant consensus factor values of the top 14 categories of human diseases

No.	Diseases category	Nt	nur	nur-nt	nur-1	ICF
1.	Dermatological	31	397	366	396	0.92
2.	Respiratory	34	374	340	373	0.91
3.	Gastrointestinal	25	247	222	246	0.90
4.	Sexual problems	22	209	187	208	0.89
5.	Internal medical	52	369	317	368	0.86
6.	spiritual problems	19	125	106	124	0.85
7.	Snake bites	9	49	40	48	0.83
8.	Headache	26	157	131	156	0.83
9.	Fever	13	68	55	67	0.82
10.	Malaria	17	88	71	87	0.81
11.	Warts	11	52	41	51	0.80
12.	Bronchitis	8	35	27	34	0.79
13.	Arthritis	6	24	18	23	0.78
14.	Anemia	5	18	13	17	0.76

6.4.2. Preference ranking

It was calculated for the eight most important medicinal plants used to treat diarrhea. This is also true in the current study area that frequently occurred diseases. Based on this analysis, *Calpurnia aurea* ranked first, followed by *Rumex nepalensis* (Table 6.4).

Table 6.4. Preference ranking of medicinal plants used to treat diarrhea at the study sites (Note: KI=key informants)

	List of medicinal plants preferred by key informants							
KI	*Cordia africana*	*Bidens pilosa*	*Verbena officinalis*	*Cucumis ficifolius*	*Lepidium sativum*	*Calpurnia aurea*	*Rumex nepalensis*	*Coffea arabica*
KI1	5	3	4	4	3	8	7	6
KI2	5	5	2	4	2	5	6	4
KI3	3	4	1	2	4	7	5	4
KI4	6	5	4	3	1	6	4	5
KI5	5	3	5	1	1	5	6	5
KI6	4	4	4	1	1	6	4	6
KI7	3	6	3	3	3	7	5	4
KI8	5	1	4	2	5	5	7	6
KI9	4	5	3	1	4	6	4	6
KI10	2	4	5	5	2	4	5	3
KI11	5	2	2	6	1	5	6	4
KI12	4	3	3	4	2	5	4	8
Total	51	45	40	36	29	69	63	61
Rank	4th	5th	6th	7th	8th	1st	2nd	3rd

6.4.3. Direct matrix ranking

The result of this study showed that there are many important plant species used by residents beyond their medicinal value categories (Medicinal, fence, charcoal, construction, furniture and firewood). The highest multipurpose tree species was the *Olea europaea subsp. cuspidata*, followed by *Eucalyptus globulus* (Table 6.5).

Table 6.5. Direct matrix ranking of 8 medicinal plant species with different uses other than medicinal use

Use diversity categories	Name of plant species							
	Cordia africana	*Croton macrostachyus*	*Eucalyptus globulus*	*Hagenia abyssinica*	*Olea europaea*	*Ficus vasta*	*Psidium guajava*	*Vachellia abyssinica*
Medicinal	3	4	3	4	5	4	4	4
Fence	4	4	4	4	4	4	4	4
Charcoal	4	4	4	5	4	4	4	4
Construction	4	2	5	3	3	3	2	4
Furniture	5	4	5	5	5	2	3	5
Firewood	3	4	4	3	5	3	2	3
Total	23	22	25	24	26	20	19	11
Rank	4th	5th	2nd	3rd	1st	6th	7th	8th

6.4.4. Information source of knowledge about medicinal plants

The current survey indicates that different informants have different sources of information on medicinal plants. Most of respondents (62.5%) got their knowledge of medicinal plants from their parents (Fig. 6.6).

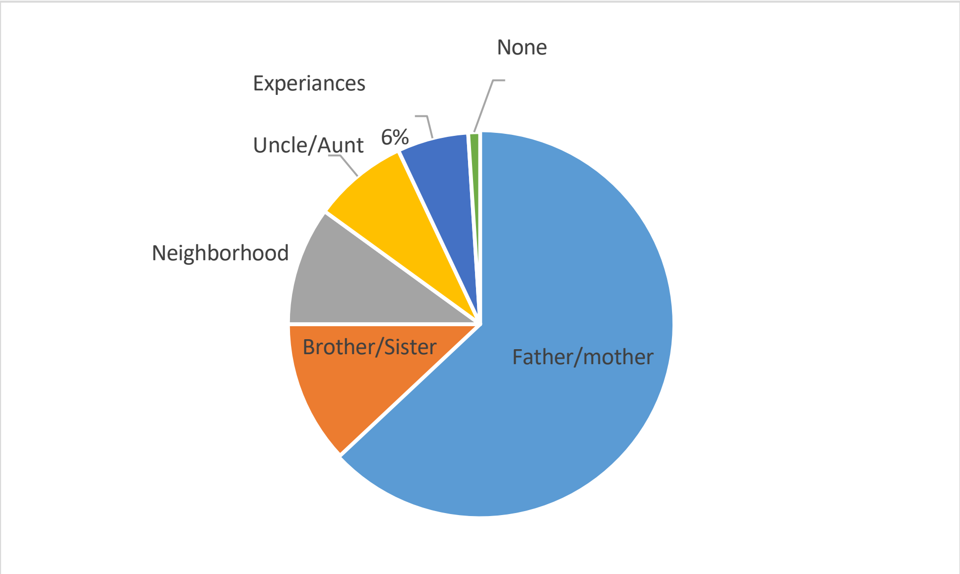


Figure 6.6. Source of medicinal plant knowledge

6.5. Discussion

In the study sites, there was a gender difference among informants, with males constituting the majority, a characteristic seen in various research contexts (Agize et al., 2022). This disparity could be attributable to men's greater involvement in activities outside the home (Misganaw et al., 2021; Yimam et al., 2022; Tahir et al., 2023). Their knowledge extends to the cultural and historical relevance of these botanical resources, emphasizing their use in herbal medicine practices. Occupation-wise, farmers made up the largest informant category, suggesting their deep involvement with and reliance on botanical resources for a variety of uses including treating different human diseases. Traders, on the other hand, were the smallest group implying that they had little involvement with medicinal plants in their daily lives.

The current study revealed that a total of 97 medicinal plants belonging to 92 genera and 52 families were documented from the study sites used to treat human diseases. The present study has high potential reservoir of medicinal plants when compared to other study site conducted in in Seharti Samre district (Araya et al., 2015). In family wise, Fabaceae was the dominant in current study. Many plant species of Fabaceae have been identified as medicinal plants by traditional healers in different parts of the country. In this respect, other findings have also reported that the family Fabaceae is the leading family a study conducted in Hawassa Zuria District of Sidama Zone (Tefera and Kim, 2019), Zuway Dugda District of Oromia region (Megersa et al., 2023), sub-Saharan Africa (Odukoya et al., 2022), in five areas in Lagos State of Nigeria (Lawal et al., 2022). This could be due to their accumulation of secondary metabolites in various parts (leaf, stem, root, and seeds) and adaptive characteristics (Asfaw and Abebe, 2022).

The vital role of church forests as primary sources for medicinal plants documents prior research highlighting their function as biodiversity sanctuaries within Ethiopia's heavily altered environment. Their religious significance has successfully maintained both plant diversity and associated traditional knowledge. However, this preservation may have carelessly created a strong dependence, with nearly half of all medicinal plants exclusively sourced from these protected biodiversity hotspots. In contrast, natural forests continue to contribute significantly; however, they likely represent a diminishing resource due to ongoing agricultural expansion and deforestation in the area.

The limited reliance on farmlands indicated that conventional agricultural practices may inadequately support medicinal plant diversity, possibly because of cultivation challenges or the prioritization of food crops.

While the widespread use of home gardens reflects adaptive responses at the local level. The gardens appear to be useful supplementary sources, perhaps accelerating the pressure of harvesting in natural habitats. This finding recommends for the inclusion of ex situ conservation methods alongside traditional in situ methods. These sourcing patterns have significant implications for conservation practice. While the continued preservation of church forests is undoubtedly necessary, our data indicate that the promotion of home garden production of medicinal plants can offer a sustainable cushion against over-exploitation of natural resources. Moreover, specific natural forest management interventions might be capable of sustaining this significant secondary source. Excessive reliance on church forests is concerning from the point of view of their long-term sustainability, especially as these lands are facing increasing pressures from climate change and evolving religious traditions. Future studies need to find out the sustainability of current harvesting operations in these forests and examine the potential for expanding home garden cultivation to other medicinally important species.

In the study sites the informants mentioned about (48) human diseases with their respective treating medicinal plants. In the study area a wide range of diseases, from minor problems like coughs, colds, and toothaches to more serious ones like cancer and jaundice. Interestingly, while some diseases, such as toothaches and wounds, are treated with a larger number of plant species, others are treated with only one or a few. This demonstrates both the depth of traditional medicinal knowledge in the communities investigated and the specialized medications for specific health conditions. Thus, informants who utilized medicinal plants for toothaches mentioned the highest number of medicinal plant species (12). This suggests that the plant species that is utilized to treat toothaches is more prevalent and readily available in the study sites. Wound was also other constraints in the study sites that treat by many medicinal plants. Similarly, (10) plant species were recognized for the management of wounds, emphasizing the importance of this health issue within the locality. The treatment of wounds posed a significant challenge, leading to the use of multiple medicinal plants for remedial purposes.

According to Belayneh et al. (2012), in the Babile wereda Erer Valley, a totalof 54 human health problems were identified, including gastrointestinal disorders and parasitic infections, cured by a great number of (15) plant species, followed by (14) medicinal plants that are used for wound healing. It is interesting also to notice that malaria is at the top of health care due to 9 (33.3%) different medicinal plant species used as a treatment, followed by snakebites with 7 (25%) of plant species also in Amaro Woreda (Mesfin et al., 2014). Similarly, Alebie et al. (2017) studied more than 200 traditional medicinal plant species and their usage in treating malaria in Ethiopia. The review emphasizes the heavy cultural reliance on these interventions in the face of inadequate access to modern healthcare and the pressing need for scientific evidence on their efficacy and safety. They urge efforts to fill knowledge gaps and sustainably incorporate these remedies into the treatment of malaria.

Herbs and shrubs were the dominant growth forms in the study sites. Similarly, in Ganta Afeshum District (Kidane et al., 2018), Sheka Zone of southern nations nationalities and peoples regional state, Ethiopia (Kassa et al., 2020), Hawassa Zuria District (Tefera and Kim, 2019) Meinit ethnic group of Ethiopia (Giday et a l., 2022) were dominated by herbs. This is due to the fact that herbs and shrubs can hide in forests, bushland, valleys, mountains, and other vegetation types and can be easily accessible around the informant compound (Chekole et al., 2015; Mekonnen et al., 2022). Herbs can grow everywhere, and most of them are annuals. Most findings showed that herbs and shrubs were the most important medicinal plant growth habits mentioned by traditional healers (Haile, 2022; Siddique et al., 2022). Nevertheless, alternative research results have suggested that trees and shrubs may assume a dominant growth habits in Suro Barguda District (Eshete and Molla, 2021). Therefore, understanding and conserving variation in growth forms of medicinal plants is critical for ecological health, human health, and cultural preservation.

The most cited plant parts for the preparation of remedies were leaves represented by 37 species (26.5%), followed by seeds represented by 22 species (15.7%) and roots represented by 19 species (13.6%). This is in line with a study conducted in Gozamin Wereda (Amsalu et al., 2018), Hulet Eju Enese woreda (Abebe and Chane, 2021), in Raya Kobo (Osman et al., 22020) reported that leaves were the most widely used plant parts. This might be due to their ease of accessibility in the surroundings.

The active ingredients such as alkaloids and tannins have been found accumulating in photosynthetic pigments of leaves (Passalacqua et al., 2006). However, roots were the most dominant plant parts used to prepare remedies in Kebridehar and Shekosh districts (Wubu, 2023). During plant parts collection, wise harvest methods are recommended to prevent the destruction and extinction of species (Chen et al., 2016). Traditional healers should refrain from harvesting entire plant parts because it results in the destruction of medicinal plants (Belayneh et al., 2012). In general, traditional healers might use alternative harvest practices to ensure the sustainability of medicinal plants. Proper preparation of plant parts containing desired medicinal compounds is crucial in traditional medicine and herbal remedies, ensuring effective utilization and minimizing environmental impact. Some traditional healers also said that they collected plants parts and allowed to dry and stored for a long period of time. These stored and powdered remedies were given to patient when at the right time.

According to the respondents, increasing the healing potential of medicinal plants through their mode of preparation is essential. Medicinal plants are prepared using various methods based on their properties and intended use. In the present study, the remdies were mostly prepared through crushing. Consistent to this crushing has also been mentioned as the most common mode of preparation in Gubalafto District (Chekole, 2017), Debre Libanos Wereda (Seyoum and Zerihun, 2014). However, the results of the present study disagree with those of other studies, which found that pounding is the most dominant mode of preparation in Raya Kobo District (Osman et al., 2020). Moreover, other reports also demonstrated that crushing might increase the efficiency of plant extraction and therefore increase its bioactivity through increasing solubility studied in Gubalafto district (Chekole, 2017). Traditional healers also used a mixture of two and/or more plant parts during preparation, as they believed that the synergistic effects of certain plant components could increase the healing of diseases a study shown in south omo, southern Ethiopia by Tolossa et al. (2013).

The traditional healers used fresh and dried medicinal plants during the preparation of remedies. The present study revealed most remedies were prepared from fresh materials. This is because the healing potential of some medicinal plants could decrease due to the volatile nature of some plant ingredients (Kidane et al., 2018).

Similar studies showed that fresh plant parts are preferred by traditional healers in Gubalafto district (Chekole, 2017), Sheka Zone of southern nations nationalities and peoples regional state (Kassa et al., 2020), bench ethnic group of Ethiopia (Giday et al., 2009), Tara-Gedam and Amba remnant forests of Libo Kemkem District (Chekole et al., 2015). In addition, Macía et al. (2005) reported that in the markets of La Paz and El Alto, Bolivia, most of medicinal remedies were prepared from fresh materials, with decoctions accounting for 47.5% of the preparations.

The most frequently reported route of administration was internal through oral intake, which accounted for about 70.8%, and dermal 12.6%. In the study sites, the traditional healers prepared the remedies added carrier material such as milk, coffee, tea and tella especially for internal diseases, which may be this also used as antidotes during vomiting. Similarly, for dermal disease, butter and vaseline were reported used during application to the diseased part. Similar findings have been reported in other regions, including Seharti Samre District, southern Tigray, Ethiopia (Araya et al., 2015), Sedie Muja District (Mekonnen et al., 2022), Mojana Wadera Woreda (Haile, 2022), and in the markets of La Paz and El Alto, Bolivia (Macia et al., 2005).

Medicinal plants can cause side effects if not administered at appropriate doses, with overdosage and prolonged treatment linked to safety concerns (Zhang et al., 2015). According to traditional healers, dosages vary for children, young adults, and pregnant women, as reported in a study from Erer Valley, Babile Wereda (Belayneh et al., 2012). In Basona Werana district, prepared remedies are measured using glasses, cups, and other materials recommended by traditional healers (Megersa et al., 2022). Similarly, traditional measurement units such as coffee cups, tins, finger lengths, teaspoons, tea glasses, and the number of powder droplets picked by two fingers have been reported for dosing medicinal plants in Sedie Muja District (Mekonnen et al., 2022). Informants reported administering the prepared medicine to patients for three to seven consecutive days, with the initial days aimed at immediate symptom relief and subsequent days focused on deeper healing and recovery. This pattern aligns with findings from the Chipinge District in Zimbabwe (Ngarivhume et al., 2015). However, challenges persist among traditional healers in accurately determining dosages during treatment in the current study sites. Consistent with Belayneh et al. (2012), this study also found a lack of dosing precision, particularly for oral administration.

The Informant Consensus Factor (ICF) was performed in the study sites to look at the informant agreement for each disease category. High ICF values indicate high agreement among informants, typically indicating plants effective for treating specific health conditions or fulfilling cultural needs (Tahir et al., 2023). In the current study dermatological diseases had the highest ICF value of 92% (0.92), followed by respiratory disease at 91% (0.91). These findings suggest a strong level of agreement among informants regarding the use of medicinal plants for treating specific disease categories. This aligns with results from Ankober District, North Shewa Zone, where high ICF values (0.70) were reported for gastrointestinal, parasitic, and dermatological disorders (Lulekal et al., 2013) and is also consistent with findings from Ganta Afeshum District (Kidane et al., 2018). However, this contrasts with findings from Hulet Eju Enese Woreda, where a higher ICF value (0.83) was reported for sudden illness (Abebe and Chane, 2021). The observed level of consensus among traditional healers highlights its potential significance in informing future drug development and ethnopharmacological research.

Preferences ranking was calculated for the eight most important medicinal plants used to treat diarrhea. In most parts of Ethiopia, diarrhea affects mainly children and infants (Tahir et al., 2023). The current study revealed that *Calpurnia aurea* was the most important to treat diarrhea followed by *Rumex nepalensis*. These herbs are important in traditional healthcare practices, particularly for treating diarrhea in children and infants, who are especially susceptible to the condition (Getnet et al., 2023). The preference ranking revealed that the local populations' reliance on these crucial plant species for diarrhea treatment. This is consistent with other finding (Abdela et al., 2022).

Direct matrix ranking identifies multipurpose medicinal plants valued by communities, supporting conservation and research efforts (Martin, 1995). The highest multipurpose tree species was the *Olea europaea subsp. cuspidata*, followed by *Eucalyptus globulus*. This fits with the finding a study in Mana Angetu district (Lulekal et al., 2008). Multipurpose medicinal plants with the highest use values are under significant pressure from overexploitation, which threatens their survival and may lead to extinction (Siddique et al., 2022). Therefore, medicinal plants with high use-value rankings require urgent conservation efforts (Eldeen et al., 2016).

The transfer of knowledge among the sources was the cause of the diversity of knowledge of medicinal plants between genders (Asfaw and Abebe, 2022). This emphasizes the importance of intergenerational knowledge transfer in preserving traditional medicinal practices, as most informants reported learning about medicinal plants from their parents. A few also acquired knowledge through trial-and-error methods. However, such practices are generally discouraged due to their inherent risks, including the potential use of harmful substances and unintended adverse health effects, highlighting the need for safer and more systematic knowledge acquisition. Many individuals with knowledge of traditional medicinal plants in the community are men. The limited transmission of this knowledge, primarily within a small group of holders, poses a risk of significant loss if not properly documented. Similar patterns of restricted knowledge transfer have been reported in various regions of Ethiopia (Zerabruk and Yirga, 2012; Hunde et al., 2006). Notably, 70% of respondents indicated that their knowledge is confined to familial lines, being shared exclusively among close relatives (Giday et al., 2022). Usually, the person who holds this knowledge, often a parent, selects one of their children typically a son to be an apprentice. In the study area, informants were referred to as magicians (ASMATEGNA), leaf cutters (QITAL BETASH), and DEBTERA in society. This labeling reduces interest in working with medicinal plants, resulting in the degradation of knowledge and the extinction of significant plants. This labeling is also common in Chekole (2017).

6.6. Conclusions

In the present study a total of 97 medicinal plants used to treat human diseases were documented. This implies the communities still rely on medicinal plants to mitigate health problems traditionally. Despite numerous uses of these medicinal plants, they are found undr risk. The main causes of the decline of medicinal plants in the study areas were identified as charcoal production and agricultural uses. These anthropogenic factors have led to the loss of medicinal plant resources and the degradation of their habitats. Emphasis should also be employed on developing sustainable harvesting and cultivation practices, integrating medicinal plants into agroecological systems, and promoting community awareness. Future study should focus on conducting pharmacological validation of key plant species and assessing the conservation status of threatened plants in the study area.

CHAPTER 7: Ethnoveterinary practices of medicinal plants in Selected Districts of West Gojjam Zone, Northwestern Ethiopia

Abebe Ayele[1, 2, *], Ali Seid [1], Amare B. Mekonnen [1], Wubetie Adnew [1], Getahun Yemata [1]

[1]Department of Biology, College of Science, Bahir Dar University, Bahir Dar, Ethiopia

[2]Department of Biology, College of Natural and Computational Sciences, Debre Berhan University, P. O. Box 445, Debre Berhan, Ethiopia

*Corresponding author email: abebeayele230@dbu.edu.et

This chapter is published in Ethnobotany Research and Applications Journal, 31(2025); 1-20.

https://ethnobotanyjournal.org/index.php/era/article/view/6662

ABSTRACT

In most parts of Ethiopia, the use of medicinal plants to treat different livestock diseases are common. However, the depletion of plant resources and the accompanied erosion and subsequent loss of traditional knowledge posed a threat to this practice. This demonstrates the fact that documentation of ethnoveterinary knowledge is mandatory to reverse the current trend. Hence, the current investigation was aimed at the documentation of ethnoveterinary practices of medicinal plants in selected districts of West Gojjam zone. Ethnoveterinary data were collected from 30 kebeles (the smallest administrative structure in Ethiopia) at West Gojjam Zone in Amhara region, Ethiopia. The ethnoveterinary data were collected from 30 key and 399 general informants aged > 20 years. Ethnoveterinary data were collected through semi- structured interviews, focus group discussion, and accompanied field walks with individual informants. Descriptive statistics were employed to summarize the data. Ranking methods such as Preference Ranking and Direct Matrix Ranking were used. To draw a graph we used SPSS software version 27. A total of 53 ethnoveterinary medicinal plants were identified belonging to 33 families and 51 genera. Asteraceae and Solanaceae were the most represented families, with five plants species each, followed by Lamiaceae and Euphorbiaceae with four plants each. The most frequently used plant parts to treat livestock diseases were leaves. Crushing was the most common method of remedy preparation followed by pounding. Most of the remedies were administered through orally. The respiratory, spiritual, and injury-related conditions had high Informant Consensus Factor (ICF) value, while Cucumis pustulatus and Withania somnifera showed the highest Fidelity Level (FL) for blackleg and spiritual illnesses, respectively. Preference ranking identified Clerodendrum myricoides as the most preferred for treating anthrax. Direct matrix ranking highlighted Olea europapaea and Eucalyptus globulus for their multiple uses in the study area. Similarly, firewood collection had 31 the most plant use diversity in the study area. This study emphasises the importance of ethnoveterinary medicinal plants in treating livestock diseases in the West Gojjam Zone and the rich traditional knowledge of local healers. However, agricultural expansion and urbanization threaten its preservation. Documenting this knowledge, integrating it into policies, and engaging communities in conservation are essential to sustain veterinary care and biodiversity for future generations.

Keywords: Ethnoveterinary, medicinal plants, indigenous knowledge, West Gojjam Zone, Amhara region

7.1. Background

Among other African countries, Ethiopia stands first in its livestock population with 66 260 988 cattle, 38 013 272 sheep and 45 716 092 goat (ESS, 2021). The livelihood of 130 million Ethiopians is based on agriculture (Zegeye et al., 2022). Animal diversity is very important in agricultural settings. Most, the farmers' (almost 85%) of the farmers' use animals for farming the land because of poverty, and acute shortage of modern farming equipment in rural areas (Yigezu, 2021). It is very important to save the animals from diseases so that they can deliver better/improved agricultural productivity. In many developing countries, including Ethiopia, a significant obstacle to livestock production is the lack of health services for livestock care (Kebede et al., 2014). In Ethiopia, animal diseases are the primary concern for livestock owners (Gizaw et al., 2021). Common health issues affecting livestock include parasitic infections, bacterial diseases, and nutritional deficiencies (Bekele et al., 2018). Inadequate facility of animal health services, primarily a public sector responsibility by livestock caretakers is considered as the biggest barrier to improving animal health and production (Gizaw et al., 2021). Thus, ensuring animal health is crucial for encouraging high agricultural production (Tufa et al., 2018).

According to the data, Ethiopia is seriously suffering from animal yield loss due to diseases and parasites (Larkins et al., 2023). The loss could reach up to 8-10% per year for cattle, 12-14% for sheep, and 11-13% for goats, and as high as 56.9% for poultry, which brings about heavy losses to farmers and pastoralists in the country (Larkins et al., 2023). The diseases causing major losses include fasciolosis, internal parasites like Haemonchus contortus, and other important diseases of livestock. Various health issues plague the cattle population in Ethiopia, including black leg, anthrax, bloating, and eye diseases, which notably hinder cattle production (Feyera et al., 2017; Feyisa et al., 2021; Asfaw et al., 2022; Abebe, 2022, Oda et al., 2024).

In most cases, pastoralists employ traditional methods of treating animal diseases using plants (Xiong & Long, 2020). Ethnoveterinary medicines are herbs that traditionally used for treating health problems in livestock, which are much cheaper compared to modern medication (Berhanu et al., 2020). Animals have been suffering from health problems, which may be effectively treated using medicinal plants (Hassan et al., 2014). Pastoralists and farmers worldwide have used these herbal remedies in treating cattle diseases for centuries, with the practices deeply embedded in traditional beliefs and practices (Khan et al., 2021).

This practice provides accessible health solutions, especially for rural areas, by utilizing locally available plants that may require no or minimal processing (Phondani et al., 2010).

Ethnoveterinary practices are generally considered to be inexpensive, relatively safe, have been used for a long time within a community, and rely on readily available medicinal plant species (Hosseinzadeh et al. 2015). The scientific investigation of these traditional methods can lead to the discovery of new therapeutic compounds Hosseinzadeh et al. (2015). This, in turn would definitely encourage integration into modern veterinary medicine, thereby contributing to sustainable livestock management (Assefa and Bahiru, 2018). In Ethiopia, traditional healing practices have long depended on medicinal plants, with local healers possessing deep knowledge of these plants and their uses to treat a wide range of health issues. Several ethnoveterinary studies across the country have provided valuable insights into the use of medicinal plants in various regions (Wassie et al., 2015; Kassa et al., 2020, Dinbiso et al., 2022; Abebe, 2022; Awoke et al., 2024; Oda et al., 2024). Despite this progress, there is still a need for further research to systematically catalog and document these plants. Traditional ethnoveterinary knowledge has primarily been passed down orally across generations through cultural expressions like folk remedies, songs, proverbs, and storytelling (Hassanali et al., 2005). However, the influence of Western culture has led many in the current generation to view these practices as outdated or even taboo, resulting in a decline in the transmission of indigenous knowledge regarding medicinal plants (Giday et al., 2009; Giday et al., 2010; Ayele et al., 2024).

In the West Gojjam Zone of Ethiopia, a similar decline in ethnoveterinary knowledge has been observed, paralleling trends seen in other regions where traditional practices and indigenous knowledge systems are being eroded. This decline poses a significant threat to the continued use, transfer, and conservation of medicinal plants, which have historically played a critical role in the health and well-being of livestock. The loss of this knowledge not only jeopardizes the cultural heritage of the communities but also undermines the potential for sustainable utilization of medicinal plant resources that could contribute to both local healthcare and biodiversity conservation efforts. Given the rapid rate at which traditional knowledge is disappearing due to various factors such as modernization, urbanization, and generational shifts, it is increasingly urgent to document and study ethnoveterinary practices before these invaluable resources are permanently lost. This is because ethnoveterinary knowledge encapsulates a wealth of practical, ecological, and cultural insights, offering an alternative or complementary approach to conventional veterinary medicine, especially in rural areas where access to modern healthcare is limited.

The systematic survey and documentation of this knowledge is therefore essential, not only to preserve these practices but also to explore their potential applications in modern veterinary science. Different studies have documented the use of ethnoveterinary medicinal plants across various parts of Ethiopia. For example, Awoke et al. (2024) investigated medicinal plants used to treat domestic animal diseases in Guraferda District, Bench-Sheko Zone, southwestern Ethiopia. Similarly, Hankiso et al. (2024) reported on ethnoveterinary plants and their utilization by the people of Soro District, Hadiya Zone, southern Ethiopia. In Enarj Enawga District, East Gojjam Zone, Birhan et al. (2018) described local practices and plant species used in livestock healthcare. Other studies have extended the focus to both human and livestock ailments: Alemneh (2021) in Yilmana Densa and Quarit Districts, and Abebe & Teferi (2021) in Hulet Eju Enese Woreda of East Gojjam Zone. Ethnoveterinary plant use has also been surveyed in western Ethiopia by Birhanu & Abera (2015) in Horro Gudurru Districts, and traditional medicinal plant practices in central eastern Ethiopia were documented by Hunde et al. (2006) in the Boosat Sub-District. Collectively, these studies highlight the widespread reliance on medicinal plants for animal and human healthcare throughout Ethiopia.

While Ayele et al. (2024) conducted an ethnobotanical study focusing on medicinal plants used to treat human diseases in the West Gojjam zone in selected districts such as Dembecha, South Achefer and Sekela; there has been a noticeable gap in research specifically addressing ethnoveterinary knowledge in these districts. However, the specifically the ethnoveterinary study was not conducted in Dembecha, South Achefer and Sekela districts. Hence, the objective of the current study was to conduct the ethnoveterinary medicinal plants utilized in these three districts of the West Gojjam Zone. By doing so, this research was aimed to contribute to the preservation of traditional knowledge, promote the sustainable use of medicinal plants, and provide a foundation for further research and potential applications in veterinary science.

7.2. Materials and Methods

7.2.1. Description of study Area

The study area was well described in chapter 1, General methodology, Section 1.4.1 of the general methodology, including a map of the study area.

7.2.2. Selection of study sites, sampling method and informants' selection

The selection of study sites, sampling methods, and informant selection procedures were briefly described in Section 1.4.2.2 under Chapter 1, General Methodology.

7.2.3. Ethnobotanical data collection and semi-structured interviews

Ethnobotanical data collection and semi-structured interviews were briefly described in Section 1.4.2.3 under Chapter 1, General Methodology

7.2.4. Plant specimen's identification and preservation

Preliminary identification of plant species was conducted in the field based on observable morphological characteristics. Subsequently, the species were further verified and documented by recording their local names, scientific names, and botanical families. This verification process involved a detailed comparison with existing botanical literature and, in many cases, cross-referencing with authoritative sources such as the Flora of Ethiopia and Eritrea (Volumes 1–7) to ensure accurate classification and nomenclature.

7.2.5. Ethical considerations

Ethical considerations are thoroughly outlined in Chapter 6, subsection 6.2.4, titled 'Ethical Considerations.

7.2.6. Data Analysis

The information on the ethnoveterinary medicinal plants was summarized using descriptive statistics (percentage and frequency). The 2013 MS Excel spreadsheet was used to perform summary calculations and create bar graphs and pie charts. The Informant Consensus Factor (ICF) was employed to assess the level of agreement among plant users regarding the use of medicinal plants for treating various disease categories in the study areas (Tariq et al., 2014). The ICF values range from 0 to 1, with values closer to 1 indicating a higher level of agreement among respondents on the significance of certain plant species in treating diseases (Table 7.3).The ICF was calculated using the following formula:

ICF=(nur-nt)/(nur-1)

Where nur = number of use citations for each disease, nt= number of species used

Fidelity level (FL): In ethnobotany, the fidelity level of medicinal plants is an important index showing the degree a plant species is preferred or more frequently used for medicinal purposes in the particular cultural or ecological context (Ugulu, 2012).

It was calculated as the proportion of informants reporting that a plant species is used for medicine, in relation to the total number of informants surveyed. The degree of fidelity will, therefore, be higher when the plant is more utilized and important within a given tradition; the contrary would show that the species is used infrequently or irregularly. Such a measure can help in indicating culturally significant species, informing conservation priorities, and advancing our understanding of the relationship between local communities and their natural environment in particular about plant diversity and sustainability. According to Ugulu (2012), the fidelity level value was estimated as follows:

FL = Ip/Iu × 100, where Ip is the number of respondents who reported the utilization of medicinal plants for a specific main ailment and Iu is the total number of respondents who mentioned the same plant for any ailment (Table 7.3).

Preference ranking: The preference ranking was conducted after Martin (1995) and Cotton (1996) for the most important medicinal plants used in the treatment of a particular illness, as traditional healers (key informants) usually treat it. Thus, a total of 10 informants were asked to give a value from 1-5. The informants gave value 5, which means medicinal plants with high potential for healing anthrax, but 1 was given for plants with less healing potential for anthrax. Finally, each value was summed and ranked (Table 7.4).

Direct matrix ranking. The direct matrix ranking was done according to Martin (1995). To compare the many uses of one plant species to those of another in the use categories, direct matrix ranking is crucial (Medicinal, fence, food, fodder, charcoal, construction, furniture, and firewood). In light of this, the values were scaled from 0 to 5 based on comparisons between plants species used in multipurpose categories. The multipurpose tree species were selected out of the total medicinal plants identified. In this study, 10 key informants were purposefully chosen based on their responses during the interview. They were asked to assign a rating from 0 to 5 (where 5 = best, 4 = very good, 3 = good, 2 = less used, 1 = least used, and 0 = not used) for each plant species category. The ratings assigned by the informants were then summed and ranked (Table 7.5).

7.3. Results

7.3.1. Sociodemographic characteristics of the informants

Out of the total informants, 62.47 and 37.76% were males and females, respectively. Age wise, 55.01% of the informants belonged to 42-62 years followed by over 62 years, which accounted for 24.00 % of the total informants. Informants from the age of 20-41 small constituted only 21% of the informants (Table 1). Most of the informants were found to be farmers, which accounted for 74.36 % of the total informants followed by church servants (8.86 %) and local healers (6.99%). Traders or merchants were the least represented in the present study (Table 7.1). Literacy status shows that 85.9% (368 individuals) are literate, with only 14.1% (61 individuals) being illiterate.

Table 7.1. Demographic information of the informants

Category		Total	Gender		Local healer	Farmer	Teacher	Church servant	Shop keeper	Traders
			M	F						
Age	20-41	90	70	20	10	71	3	10	2	4
	42-62	236	137	99	15	170	12	25	10	4
	>62	103	60	43	5	78	4	13	4	4
	Total	429	268	162	30	319	19	38	17	12
Education status	Literate	368								
	Illiterate	61								
	Total	429								

7.3.2. Diversity of ethnoveterinary medicinal plants

We identified a total of 53 ethnoveterinary medicinal plants representing 33 families and 51 genera in the study sites. The local name, family name, scientific name, plant parts used, and preparation methods of all the medicinal plants were noted. There were five species mentioned from the Asteraceae family and five from the Solanaceae family that were the most frequently mentioned plant species, the next most frequently mentioned family groups were the Lamiaceae and Euphorbiaceae, with four species each. The informants reported two species from other family groups including Fabaceae, Cucurbitaceae, Rutaceae, Myrtaceae, and Rosaceae. The remaining 24 species were from 24 families (Appendix 8).

Sources of Medicinal Plants for Ethnoveterinary Practices in the Study area

In the study area, ethnoveterinary practices rely on medicinal plants sourced from a variety of locations, including church forests, home gardens, wildlands, and farmlands. Church forests are the most important source (40%), acting as both sacred sites and crucial biodiversity hotspots. Home gardens are the second most important source (35%), demonstrating healers' cultivation efforts. While diminished, wildlands still provide 20% of medicinal plants, and farmlands contribute a minimal 5%. The reliance on church forests highlights their vital role in preserving both plant diversity and traditional knowledge, to protect medicinal plant sources, ensuring the preservation of biodiversity and ethnoveterinary practices.

7.3.3. Growth forms of medicinal plants

Herbs comprised of the majority of the growth form in the present study, accounting for 22 (41%) of the species, followed by shrubs, which represented 21 (40%) of the species (Fig. 7.1). About 17 % of the medicinal plants used for ethnoveternary medicine were trees. Climber growth form was the least used representing only 2 % of the total.

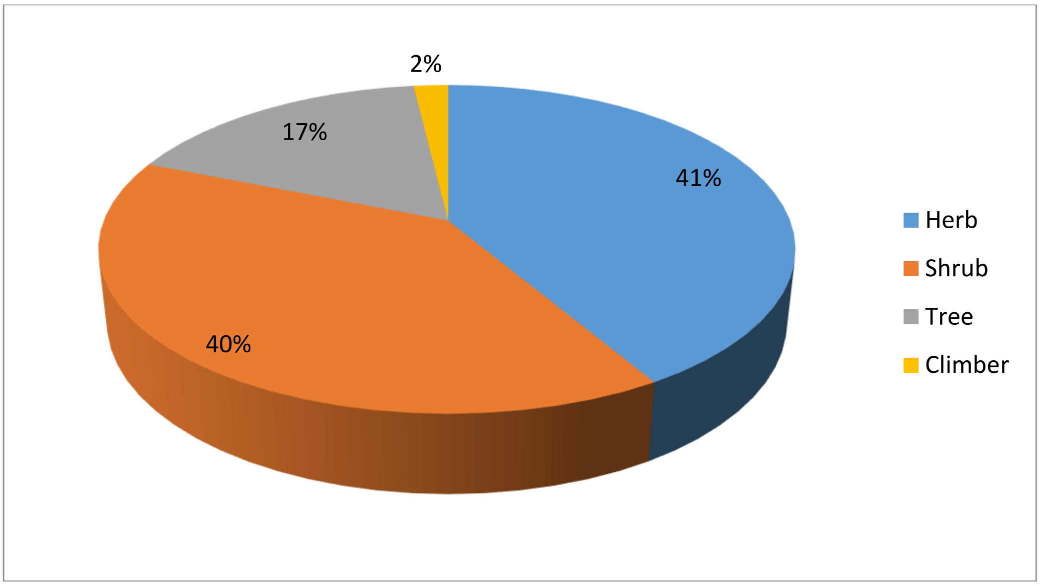


Figure 7.1. Growth form of ethnoveternary medicinal plants at study sites

7.3.4. Plant parts used for the preparation of the remedies

The leaves were found to be the most frequently used plant parts (96.23%) for the preparation of ethnoveterinary remedies. The second frequently used plant part for ethnoveternary remedy preparation was the mixture of roots and leaves, accounting for 32.08%, followed by roots and fruits (Fig. 7.2). By contrast, the combined form of fruits with leaves and whole plant were rarely used plant parts in the preparation of remedies for treating livestock diseases (Fig.7.2).

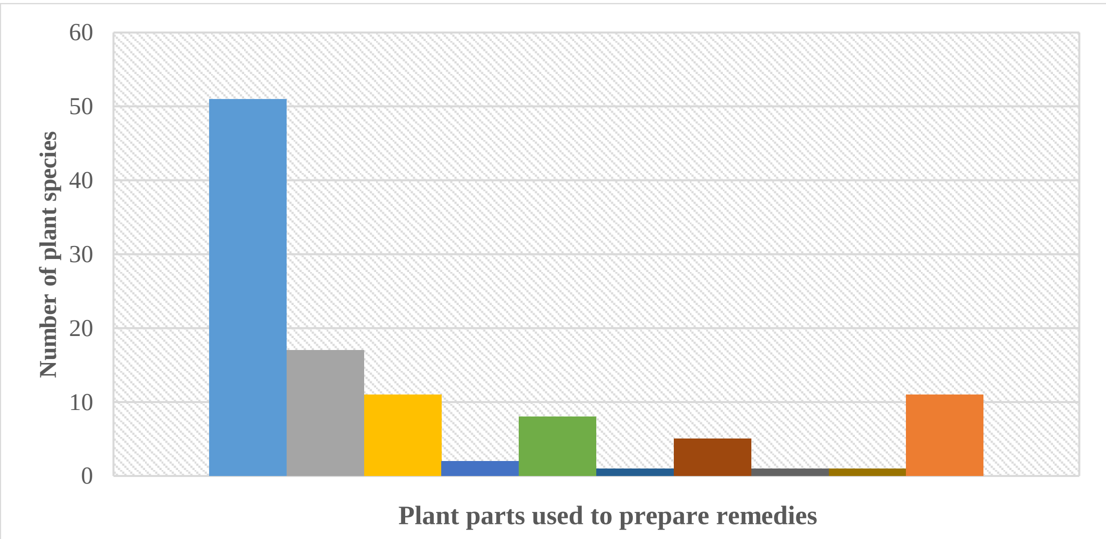


Figure 7.2. Plant parts used to prepare remedies at study sites

7.3.5. Method of preparation

The local traditional healers prepared the remedies using various methods in the study area. Most of the remedies were prepared by crushing 37 (69%), followed by pounding 16 (30%) (Fig.7.3). In the present study, squeezing plant parts was the least mode of remedy preparation.

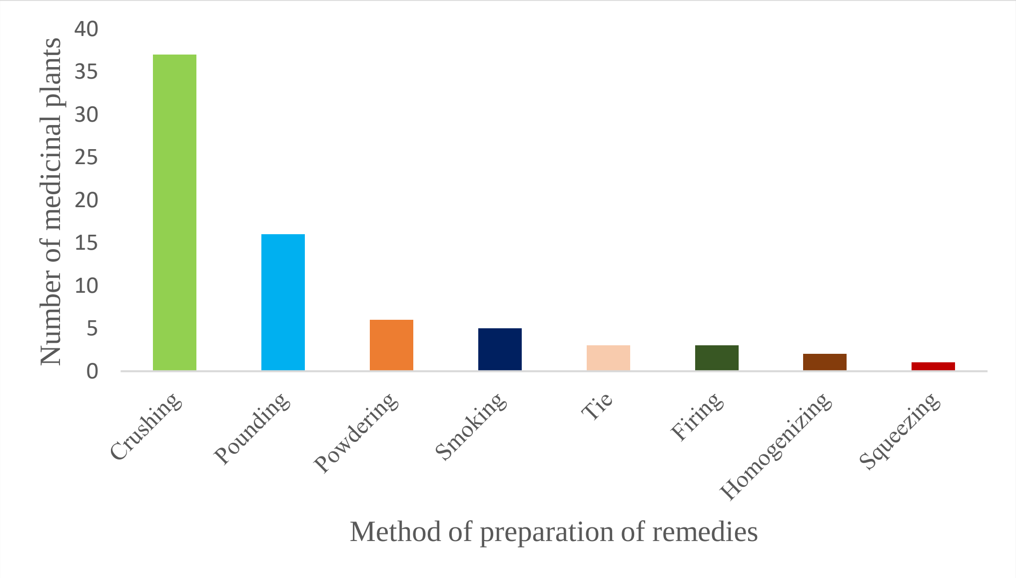


Figure 7.3. Method of preparation of remedies at the study sites

7.3.6. Route of administration

The predominant route of administering ethnoveterinary processed remedies was oral, which was applied to 36 species. This, in turn, followed by nasal administration, applied to 9 species and dermal application, which encompasses 6 species (Fig. 7.4).

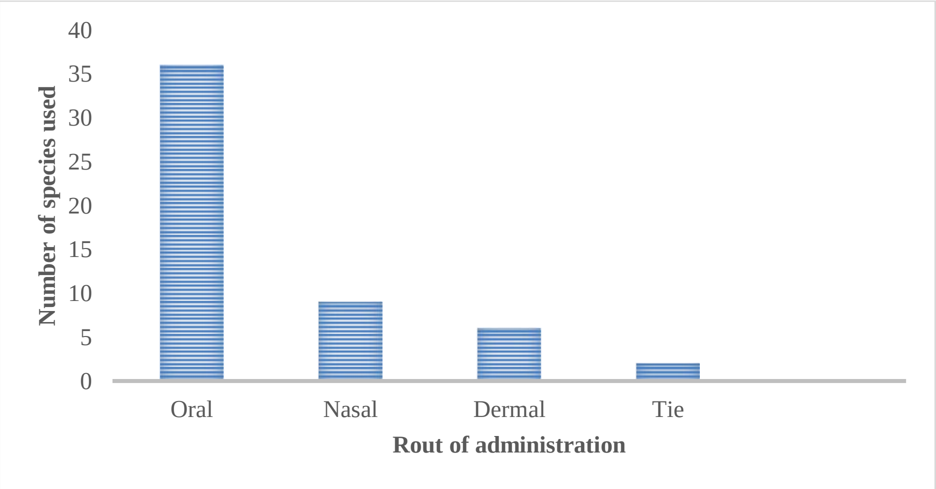


Figure 7.4. Mode of route of administration

7.3.7. Multipurpose of Ethnoveterinary medicinal plants

Informant Consensus Factor (ICF)

The ICF values calculated for each category of disease show that there is great consensus among informants regarding the medicinal plant uses in ethnoveterinary practices. The ICF values showed strong consensus for spiritual or psychological conditions (1.000). This was followed by respiratory conditions (0.996), and injury- related conditions (0.984). On the other hand, gastrointestinal issues and febrile conditions had ICF values of 0.970 and 0.971, respectively (Table 7.2).

Table 7.2. Informant Consensus Factor

Diseases Category	Nt	Nur	ICF
Parasitic Infections	9	189	0.957
Infectious Diseases	13	208	0.942
Respiratory Conditions	2	269	0.996
Gastrointestinal Issues	14	429	0.97
Injury-Related Conditions	5	256	0.984
Inflammatory or Swelling Conditions	3	123	0.984
Febrile or Sudden Illnesses	4	103	0.971
Spiritual or Psychological Conditions	1	98	1

Fidelity Level (FL)

In the study area, a total of eight commonly used ethnoveterinary medicinal plants were identified, which have variable fidelity levels for the treatments of various livestock ailments in the study area. The FL % for each plant species has been calculated on the basis of the proportion of informants who reported its use against a particular ailment. Among them, the species *Cucumis pustulatus* expressed the highest FL level, which is 96.08%, mainly for the treatment of blackleg. Thus, it shows its importance in the communities culture and is widely used for this condition. The plant Withania somnifera was used for spiritual illness and had a high FL level of 94.29%, showing its importance in managing both physical and spiritual health issues in the community. Other plants utilized for livestock ailments like *Datura stramonium* for the treatment of wounds and *Echinops kebericho* for sudden sicknesses were almost equally high in their fidelity levels: 90.70% and 92.31%, respectively (Table 7.3).

Table 7.3. Fidelity level of most commonly used ethnoveterinary medicinal plants in the study area

Plant species	Used to treat	Ip	Iu	FL %
Cucumis pustulatus	Blackleg	49	51	96.08
Datura stramonium	Wound	39	43	90.7
Withania somnifera	Spiritual illness	33	35	94.29
Dodonaea angustifolia	Broken part	28	31	90.32
Echinops kebericho	Sudden illness	24	26	92.31
Erythrina brucei	Eye diseases	26	29	89.66
Calpurnia aurea	Stomachache	39	44	88.64
Artemisia abyssinica	Diarrhea	37	41	90.24

Preference ranking

The preference ranking was calculated for five most important medicinal plants used to treat anthrax. Based on the preference of key informants *Clerodendrum myricoides* species was ranked first, followed by *Thalictrum rhynchocarpum* used to treat anthrax (Table 7.4).

Table 7.4. Preference ranking of ethnoveterinary medicinal plants used to treat anthrax at the study sites (Note: KI=key informants)

List of medicinal plants	Key informants												
	KI 1	KI 2	KI 3	KI 3	KI 4	KI 5	KI 6	KI 7	KI 8	KI 9	KI10	Total	Rank
Clerodendrum myricoides	4	5	5	5	1	3	4	3	4	4	4	42	1st
Clutia abyssinica	2	4	3	2	4	1	3	2	3	3	2	29	3rd
Lagenaria siceraria	1	3	2	2	2	3	1	2	1	2	5	24	5th
Maesa lanceolate	3	2	2	2	3	1	3	2	3	3	2	26	4th
Thalictrum rhynchocarpum	5	3	4	3	4	4	2	4	4	2	3	38	2nd

Direct matrix ranking

In this study, we contrasted the various applications of five species of medicinal plants for their multipurpose uses in the current study. A total of 13 key informants were contacted for their opinions in order to determine the multiple uses of medicinal plants in the study areas. According to the results of the direct matrix ranking, Olea europaea ranked first, followed by Eucalyptus globulus (Table 7.5). Similarly, ethnoveternary medicinal plant species used for firewood collection had the highest use diversity.

Table 7.5. Direct matrix of five ethnoveternary medicinal plant species from study sites

Name of plant species	Use diversity categories							
	Medicinal	Furniture	Construction	Fence	Charcoal	Firewood	Total	Rank
Syzygium guineense	3	3	4	3	2	5	20	5th
Olea europaea	5	4	5	4	4	4	26	1st
Hagenia abyssinica	4	5	4	3	4	4	24	3rd
Croton macrostachyus	4	4	3	3	4	4	22	4th
Eucalyptus globulus	3	4	5	4	4	5	25	2nd
Total	19	20	21	17	18	22		
Rank	4th	3rd	2nd	6th	5th	1st		

7.3.8. Proportion of medicinal plants used for treating livestock diseases

There are different types of ethnoveterinary medicinal plants used to treat various livestock diseases in the study areas (Fig. 7.5). The highest numbers of plant species were used to treat leeches, wound treatment and sudden disease conditions each with seven plant species. Eye diseases and diarrhoea were the second group of livestock disease treated with higher number of plant species, each with six species. Livestock diseases such as anthrax, bloating, coccidiosis, and febrile illnesses were treated with five plant species each (Figure 7.5). Black leg, donkey haemorrhoids, nasal bleeding, rabies, and leech infections were livestock diseases treated by the least number of plant species (Figure 7.5).

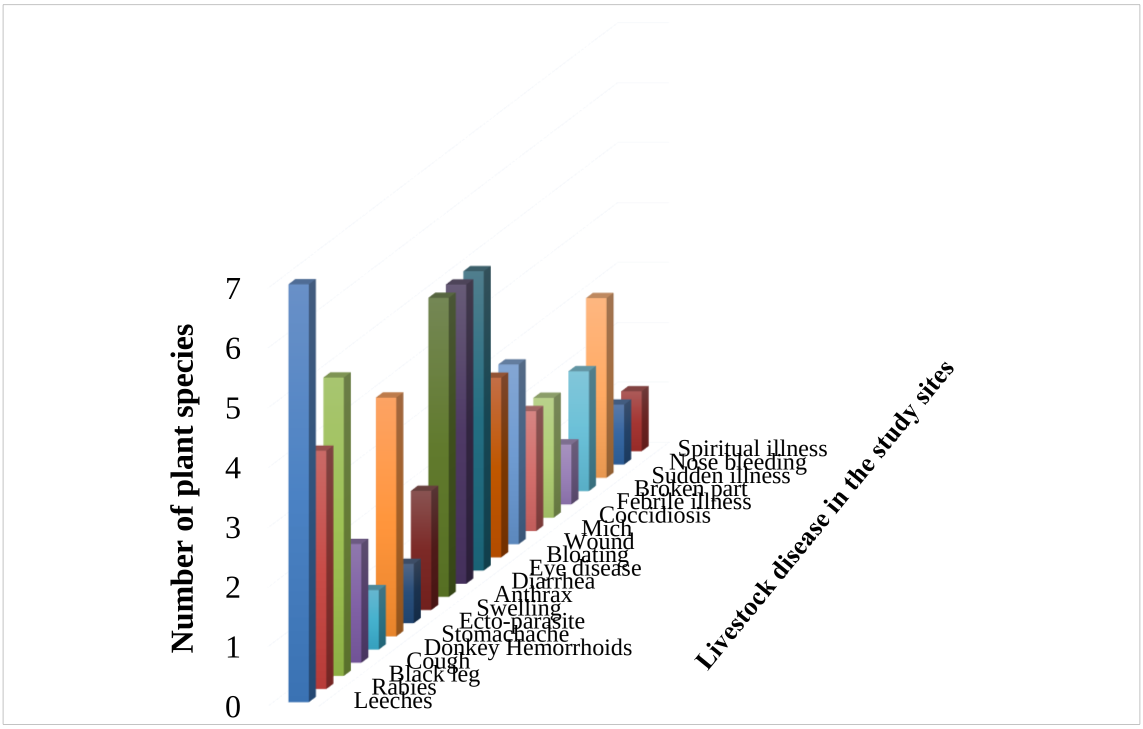


Figure 7. 5. Proportion of medicinal plants used to treat different livestock diseases

7.4. Discussion

A relatively low number of ethnoveterinary remedies were used to treat livestock diseases in many of the study areas. In different parts of the study areas showed that less number of ethnoveterinary plants were reported in Gera district by Gonfa et al. (2020); in the Omusati and Kunene regions, in Namibia by Eiki et al. (2022); in Mojana Wodera district by Abebe (2022) and in Bensa Woreda (Tekle, 2015). However, the present study documented more ethnoveterinary plants in comparison to the above previous study areas, indicating richer plant diversity in the current surveyed area. The current study showed that the most predominant growth forms were herbs. This finding was inconsistent with other earlier studies in Bale Mountains (35 species, 47.3%) reported by Yinger et al. (2007) & harbs as the most dominant habits by Feyera et al. (2017). Herbs are important plant parts because they are more accessible and in flower every year, so that they play a significant role in traditional veterinary practices (Romha et al., 2015; Dilbato et al., 2023).

The present results indicated that the most used plant part for drug preparation was leaves, which agreed with earlier ethnoveterinary studies (Dilbato et al., 2023; Abebe, 2022) that showed leaves to be the primary plant part used. In contrast, roots may affect plant regeneration adversely and may lead to extinction, as cited by Tadesse et al. (2019). The traditional healers acknowledge the leaves' effectiveness in treating various ailments in animals, and this calls for the selection and harvesting of leaves for proper plant parts. Selection for proper plant parts for harvesting is important for sustainability in that it maintains the regenerating power of the plant; for instance, root harvesting is not recommended unless there is the adoption of sustainable practices to prevent over-harvesting and hence plant depletion. Poor methods of harvesting lead to the extinction of some plant species (Papageorgiou et al., 2020). Appropriate and viable harvesting methodologies, therefore, need to be in place so that medicinal plants could continuously be made available for future applications, hence their value in traditional medicinal use and development of ecological balance should be maintained.

The most preparation methods at the study sites were found to be crushing and pounding, which is in agreement with previous studies where crushing was recognized as the most used technique by Romha et al. (2015), and Majeed et al. (2020). According to traditional healers, this is because crushing improves the extraction efficiency of biologically active compounds, hence increasing the bioactivity of the plant parts.

This justifies the notion that proper sample preparation technique plays an important role in ensuring full therapeutic potential of plant specimens (Krakowska-Sieprawska et al., 2022).

Ethnoveterinary medicinal plants can be administered via various methods: orally, by having remedies consumed and absorbed through the digestive tract, often involving the crushing of plant parts and mixing them with water or other liquids for cattle to ingest. In consistent to this result in various parts of Ethiopia, processed remedies were mostly administered through oral route (Feyera et al., 2017; Yinger et al., 2007). Traditional healers often prefer oral administration of medicinal plants when treating cattle because it is an efficient way to deliver therapeutic compounds to the animals (Tichy & Novak, 1998; Palombo, 2011). By administering plant-based remedies through drinking water, feed, or oral dosing, and the active ingredients can be absorbed into the bloodstream and target internal issues such as digestive disorders, infections, or inflammation. This method is less stressful for the animals, especially when compared to injections, and allows for easier integration into daily care routines. The nasal route is preferred to apply plant remedies through the nostrils, such as using juice or crushed plant parts to address respiratory issues.

In dermal route, processed remedies are directly applied to skin or the affected area, following utilizing preparations like crushed leaves combined with other substances to treat wounds or irritations. A portion of the plant (such as a stem) is tied to the affected or broken area or wound, typically for the treatment of fractures or injuries.

The high ICF values obtained in most of the disease categories indicated a high cultural consensus in the community. They support the perceived efficacy of these plant-based treatments in ethnoveterinary practices. For instance, the highest ICF value was obtained for respiratory conditions (0.996), indicating virtual agreement on its remedy. In contrast to the present study, the highest ICF value had the external parasites and skin problems in selected districts of southern Ethiopia (Romha et al., 2015). This may represent both its prevalence and traditional treatments of effectiveness in the community. Spiritual/psychological problems have an absolute consensus of ICF = 1.000, supposing that this category is culturally perceived in a peculiar manner, with a certain remedy likely to be very important. In other study showed that yoke sore (wound) had the highest informant consensus factor (ICF) value (1.00), followed by leech infestation (0.92) and endoparasite infections (0.90) (Feyisa et al., 2021). Similarly, gastrointestinal problems ICF = 0.970, injury conditions ICF = 0.984, and febrile illness/sudden problems ICF = 0.971 indicated highly unanimous information, assuming that these sicknesses are generally received and plant remedies are developed to treat them. By contrast, the somewhat lower ICF values for parasitic infection (0.957) and infectious diseases (0.942) point either toward greater ranges of treatments or variable perceptions of treatment efficacies, which might then indicate the possible need for a greater variety of remedies in addressing those particular conditions.

The highest level of fidelity for many of the ethnoveterinary plants among the respondents in the study area shows the deeply rooted knowledge and belief in those plants for traditional healing by the community. The *Cucumis pustulatus* species had the highest fidelity level at 96.08%, suggests that it is important in treating blackleg, which is a common disease among livestock in the study area, on the other hand, Withania somnifera is generally used to treat spiritual illness with a FL of 94.29% indicating evidence that animal health encompasses body and spirit. Unlike the present study, *Nicotiana tabacum, Malva parviflora*, and *Calpurnia aurea* showed the highest fidelity level (100%) and rank order priority (100%) for treating leech infestations, retained placenta, and snake poisoning, respectively (Feyisa et al. 2021). The plants of high fidelity class include *Datura stramonium* and *Echinops kebericho,* restricted to the treatment of wound and sudden ailments.

Plants with low fidelity levels include *Erythrina brucei* and *Calpurnia aurea*, at 89.66% and 88.64%, respectively, probably deal with more general purposes in medicinal use or serve as alternative medicine for similar conditions. These findings again underscore the two most influential factors in plant selection for medicinal applications: local ecological availability and community cultural tradition. The fact that certain plants are used consistently across specific diseases is evidence not only of their perceived effectiveness in treating certain ailments but also of the depth of cultural tradition regarding plant knowledge passed down through generations.

This knowledge is very important for the preservation of traditional practices and may introduce perspectives for further research on the pharmacological properties of these plants, in search of new treatments against animal diseases. Besides this, the high level of fidelity indicates a dependence that is stable, probably determined by factors such as the low availability of modern veterinary services or simply a cultural preference for traditional remedies. The preference ranking of the ethnoveterinary medicinal plants used in treating anthrax, as done by the key informants had some variations in the selected medicinal plants. Clerodendrum myricoides was highly preferred and ranked first, meaning it is widely used and highly supported by the informants for the treatment of anthrax. This was closely followed by *Thalictrum rhynchocarpum*, ranked second and hence was also one of the important plants in local ethnoveterinary practices. Coming third, with 29, was *Clutia abyssinica*, emerging as one of the commonly used plants, while less favored were *Maesa lanceolata* and *Lagenaria siceraria*, ranked fourth and fifth, respectively. Results from the fidelity level showed a clear preference for *Clerodendrum myricoides* and *Thalictrum rhynchocarpum*, suggests an indication of their potential importance in local medicinal knowledge and practices in the controlling anthrax in livestock. The ranking further shows that though some plants are more widely favored compared to others, this may be in regard to perceived efficacy, availability, or traditional knowledge.

At the study sites, multipurpose species, particularly Olea europaea, are facing significant threats due to their frequent harvesting for non-medicinal uses, including construction, furniture-making, fencing, charcoal production, and firewood. Without sensible and effective conservation measures, the extinction of this species is imminent. Research finding indicates that many multifunctional medicinal plants are at risk Hassan et al. (2014), highlighting the urgent need of these medicinal plants for sustainable management practices. To mitigate this threat, it is imperative to promote the prudent use of such valuable medicinal plants and explore alternative approaches to their application, thereby ensuring their survival and continued contribution to both human health and biodiversity conservation.

Interviewed traditional healers showed that medicinal plants used in treating livestock diseases were quite diverse, with a complexity of local knowledge. Among these leeches infestation represented one of the most common types of diseases, and there were seven medicinal plant species identified for treating them, specifically *Achyranthes aspera*, *Cicer arietinum*, *Citrus aurantiifolia*, *Juniperus procera*, *Nicotiana tabacum*, *Rhamnus prinoides*, and *Rumex nervosus*. Furthermore, the healers indicated a number of animal diseases treated with medicinal herbs for 20 different conditions, showing the wide range of therapies available from plant-based remedies. The conditions most frequently mentioned by informants include parasites of leeches infestation, diarrhoea, and anthrax diseases, most of which require multiple plant species to treat due to their complex nature. This is in agreement with works earlier conducted by Abraha (2007), Assefa and Bahiru (2018), and Asfaw et al. (2022). Relatively rare conditions, such as haemorrhoids of donkeys, febrile illness, ectoparasites, and bleeding from the nose, were treated associated with one or two species only; since treatment approaches are so simple. These results indicated the close linkage of plant remedies to animal health, which calls for further research to fully understand the diversity and specificity of plant species to various diseases treatments. This would contribute to such studies supporting conservation, adding in depth knowledge to sustainable ethnoveterinary practices, and linking traditional knowledge with state-of-the-art of modern scientific methodology.

7.5 Conclusion and Recommendation

The study documented 53 ethnoveterinary medicinal plants from 33 families and 51 genera, with Asteraceae and Solanaceae being the most represented. Herbs (41%) and shrubs (40%) were dominant, and leaves (96%) were the most frequently used plant part, with remedies mainly prepared by crushing (69%) and administered orally (68%). Informant Consensus Factor (ICF) showed strong agreement, particularly for spiritual/psychological (1.0), respiratory (0.996), and injury-related (0.984) conditions, while Fidelity Level (FL) analysis highlighted Cucumis pustulatus (96.1%) for blackleg, Withania somnifera (94.3%) for spiritual illness, and Echinops kebericho (92.3%) for sudden sickness. Preference ranking identified Clerodendrum myricoides as the top anthrax remedy, and Olea europaea as the most multipurpose species. However, anthropogenic influences such as agricultural expansion, urban growth, and the migration of traditional healers threaten the preservation of this knowledge and the plants themselves. This underlines the urgency of documenting ethnoveterinary knowledge and integrating it into policy, as veterinary medicine can benefit greatly from such resources. The study emphasizes the role of local communities in conservation and recommends systematic documentation, community involvement, biodiversity monitoring, education-based capacity building, and public awareness to ensure sustainable use and preservation of ethnoveterinary medicinal plants.

CHAPTER 8. SUMMARY AND RECOMMENDATIONS

SUMMARY

Church forests in the highlands of Ethiopia are small patches of natural forest found around Ethiopian Orthodox Tewahido Churches. These forests support high native species richness, provide significant carbon storage, and preserve plant-based healthcare practices that are deeply rooted in local culture. They are used for worship and burials but also protect many native plants, animals and medicinal plants. These forests have been kept for hundreds of years because of strong religious beliefs. Today, they are in danger due to farming, tree cutting, and other human activities. Even though they are small, church forests are very important for nature and culture. Protecting them is necessary to keep local biodiversity and traditional values alive for future generations.

The present study was conducted in West Gojjam zone Amhara Regional State, Ethiopia. The data was collected from twenty-six church forests. The church forests were selected by using stratified sampling methods by considering different factors such as elevation, distance to population center wall and siz of forest. This study was examined various aspects of church forests, including the composition and regeneration status of woody species, above-ground biomass, and carbon storage, types and levels of human disturbance, and soil nutrient variations across different land covers. All factors were analyzed in relation to elevation, forest size, distance from settlements, and the existence of protective walls. Moreover, the present study included an ethnobotanical assessment of medicinal plants used to treat human and livestock diseases in selected districts of the West Gojjam Zone. The integration of ecological and ethnobotanical studies in West Gojjam's church forests emphasizes their dynamic and multifaceted role as both biodiversity hotspots and vital sources of traditional medicinal knowledge.

The first study was focused on woody species composition and regeneration status of church forests in West Gojjam zone. In this study a total of 111 woody species were identified belonging to 95 genera and 51 families. Most species (82.88%) were indigenous, while 1.8% was endemic. Species richness varied from 7 to 45 per forest. Fabaceae was the most dominant family. The forests showed an average basal area of 29.268 m^2 ha^{-1} and a total stem density of 5880 individuals' ha^{-1}. Regeneration status was good, with 6136 seedlings and 5923 saplings ha^{-1}.

The distribution classes of DBH and height showed an inverted J-shaped distribution, this implies that the highest number of individual trees were young and had the lowest DBH and height classes. The most abundant species were *Eucalyptus camaldulensis*, *Calpurnia aurea*, and *Juniperus procera*, while *Ficus vasta* had the highest basal area. IVI highlighted *Ficus vasta* and *Juniperus procera* as ecologically dominant. Elevation significantly influenced tree density, abundance and species richness.

The second study was focused on estimation of carbon stocks of woody plant species in church forests of West Gojjam zone, highlighting their role in climate change mitigation. The forests possess an AGB of 31.97 ± 3.31 tons ha^{-1} and an overall carbon stock of 26.48 ± 2.83 tons ha^{-1} and can sequester an amount of approximately 97.15 ± 10.47 tons of CO_2 equivalent ha^{-1}. Highest AGB recorded from Debre Mihret Mesk Kidanemihret church forest (99.00 tons ha^{-1}), while lowest was from Korch Silassie church forest. Dominant tree species such as *Ficus vasta* and *Juniperus procera* had the highest carbon storage potential, with *Ficus vasta* alone contributing a significant proportion of aboveground biomass and carbon pools due to its large size and growth.

The third study was focused on human disturbances and their impact on woody species diversity in sacred church forests of West Gojjam zone. In this study, there were recoreded different types of human and natural disturbance that had effects on woody specis compositions and diversity. The study area experienced an average human disturbance of 24.35%, reflecting the impact of human activities on the church forests. All types of human disturbnce such as grave construction, agricultural expansion, logging, grazing, and infrastructure development, all reduce species richness, density, and biomass. In addition, disturbances such as trails, plantations, and cut stumps are found to disproportionately affect forest edges, where species richness and soil are greatly diminished compared to the interior church forest. This implies that the structural and functional integrity of these forests is mainly vulnerable at their edges.

The fourth study was on focused on the impact of human disturbance on church forest soil properties. This study examined both physical and chemical properties of soils across three different land cover types (church forests, outsid and eucalyptus plantations). The soil samples were collected from these three-land cover tpyes as a replicate form. A total of 303 soil sample was analyzed their physical (water content and bulk density) and chemical (soil carbon, total nitrogen and available phosphorus) properties.

The result revealed that church forests had the highest moisture content (42.98%), porosity (16.08%) and nutrient levels, including carbon (57.22%), phosphorus (0.0445 ppm), and nitrogen (0.56%). However, Soils outside church forests, especially near agricultural land, had lower fertility than those inside. Eucalyptus plantations showed reduced moisture (28.34%), more acidic pH (4.95), and nutrient depletion. Nutrient levels declined from the forest interior to the edges. Edge effects caused slight increases in bulk density (0.58 vs. 0.57 g/cm^3) and variability in water content, indicating soil compaction and stress on plant growth. Porosity was slightly higher inside (16.58%) than at the edges (15.88%), suggesting limited root development and water retention near edges.

The fith study was focused on ethnobotanical study of medicnal plants used to treat human diseases in West Gojjam zone. In this study a total of 429 informants (399 general and 30 key informants) were involved to collect data from three districts (Dembecha, South Achefer and Sekala districts). From the study districts 97 medicnal plants used to treat human diseases were documented. Fabaceae was the dominant family. Most of the medicnal plant parts to prepare remedies were leaves. They prepared remedies through crushing and pounding and administrated through oral. *Calpurnia aurea* was the most highly ranked plant for treating diarrhea, followed by *Rumex nepalensis*. *Olea europaea subsp. cuspidata* was the most important multipurpose plant species.

The sixth study was focused on ethnobotanical study of medicinal plants used to treat livestock diseases in West Gojjam zone. In this study a total of 429 informants (399 general and 30 key informants) were involved to collect data from three districts (Dembecha, South Achefer and Sekala districts). A total of 53 medicinal plants were documented from the study area. Asteraceae and Solanaceae were the most used families with five plants each. The most common plant part to use from the plants to treat livestock diseases was leaves. The most common preparation method of the remedies appeared was crushing followed by pounding. Most remedies were administered orally. *Cucumis pustulatus* and *Withania somnifera* had the highest FL for blackleg and spiritual illnesses, respectively. *Clerodendrum myricoides* are the most preferred for treating anthrax. The direct matrix ranked *Eucalyptus globulus* and *Olea europaea subsp. cuspidata* the highest and made this distinction because of their multiple uses in their study area.

Recommendations

The findings of this study highlight the critical ecological and cultural roles of church forests in the West Gojjam Zone. To ensure their long-term preservation and enhance their benefits, the following targeted recommendations are proposed:

1. For Enhanced Biodiversity Conservation and Forest Management:

Implement Buffer Zones: Establish and actively restore native vegetation in buffer zones around church forests. This will mitigate edge effects, reduce soil degradation, and create a transitional habitat that protects the forest core from external pressures.

Control Invasive Species: Develop and enact management plans to control the spread of exotic species, particularly *Eucalyptus camaldulensis*. This should include selective removal and replacement with indigenous tree species to restore ecological balance and improve native regeneration.

Promote Native Species Restoration: Launch enrichment planting programs within church forests, focusing on native species with high ecological value (e.g., high IVI and carbon storage potential like *Ficus vasta* and *Juniperus procera*) to bolster structural complexity and resilience.

2. For Mitigating Human Disturbances:

Regulate Land-Use Practices: Collaborate with church authorities and local communities to formally regulate or relocate disruptive activities such as arbitrary grave construction, large gatherings, and clearing within the forest. Designate specific, less ecologically sensitive areas for these purposes.

Manage Grazing Pressure: Work with communities to develop and enforce agreements on controlled grazing, such as seasonal restrictions or the use of tethered grazing, to allow for natural seedling establishment and reduce soil compaction.

Strengthen Physical Protection: While walls alone were not a definitive factor for biomass, maintaining and constructing protective walls around church forests remains a valuable strategy to deter unauthorized entry and livestock, thereby reducing physical disturbance.

3. Integrate Church Forests into Climate Change Mitigation Programs:

As church forests demonstrated notable carbon sequestration potential (mean total carbon ≈ 26.48 t ha^{-1}), integrating them into carbon credit and REDD+ schemes is essential. This can incentivize conservation and provide sustainable financial benefits to local communities.

Develop Sustainable Income Alternatives: Actively support church communities in developing alternative income sources to reduce reliance on forest-destructive activities like converting forestland to agriculture. This could include promoting non-timber forest products, beekeeping, or eco-cultural tourism that aligns with the sacred nature of the sites.

4. For Soil Conservation and Land Rehabilitation:

Promote Sustainable Agriculture: Encourage the adoption of soil conservation practices (e.g., agroforestry, reduced tillage) in the agricultural lands surrounding church forests to improve soil health and reduce the fertility contrast with the forest interior.

Rehabilitate Degraded Lands: Initiate programs to rehabilitate degraded lands, especially those currently under monoculture eucalyptus plantations, by interplanting or replacing them with native species to restore soil nutrient cycling and water retention capacity.

5. Promote Traditional Knowledge Documentation and Ethnobotanical Conservation:

Given that medicinal plant knowledge is transmitted orally and threatened by modernization, initiatives should focus on documenting, validating, and conserving medicinal plants within church forests particularly species with high Informant Consensus Factor (ICF) and Fidelity Level (FL) values to safeguard cultural and medicinal heritage.

6. Strengthening Institutional Collaboration and Continuous Monitoring

Collaboration between the Ethiopian Orthodox Tewahedo Church, local communities, and environmental institutions should be strengthened to ensure effective church forest conservation. Integrating traditional stewardship with scientific management enhances restoration success. Regular monitoring of vegetation, biodiversity, and carbon stock is also recommended to support adaptive management and evidence-based decision-making.

References

Abbott, A. (2018). Biodiversity thrives in Ethiopia's church forests: Ecologists are working with the nation's Tewahedo churches to preserve these pockets of lush, wild habitat. https://www.nature.com/immersive/d41586-019-00275-x/index.html. Accessed 9 Dec 2019.

Abdela, G., Girma, Z., and Awas, T. (2022). Ethnobotanical study of medicinal plant species in Nensebo District, southeastern Ethiopia. *Ethnobotany Research and Applications,* 24, 1-25. https://doi.org/10.32859/era.24.28.1-25.

Abe, R., and Ohtani, K. (2013). An ethnobotanical study of medicinal plants and traditional therapies on Batan Island, the Philippines. *Journal of Ethnopharmacology,* 145(2), 554-565. https://doi.org/10.1016/j.jep.2012.11.029.

Abebe, B., and Chane, T. (2021). Ethnobotanical study of medicinal plants used to treat human and livestock ailments in Hulet Eju Enese Woreda, East Gojjam Zone of Amhara Region, Ethiopia. *Evidence-Based Complementary and Alternative Medicine*, 2021, Article ID 6668541. https://doi.org/10.1155/2021/6668541.

Abebe, D., and Hagos, E. (1991). Plants as a primary source of drugs in traditional health practices of Ethiopia. In J. M. M. Engels, J. G. Hawkes, & M. Worede (Eds.), *Plant genetic resources of Ethiopia* (pp. 101–113). Cambridge University Press.

Abebe, D., Debela, A., and Urga, K. (2003). Medicinal and other useful plants of Ethiopia. EHNRI. Addis Ababa, Ethiopia.

Abebe, M. (2022). The study of ethnoveterinary medicinal plants at Mojana Wodera District, Central Ethiopia. *PLOS ONE,* 17(5), e0267447.

Abebe, A., Bekele, T., Lulekal, E., and Coayla, E. (2023). Local communities and parishioner s perceptions on monasteries forest patch plant biodiversity conservation in Northern Wollo, Ethiopia. *International Journal of Forestry Research,* 2023, 1-6. https://doi.or g/10.1155/2023/2597123.

Abebe, G., Tsunekawa, A., Haregeweyn, N., Taniguchi, T., Wondie, M., Adgo, E. Masunaga, T., Tsubo, M., Ebabu, K., Mamedov, A., et al. (2020). Effect of soil microbiome from church forest in the Northwest Ethiopian Highlands on the growth of *Olea europaea* and *Albizia gummifera* seedlings under glasshouse conditions. *Sustainability,* 12(12), 4976. https://doi.org/10.3390/su12124976.

Abera, B. (2014). Medicinal plants used in traditional medicine by Oromo people, Ghimbi District, Southwest Ethiopia. *Journal of Ethnobiology and Ethnomedicine,* 10(1), 40.

Abera, M. (2019). A review on the significance of traditional medicinal plants for human use in Ethiopia. *Journal of Plant Pathology and Microbiology,* 10(9), 484.

Abiyou, T., Hailu, T., and Teshome, S. (2015). The contribution of Ethiopian Orthodox Tewahido Church in forest management and its best practices to be scaled up in North Shewa Zone of Amhara Region, Ethiopia. *Agriculture, Forestry, and Fisheries*, 4(3), 123-137. https://doi.org/10.11648/j.aff.20150403.18.

Abraha, G. (2007). Major animal health problems of market-oriented livestock development in Atsbi Womberta Woreda, Tigray Regional State. (DVM thesis). Addis Ababa University. Available from: https://cgspace.cgiar.org/server/api/core/bitstreams/361bda8a-bc09-4f2c-9adb-bfa8b77ea5e3/content

Abunie, A., and Dalle, G. (2018). Woody species diversity, structure, and regeneration status of Yemrehane Kirstos Church Forest of Lasta Woreda, North Wollo Zone, Amhara Region, Ethiopia. *International Journal of Forestry Research,* 2018, 1-8. https://doi.org/10.1155/2023/2597123.

Adame, M. F., Cherian, S., Reef, R., and Stewart-Koster, B. (2017). Mangrove root biomass and the uncertainty of belowground carbon estimations. *Forest Ecology and Management,* 403, 52-60. https://doi.org/10.1016/j.foreco.2017.08.016.

Addi, A., Demissew, S., Soromessa, T., and Asfaw, Z. (2019). Carbon stock of the moist afromontane forest in Gesha and Sayilem Districts in Kaffa Zone: An implication for climate change mitigation. *Journal of Ecosystem and Ecography,* 9, 259. https://doi.org/10.4172/2157-7625.1000259.

Adimassu, Z., Tamene, L., and Degefie, D. T. (2020). The influence of grazing and cultivation on runoff, soil erosion, and soil nutrient export in the central highlands of Ethiopia. *Ecological Processes,* 9(1), 23. https://doi.org/10.1186/s13717-020-00230-z

Admassie, Y. (1995). Twenty years to nowhere: Property rights, land management and conservation in Ethiopia (Doctoral dissertation). Uppsala University.

Aerts, R., Lerouge, F., November, E., Lens, L., Hermy, M., and Muys, B. (2007). Land rehabilitation and the conservation of birds in a degraded Afromontane landscape in northern Ethiopia. *Biodiversity and Conservation,* 17(1), 53-69. https://doi.org/10.1007/s10531-007-9230-2.

Aerts, R., Van Overtveld, K., November, E., Alemayehu Wassie, A., Abiyu, A., Demissew, S., and Muys, B. (2016). Conservation of the Ethiopian church forests: Threats, opportunities and implications for their management. *Science of the Total Environment,* 551-552, 404-414. https://doi.org/10.1016/j.scitotenv.2016.02.034

Alebie, G., Urga, B., and Worku, A. (2017). Systematic review on traditional medicinal plants used for the treatment of malaria in Ethiopia: Trends and perspectives. *Malaria Journal,* 16, 307. https://doi.org/10.1186/s12936-017-1953-2.

Alem, D., Dejene, T., Geml, J., Oria-de-Rueda, J.A., and Martín-Pinto, P. (2022). Metabarcoding analysis of the soil fungal community to aid the conservation of underexplored church forests in Ethiopia. *Scientific Reports,* 12. https://doi.org/10.1038/s41598-022-08828-3.

Alem, S., Woldemariam, T., and Pavlis, J. (2010). Evaluation of soil nutrients under *Eucalyptus grandis* plantation and adjacent sub-montane rain forest. *Journal of Forestry Research*, 21(4), 457-460.

Alemayehu, G., Asfaw, Z., and Kelbessa, E. (2015). Plant diversity and ethnobotany in Berehet District, North Shewa Zone of Amhara Region (Ethiopia) with emphasis on wild edible plants. *Journal of Medicinal Plants Studies*, 3(6), 93-105.

Alemayehu, K., Asfaw, Z., and Kelbessa, E. (2015). Ethnobotany of medicinal plants in Ada'a District, East Shewa Zone of Oromia Regional State, Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 11, 25. https://doi.org/10.1186/s13002-015-0017-4

Alemneh, D. (2020). Ethnobotany of wild edible plants in Yilmana Densa and Quarit Districts of West Gojjam Zone, Amhara Region, Ethiopia. *Ethnobotany Research and Applications*, 20. https://doi.org/10.32859/era.20.47.1-14

Alemu, M., Asfaw, Z., Lulekal, E., et al. (2024). Ethnobotanical study of traditional medicinal plants used by the local people in Habru District, North Wollo Zone, Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 20(1), 4. https://doi.org/10.1186/s13002-023-00644-x.

Alignier, A., and Deconchat, M. (2013). Patterns of forest vegetation responses to edge effect as revealed by a continuous approach. *Annals of Forest Science*, 70, 601-609. https://doi.org/10.1007/s13595-013-0301-0.

Alongi, D. (2012). Carbon sequestration in mangrove forests. *Carbon Management*, 3(3), 313-322. https://doi.org/10.4155/cmt.12.20.

Amanuel, A., and Dalle, G. (2018). Woody species diversity, structure, and regeneration status of Yemrehane Kirstos Church Forest of Lasta Woreda, North Wollo Zone, Amhara Region, Ethiopia. *International Journal of Forestry Research*, 2018, 5302523. https://doi.org/10.1155/2018/5302523.

Amare, B. M., Berhane, G., Wassie, W., and Berhanu, A. T. (2019). Review: Church forests, the green spots of Ethiopian highlands. *Asian Journal of Forestry*, 3(2). https://doi.org/10.13057/asianjfor/r00300201.

Amsalu, N., Bezie, Y., Fentahun, M., Alemayehu, A., and Amsalu, G. (2018). Use and conservation of medicinal plants by indigenous people of Gozamin Wereda, East Gojjam Zone of Amhara Region, Ethiopia: An ethnobotanical approach. *Evidence-Based Complementary and Alternative Medicine*, 2018, 1-23. https://doi.org/10.1155/2018/2973513.

Andersen, L. E. (2002). The dynamics of deforestation and economic growth in the Brazilian Amazon. Cambridge University Press.

Anderson, L. (2007). Faith as a means of healing: Traditional medicine and the Ethiopian Orthodox Church in and around Lalibela. Independent Study Project (ISP) Collection, 128. Retrieved from https://digitalcollections.sit.edu/isp_collection/128.

Araya, S., Abera, B., and Giday, M. (2015). Study of plants traditionally used in public and animal health management in Seharti Samre District, Southern Tigray, Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 11, 22. https://doi.org/10.1186/s13002-015-0015-5.

Asefa, M., Cao, M., He, Y., Mekonnen, E., Song, X., and Yang, J. (2020). Ethiopian vegetation types, climate and topography. *Plant Diversity*, 42(4), 302-311. https://doi.org/10.1016/j.pld.2020.04.004.

Asfaw, A., Lulekal, E., Bekele, T., et al. (2022). Medicinal plants used to treat livestock ailments in Ensaro District, North Shewa Zone, Amhara Regional State, Ethiopia. *BMC Veterinary Research*, 18(1).

Asfaw, D., Tiki, L., and Worku, D. (2019). Carbon storage potential of Kubayo Forest and its implication for climate change mitigation, change Bale Zone, southeastern Ethiopia. *Chemical and Materials Research*, 11(9). https://doi.org/10.7176/cmr/11-9-02.

Asfaw, M. M., and Abebe, F. B. (2022). Traditional medicinal plant species belonging to Fabaceae family in Ethiopia: A systematic review. *International Journal of Plant Biology*, 12(1), 8473. https://doi.org/10.4081/pb.2021.8473.

Ashebo, T. (2019). A review on the qualitative method of the study of people-plants' relationship in their environment. International Journal of Environmental Science and Natural Resources, 22(1), 556078. https://doi.org/10.19080/IJESNR.2019.22.556078.

Asmare, T. K., Abayneh, B., Yigzaw, M., and Birhan, T. A. (2023). The effect of land cover type on selected soil physicochemical properties in Shihatig watershed, Dabat district, Northwest Ethiopia. *Heliyon*, 9, e16038. https://doi.org/10.1016/j.heliyon.2023.e16038.

Assa, B. S. K. (2020). The deforestation-income relationship: Evidence of deforestation convergence across developing countries. *Environment and Development Economics*, 26, 1–20. https://doi.org/10.1017/s1355770x2000039x.

Assefa, A., and Bahiru, A. (2018). Ethnoveterinary botanical survey of medicinal plants in Abergelle, Sekota, and Lalibela districts of Amhara region, Northern Ethiopia. *Journal of Ethnopharmacology*, 213, 340–349.

Atsbha, T., and Wayu, S. (2020). Utilization of indigenous tree and shrub species as animal feed resources in South Tigray, North Ethiopia, and implication for sustainable livestock production. Amazonian *Journal of Plant Research*, 4(3), 594–608. https://doi.org/10.26545/ajpr.2020.b00069x.

Atsbha, T., Desta, A. B., and Zewdu, T. (2019). Woody species diversity, population structure, and regeneration status in the Gra-Kahsu natural vegetation, southern Tigray of Ethiopia. *Heliyon*, 5, e01120. https://doi.org/10.1016/j.heliyon.2019.e01120

Awoke, A., Gudesho, G., Akmel, F., et al. (2024). Ethnobotanical study of medicinal plants in the southwestern region of Ethiopia. *Ethnobotany Research and Applications*, 29, 67.

Ayalew, H., Tewelde, E., Abebe, B., Alebachew, Y., and Tadesse, S. (2022). Endemic medicinal plants of Ethiopia: Ethnomedicinal uses, biological activities and chemical constituents. *Journal of Ethnopharmacology*, 293, 115307. https://doi.org/10.1016/j.jep.2022. 115307.

Ayele, A. H., Seid, A., Mekonnen, A. B., Adnew, W. W., and Yemata, G. (2024). Ethnobotanical study of the traditional use of medicinal plants used for treating human diseases in selected districts of West Gojjam zone, Amhara Region, Ethiopia. *Phytomedicine Plus*, 4(3), 100620.

Ayele, A., Seid, A., Mekonnen, A. B., Wassie, W. A., Yemata, G., Yihune, E., Mekuriaw, A., and Shimeles, L. (2024). Woody species diversity, structure, and regeneration status of the church forests in West Gojjam Zone, northwestern Ethiopia. *Trees, Forests and People*, 16, 100570. https://doi.org/10.1016/j.tfp.2024.100570

Baez, M., Woods, C. L., & Cardelús, C. L. (2022). Sacred church forests in Northern Ethiopia: Biodiversity and cultural islands. In F. Montagnini (Ed.), Biodiversity islands: Strategies for conservation in human-dominated environments (pp. 531–548). Springer. *Topics in Biodiversity and Conservation*, http://dx.doi.org/10.1007/978-3-030-92234-4_21.

Bagnall, D. K., Shanahan, J. F., Flanders, A., Morgan, C. L. S., and Honeycutt, C. W. (2021). Soil health considerations for global food security. *Agronomy Journal*, 113, 4581–4589. https://doi.org/10.1002/agj2.20783

Balick, M., and Cox, P. (1996). Plants, people and culture: Science of ethnobotany. Scientific American Library.

Balunas, M., and Kinghorn, A. (2005). Drug discovery from medicinal plants. *Life Sciences*, 78(5), 431-441. https://doi.org/10.1016/j.lfs.2005.09.012.

Balwant, R., Sanjay, G., K., C. S., and R., S. R. (2014). Community structure, regeneration potential and future dynamics of natural forest site in part of Nanda Devi Biosphere Reserve, Uttarakhand, India. *African Journal of Plant Science*, 8(7), 380–391. https://doi.org/10.5897/ajps2014.1191.

Banana, A. Y., Buyinza, M., Luoga, E., and Ongugo, P. (2010). Emerging local economic and social dynamics shaping East African forest landscapes. In G. Mery, P. Katila, R. I. Alfaro, M. Kanninen, M. Labovikov, and J. Varjo (Eds.), Forests and society: Responding to global drivers of change (IUFRO World Series, Vol. 25, pp. 315–335). Vienna.

Barbero, M., Bonin, G., Loisel, R. et al. (1990). Changes and disturbances of forest ecosystems caused by human activities in the western part of the mediterranean basin. *Vegetatio*, 87, 151–173. https://doi.org/10.1007/BF00042952.

Bartlett, J. E., Kotrlik, J. W., and Higgins, C. (2001). Organizational research; Determining appropriate sample size for survey research. *Journal of Information Technology, Learning and Performance*, 19(1), 43-50.

Bassa, T. (2018). Ethnobotanical study of medicinal plants in Wolaita Zone, Southern Ethiopia. *Journal of Health, Medicine and Nursing*, 48, 1–12.

Baul, T. K., Chakraborty, A., Nandi, R., Mohiuddin, M., Kilpeläinen, A., and Sultana, T. (2021). Effects of tree species diversity and stand structure on carbon stocks of homestead forests in Maheshkhali Island, Southern Bangladesh. *Carbon Balance and Management*, 16. https://doi.org/10.1186/s13021-021-00175-6.

Baveye, P., Baveye, J., and Gowdy, J. (2016). Soil "ecosystem" services and natural capital: Critical appraisal of research on uncertain ground. *Frontiers in Environmental Science*, 4, Article 41. https://doi.org/10.3389/fenvs.2016.00041.

Bayle, G. K. (2019). Ecological and social impacts of eucalyptus tree plantation on the environment. *Journal of Biodiversity Conservation and Bioresource Management*, 5(1), 93. https://doi.org/10.3329/jbcbm.v5i1.42189.

Beche, D., Tack, A., Nemomissa, S., Warkineh, B., Lemessa, D., Rodrigues, P., Fischer, J., and Hylander, K. (2022). Spatial variation in human disturbances and their effects on forest structure and biodiversity across an Afromontane forest. *Landscape Ecology*, 37, 493–510.

Bedru, B. (2007). Economic valuation and management of common-pool resources: The case of exclosures in the highlands of Tigray, Northern Ethiopia. Ph.D. dissertation. Department Landbeheer en-Economie, Katholieke Universiteit, Leuven: Belgium.

Bekele, A., Alemu, D., Teklewold, T., et al. (2018). Strategies for animal disease control in Ethiopia: A review of policies, regulations and actors. *Journal of Veterinary Medicine and Animal Health*, 10(12), 256–265.

Bekele, G., and Reddy, P. R. (2015). Ethnobotanical study of medicinal plants used to treat human ailments by Guji Oromo tribes in Abaya District, Borana, Oromia, Ethiopia. *Universal Journal of Plant Science*, 3(1), 1-8. https://doi.org/10.13189/ujps.2015.030101.

Bekele, M., Tesfaye, Y., Mohammed, Z., Zewdie, S., Y, T., Brockhaus, M., and Habtemariam, K. (2015). The context of REDD+ in Ethiopia: Drivers, agents, and institutions (Occasional Paper 127). CIFOR. https://doi.org/10.17528/cifor/005654.

Bekele, T. (1993). Studies on remnant Afromontane forests on the central plateau of Shewa, Ethiopia. *Acta Phytogeographica Suecica*, 79, 1–58.

Belayneh, A., Asfaw, Z., Demissew, S., and Bussa, N. F. (2012). Medicinal plants potential and use by pastoral and agro-pastoral communities in Erer Valley of Babile Wereda, Eastern Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 8(1). https://doi.org/10.1186/1746-4269-8-42.

Bell, J.-L., Boyer, J. N., Crystall, S. J., Nichols, W. F., and Pruyn, M. (2017). Floristic quality as an indicator of human disturbance in forested wetlands of northern New England. *Ecological Indicators*, 83, 227–231. https://doi.org/10.1016/j.ecolind.2017.08.010

Bell, M. J., Moody, P. W., Yo, S. A., and Connolly, R. D. (1999). Using active fractions of soil organic matter as indicators of the sustainability of Ferrosol farming systems. *Australian Journal of Soil Research*, 37, 279–287.

Berhanu, M., Tintagu, T., Fentahun, S., and Giday, M. (2020). Ethnoveterinary survey of medicinal plants used for treatment of animal diseases in Ambo District of Oromia Regional State of Ethiopia. *Evidence-Based Complementary and Alternative Medicine*, 2020, 1–12.

Bhagwat, S., and Rutte, C. (2006). Church forests: Potential for biodiversity management. *Frontiers in Ecology and Environment*, 4, 519-524. https://doi.org/10.1890/15409295 (2006)4[519:SGPFBM]2.0.CO;2.

Bhandari, S., and Bam, S. (2014). Comparatives study of soil organic carbon (SOC) under forest, cultivated and barren land: A case of Chovar Village, Kathmandu. Nepal *Journal of Science and Technology*, 14, 103-108. https://doi.org/10.3126/njst.v14i2.10 422.

Birhanu, T., Mohammed, A. S., and Mekonnen, A. B. (2021). Floristic composition, structure and regeneration status of woody plants in church forests of Dangila, Northwestern Ethiopia. *Cogent Food and Agriculture*, 7(1) 1911438. https://doi.org/10.1080/23311 932.2021.1911438.

Bishaw, B. (2001). Deforestation and land degradation in the Ethiopian Highlands: A strategy for physical recovery. *Northeast African Studies*, 8, 7-25. https://doi.org/10.1353/nas. 2005.0014.

Bitariho, R., Babaasa, D., and Byaruhanga, A. (2023). Changes in floristic composition, diversity and anthropogenic perturbations in an East African tropical forest. *African Journal of Ecology*, 61(4), 815–828. https://doi.org/10.1111/aje.13178.

Bitew, A. (2024). Role of land use dynamic nature and their influence on soil physico-chemical properties in various watersheds in Ethiopia. *Journal of Advances in Agriculture*. https://doi.org/10.24297/jaa.v15i.9572.

Bloomfield, L. S., McIntosh, T. L., and Lambin, E. F. (2020). Habitat fragmentation, livelihood behaviors, and contact between people and nonhuman primates in Africa. *Landscape Ecology*, 35(4), 985–1000. https://doi.org/10.1007/s10980-020-00995-w.

Bodart, C., Brink, A. B., Donnay, F., Lupi, A., Mayaux, P., & Achard, F. (2013). Continental estimates of forest cover and forest cover changes in the dry ecosystems of Africa between 1990 and 2000. Journal of Biogeography, 40(6), 1036–1047. DOI: 10.1111/jbi.12084.

Bogale Worku, B., Genete Muluneh, M., and Molla, T. (2023). Influence of elevation and anthropogenic disturbance on woody species composition, diversity, and stand structure in Harego Mountain Forest, northeastern Ethiopia. *International Journal of Forestry Research*, 2023, 1–17. https://doi.org/10.1155/2023/8842408.

Bonan, G. B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science*, 320, 1444–1449.

Botkin, D. B., and Keller, E. A. (2014). Environmental sciences: Earth as a living planet (eBook version). John Wiley. http://www.wiley.com/WileyCDA/WileyTitle/productC d-EHEP002529.html.

Boz, G., and Maryo, M. (2020). Woody species diversity and vegetation structure of Wurg Forest, Southwest Ethiopia. International Journal of Forestry Research, 2020, 1-17. https://doi.org/10.1155/2020/8823990.

Brady, N. C., and Weil, R. R. (2008). The nature and properties of soils. Pearson Prentice Hall.

Brasileiro, D. S., Gaspar, A., Pereira, B., Bezerra, D., Mara, I., and Dafos, R. (2023). Chemical and textural properties of floodplain forest soils in the Eastern Amazon, Brazil. *African Journal of Agricultural Research*, 19(1), 91-100. https://doi.org/10.58 97/ajar2022.16242.

Bremner, J. M., and Mulvaney, C. S. (1982). Nitrogen-total. In A. L. Page and R. H. Miller (Eds.), Methods of soil analysis. Part 2 (2nd ed., Agron. Monogr. 9, pp. 595–624). ASA and SSSA: Madison, WI.

Briggs, L. J. (2016). The mechanics of soil moisture paperback (38 p). Wentworth Press.

Briliawan, B.D., Wijayanto, N., and Wasis, B. (2022). Visual soil structure quality and its correlation to quantitative soil physical properties of upland rice site in Falcataria moluccana agroforestry system. *Biodiversitas Journal of Biological Diversity*, 23. https://doi.org/10.13057/biodiv/d230423.

Briones, M., and Ineson, P. (1996). Decomposition of Eucalyptus leaves in litter mixtures. Soil Biology and Biochemistry, 28, 1381–1388.

Brockerhoff, E. G., Barbaro, L., Castagneyrol, B., et al. (2017). Forest biodiversity, ecosystem functioning and the provision of ecosystem services. *Biodiversity and Conservation*, 26(9), 3005–3035. https://doi.org/10.1007/s10531-017-1453-2.

Brown, R.W., Chadwick, D.R., Bending, G.D., Collins, C.D., Whelton, H.L., Daulton, E., Covington, J.A., Bull, I.D., and Jones, D.L. (2022). Nutrient (C, N and P) enrichment induces significant changes in the soil metabolite profile and microbial carbon partitioning. *Soil Biology and Biochemistry*, 172, 108779. https://doi.org/10.1016/j.soi lbio.2022.108779.

Bruchac, M. (2014). Indigenous knowledge and traditional knowledge. In C. Smith (Ed.), Encyclopedia of global archaeology (pp. 3814-3824). Springer.

Bryan, E., Deressa, T.T., Gbetibouo, G.A., and Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science and Policy*, 12, 413–426. https://doi.org/10.1016/j.envsci.2008.11.002

Buchanan, J. R. (2014). Decentralized wastewater treatment. In Comprehensive Water Quality and Purification (Vol. 3, pp. 244-267). Elsevier. https://doi.org/10.1016/B978 -0-12-382182-9.00050-5.

Caicoya, T., Biber, P., Poschenrieder, W., Schwaiger, F., and Pretzsch, H. (2018). Forestry projections for species diversity-oriented management: An example from Central Europe. *Ecological Processes*, 7(1). https://doi.org/10.1186/s13717-018-0135-7.

Capek, P., Kotas, P., Manzoni, S., and Šantrůčková, H. (2016). Drivers of phosphorus limitation across soil microbial communities. Functional Ecology, 30, 1705–1713. https://doi.org/10.1111/1365-2435.12650.

Cardelús, C. L., Baimas-George, M., Lowman, M., and Eshete, A. W. (2013). Church forest status and carbon sequestration in northern Ethiopia. In M. Lowman, S. Devy, and T. Ganesh (Eds.), Treetops at risk (pp. 119–122). Springer. https://doi.org/10.1007/978-1-4614-7161-5_11.

Cardelús, C. L., Mekonnen, A. B., Jensen, K. H., Woods, C. L., Baez, M. C., Montufar, M., Bazany, K., Tsegay, B. A., Scull, P., and Peck, W. H. (2020). Edge effects and human disturbance influence soil physical and chemical properties in sacred church forests in Ethiopia. *Plant and Soil*, 453(1-2), 329–342. https://doi.org/10.1007/s11104-020-04595-0.

Cardelús, C. L., Scull, P., Hair, J., George, B. M., Lowman, M., and Wassie, A. (2013). A preliminary assessment of Ethiopian sacred grove status at the landscape and ecosystem scales. *Journal of Diversity*, 5, 320-334. https://doi.org/10.3390/d5020320.

Cardelus, C. L., Woods, C. L., Bitew Mekonnen, A., Dexter, S., Scull, P., and Tsegay, B. A. (2019). Human disturbance impacts the integrity of sacred church forests, Ethiopia. *PLOS ONE*, 14(3), e0212430. https://doi.org/10.1371/journal.pone.0212430.

Cardelús, C., Scull, P., Eshete, A. W., Woods, C., Klepeis, P., Kent, E., and Orlowska, I. (2017). Shadow conservation and the persistence of church forests in northern Ethiopia. *Biotropica*, 49(5), 726-733. https://doi.org/10.1111/btp.12431.

Cardelús, C.L., Amare Bitew Mekonnen, Jensen, K.H., Woods, C.L., Baez, M.C., Montufar, M., Bazany, K., Berhanu Abraha Tsegay, Scull, P., and Peck, W.H. (2020). Edge effects and human disturbance influence soil physical and chemical properties in Sacred Church Forests in Ethiopia. *Plant and Soil*, 453, 329–342. https://doi.org/10.1007/s11104-020-04595-0.

Castro-Díez P., Fierro-Brunnenmeister N., González-Muñoz, N., and Gallardo, A. (2011). Effects of exotic and native tree leaf litter on soil properties of two contrasting sites in the Iberian Peninsula. *Plant and Soil,* 350, 179–191.

Catarino, L., and Romeiras, M.M. (2020). Biodiversity of vegetation and flora in tropical Africa. *Diversity*, 12(10), 369. https://doi.org/10.3390/d12100369.

Cavalcanti, E.A., and Larrazábal, M.E. (2004). Macrozooplankton of the Exclusive Economic Zone of Northeast Brazil (Second Oceanographic Expedition - REVIZEE/NE II) with emphasis on copepods (crustaceans). *Brazilian Journal of Zoology*, 21(3), 467–475. https://doi.org/10.1590/s0101-81752004000300008.

Central Statistical Agency of Ethiopia. (2007). The 2007 population and housing census of Ethiopia: Statistical report for Addis Ababa City Administration. Office of the Population Census Commission.

César, R., Belei, L., Badari, C., Viani, R., Gutierrez, V., and Chazdon, R. (2020). Forest and landscape restoration: A review emphasizing principles, concepts, and practices. Land, 10(1), 28. https://doi.org/10.3390/land10010028.

Chamberlain, J. L., Darr, D., and Meinhold, K. (2020). Rediscovering the contributions of forests and trees to transition global food systems. *Forests*, 11(10), 1098. https://doi.org/10.3390/f11101098.

Chapin, F. S., Woodwell, G. M., Randerson, J. T., Rastetter, E. B., Lovett, G. M., Baldocchi, D. D., ... and Schulze, E. D. (2006). Reconciling carbon-cycle concepts, terminology, and methods. *Ecosystems*, 9, 1041-1050. https://doi.org/10.1007/s10021-005-0105-7.

Chapin, F.S., Matson, P.A., and Mooney, H.A. (2011). Principles of terrestrial ecosystem ecology. Springer, New York.

Chapuis-Lardy, L., Contour-Ansel, D., and Bernhard-Reversat, F. (2002). High-performance liquid chromatography of water-soluble phenolics in litter of three Eucalyptus hybrids (Congo). *Plant Science*, 163, 17–22.

Chave, J., Coomes, D., Jansen, S., Lewis, S. L., Swenson, N. G., and Zanne, A. E. (2009). Towards a worldwide wood economics spectrum. *Ecological Letters*, 12(4), 351–366. https://doi.org/10.1111/j.14610248.2009.01285.x.

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B., and Henry, M. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, 20(10), 3177-3190. https://doi.org/ 10.1111/gcb.12629.

Chazdon, R. L., Brancalion, P. H. S., Laestadius, L., et al. (2016). When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *Ambio*, 45, 538–550. https://doi.org/10.1007/s13280-016-0772-y.

Chekole, G. (2017). Ethnobotanical study of medicinal plants used against human ailments in Gubalafto District, Northern Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 13, 55.

Chekole, G., Asfaw, Z., and Kelbessa, E. (2015). Ethnobotanical study of medicinal plants in the environs of Tara-Gedam and Amba remnant forests of Libo Kemkem District, Northwest Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 11(1), 4. https://doi.org/10.1186/1746-4269-11-4.

Chen, J., Franklin, J. F., and Spies, T. A. (1993). Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas-fir forest. *Agricultural and Forest Meteorology*, 63, 219–237.

Chen, J., Paw, U. K. T., North, M., and Franklin, J.F. (2024). The contributions of microclimatic information in advancing ecosystem science. *Agricultural and Forest Meteorology*, 355, 110105–110105. https://doi.org/10.1016/j.agrformet.2024.110105.

Chen, S.-L., Yu, H., Luo, H.-M., et al. (2016). Conservation and sustainable use of medicinal plants: Problems, progress, and prospects. *Chinese Medicine*, 11(1), 37. https://doi.org /10.1186/s13020-016-0108-7.

Chen, X., Luo, M., and Larjavaara, M. (2023). Effects of climate and plant functional types on forest above-ground biomass accumulation. *Carbon Balance and Management*, 18, 5. https://doi.org/10.1186/s13021-023-00225-1.

Cherinet, A., and Lemi, T. (2023). The role of forest ecosystems for carbon sequestration and poverty alleviation in Ethiopia. *International Journal of Forestry Research*, 2023, 1–10. https://doi.org/10.1155/2023/3838404.

Chidumayo, E., & Marunda, C. (2010). Dry Forests and Woodlands in Sub-Saharan Africa: Context and Challenges. In E. N. Chidumayo & D. J. Gumbo (Eds.), The Dry Forests and Woodlands of Africa: Managing for Products and Services (pp. 1–9). Routledge. DOI: 10.4324/9781849776547.

Chimdessa, T. (2023). Forest carbon stock variation with altitude in Bolale Natural Forest, Western Ethiopia. *Global Ecology and Conservation*, 45, e02537. https://doi.org/10.1016/j.gecco.2023.e02537.

Chinasho, A., Soromessa, T., and Bayable, E. (2015). Carbon stock in woody plants of Humbo Forest and its variation along altitudinal gradients: The case of Humbo District, Wolaita Zone, Southern Ethiopia. *International Journal of Environmental Protection and Policy*, 3(4), 97–103. https://doi.org/10.11648/j.ijepp.20150304.13.

Choksi, P. (2022). Examining patterns and impacts of forest resource extraction and forest degradation in tropical dry forests. IGI Global eBooks. 830-851. https://doi.org/10.4018/978-1-6684-5678-1.ch042.

Christopher, A. (2020). Woody plant species composition and diversity in West Bank Forest of International Institute of Tropical Agriculture (IITA) Ibadan, Oyo State, Nigeria. *Journal of Experimental Agriculture International*, 42(2), 63-78. https://doi.org/10.9734/jeai/2020/v42i230470.

Chu, C., Mortimer, P.E., Wang, H., Wang, Y., Liu, X., and Yu, S. (2014). Allelopathic effects of Eucalyptus on native and introduced tree species. *Forest Ecology and Management*, 323, 79–84. https://doi.org/10.1016/j.foreco.2014.03.004.

Cochran WG. (1997). Sampling techniques. 3rd ed. New York (NY): John Wiley and Sons.

Corlett, R. (2016). Plant diversity in a changing world: Status, trends, and conservation needs. *Plant Diversity*, 38(1), 10-16. https://doi.org/10.1016/j.pld.2016.01.001

Coté, M. (2003). Dictionary of forestry. Ordre des Ingenieur Forestrieers du Quebéc, 744.

Cotton CM. (1996). Ethnobotany: principles and applications. Chichester (England): John Wiley and Sons Ltd.

CSA. (2007). Population and housing census of Ethiopia: The third national population and housing census, conducted in May and November 2007.

Cubides, P.J.I., and Cardona, J.N.U. (2011). Anthropogenic disturbance and edge effects on anuran assemblages inhabiting cloud forest fragments in Colombia. *Natureza and Conservação*, 9, 39–46. https://doi.org/10.4322/natcon.2011.004.

Cui, R., Wang, C., Cheng, F., Ma, X., Cheng, X., He, B., and Chen, D. (2023). Effects of Successive Planting of Eucalyptus on Soil Physicochemical Properties 1–3 Generations after Converting Masson Pine Forests into Eucalyptus Plantations. *Polish*

Journal of Environmental Studies, 32(5), 4503-4514. https://doi.org/10.15244/pjoes/169015.

Currie, W. S. (1999). The responsive C and N biogeochemistry of the temperate forest floor. *Trends in Ecology and Evolution*, 14(8), 316–320. https://doi.org/10.1016/S0169-5347(99)01645-6.

Dada, A.D., Matthew, O.J., and Odiwe, A.I. (2024). Nexus between carbon stock, biomass, and CO2 emission of woody species composition: evidence from Ise-Ekiti Forest Reserve, Southwestern Nigeria. Carbon Research, 3. https://doi.org/10.1007/s44246-024-00115-2

Dagar, J. C., Gupta, S. R., & Dimobe, K. (2024). Agroforestry from a global perspective: Recent developments, technological advancements, and emerging research trends. In S. Kumar, B. Alam, S. Taria, P. Singh, A. Yadav, & A. Arunachalam (Eds.), *Agroforestry solutions for climate change and environmental restoration*. Springer. https://doi.org/10.1007/978-981-97-5004-7_1.

Dagne, Y., and Birhanu, L. (2023). Floristic composition and plant community distribution along environmental gradients in guard dry Afromontane Forest of northwestern Ethiopia. *BMC Ecology and Evolution*. doi: 10.1186/s12862-023-02154-6.

Dahmani, R., Borsali, A. H., Merzouk, A., Zouidi, M., and Farnet da Silva, A. M. (2023). Dynamics of chemical and microbial properties of Algerian forest soils: Influence of natural and anthropogenic factors (Northwest of Tlemcen). *Forest Science and Management*, 2023. https://doi.org/10.2478/fsmu-2023-0004.

Daigneault, A., Baker, J. S., Guo, J., Lauri, P., Favero, A., Forsell, N., Johnston, C., Ohrel, S. B., and Sohngen, B. (2022). How the future of the global forest sink depends on timber demand, forest management, and carbon policies. *Global Environmental Change*, 76, 102582. https://doi.org/10.1016/j.gloenvcha.2022.102582

Defries, R. S., Bounoua, L., and Collatz, G. J. (2002). Human modification of the landscape and surface climate in the next fifty years. *Global Change Biology*, 8(5), 438–458. https://doi.org/10.1046/j.1365-2486.2002.00483.x.

Demessie, A., Singh, B.R., Lal, R., and Strand, L.T. (2012). Leaf litter fall and litter decomposition under Eucalyptus and coniferous plantations in Gambo District, southern Ethiopia. Acta Agriculturae Scandinavica, Section B - *Soil and Plant Science*, 1–10. https://doi.org/10.1080/09064710.2011.645497.

Demssew, S., and Friis, I. (2009). Natural vegetation of the Flora area. In I. Hedberg, I. Friis, and E. Persson (Eds.), Flora of Ethiopia and Eritrea (Vol. 8, pp. 27–32). National Herbarium, Biology Department, Science Faculty, Addis Ababa University, Addis Ababa, Ethiopia and Department of Systematic Botany, Uppsala University, Uppsala, Sweden.

Deng, C., Daley, T., and Smith, A. (2015). Applications of species accumulation curves in large-scale biological data analysis. *Quantitative Biology*, 3(3), 135–144. https://doi.org/10.1007/s40484-015-0049-7.

Deribew, K.T., and Dalacho, D.W. (2019). Land use and forest cover dynamics in the north-eastern Addis Ababa, Central Highlands of Ethiopia. *Environmental Systems Research*, 8(8). https://doi.org/10.1186/s40068-019-0137-1.

Desta, Y., Debella, A., and Assefa, G. (1996). Traditional Medicine: Global and National perspectives. In D. Abebe (Ed.), Proceedings of the Workshop on Development and Utilization of Herbal Remedies in Ethiopia (pp. 1-19). Ethiopian Health and Nutrition Research Institute, Addis Ababa.

Dhaulkhandi M., Dobhal A., Bhatt S. and Kumar M. (2008). Community structure and regeneration potential of natural forest site in Gangotri, India. *Journal of Basic and Applied Sciences*; 4: 49–52.

Dibaba, A., Soromessa, T., Kefalew, A., and Addi, A. (2020). Woody species diversity, vegetation structure, and regeneration status of the moist Afromontane forest of Agama in southwestern Ethiopia. *International Journal of Ecology*, 2020, 1–10. https://doi.org/10.1155/2020/1629624.

Dilbato, T., Begna, F., and Tolosa, T. (2023). Medicinal plants and non-plant remedies used in the treatment of livestock ailments in Dawuro Zone, Southwestern Ethiopia. Ethiopian. *Veterinary Journal*, 27(1), 72–92.

Dinbiso, T. D., Fulasa, T. T., and Deressa, F. B. (2022). Ethnoveterinary practices of medicinal plants used in animal health management in the Dawuro Zone, Southern Ethiopia. *Economic Botany*, 76(1), 60–83.

Dinkayoh, T. (2016). Deforestation in Ethiopia: Causes, impacts, and remedy. *International Journal of Engineering Development and Research*, 4(2), 204–208.

Doda Doffana, Z. (2017). Sacred natural sites, herbal medicine, medicinal plants, and their conservation in Sidama, Ethiopia. *Cogent Food and Agriculture*, 3(1), 1365399. https://doi.org/10.1080/23311932.2017.1365399.

Don, A., and Kalbitz, K. (2005). Amounts and degradability of dissolved organic carbon from foliar litter at different decomposition stages. *Soil Biology and Biochemistry*, 37, 2171–2179.

Du, E. (2023). Effects of Nitrogen Deposition on Forest Ecosystems. In H. Akimoto and H. Tanimoto (Eds.), Handbook of Air Quality and Climate Change. Springer, Singapore. https://doi.org/10.1007/978-981-15-2760-9_27.

Du, E., Terrer, C., Pellegrini, A. F. A., Ahlström, A., van Lissa, C. J., Zhao, X., Xia, N., Wu, X., Jackson, R. B. (2020). Global patterns of terrestrial nitrogen and phosphorus limitation. *Nature Geoscience*, 13, 221–226. https://doi.org/10.1038/s41561-019-0530-4

Du, H., Zeng, F., Peng, W., Wang, K., Zhang, H., Liu, L., and Song, T. (2015). Carbon Storage in a Eucalyptus Plantation Chronosequence in Southern China. *Forests*, 6(6), 1763-1778. https://doi.org/10.3390/f6061763.

Durai, M. V. (2023). Chemical properties of soil in forest and non-forest land use in Bangalore rural forest division, Karnataka. Annals of Plant and Soil Research, 25(1), 110–119. https://doi.org/10.47815/apsr.2023.10243.

Duria, J. J. C., Baltazar, E. G., Mercado, J. J. S., and Lagasca, A. C. (2023). Towards inclusive development: Situating the socio-economic wellbeing and environmental issues of an Indigenous cultural community in the Philippines. *Open Journal of Ecology*, 13(6), 367–386. https://doi.org/10.4236/oje.2023.136023.

Edwards, S., Tadesse, M., and Hedberg, I. (1995). Canellaceae to Euphorbiaceae. In The National Herbarium, Vol. 2. Addis Ababa University, Addis Ababa and Uppsala. Flora of Ethiopia and Eritrea (Vol. 2).

Egeta, D., Hirpa, G. Y., Eshete, A., and Debela, H. B. (2023). Physical and chemical properties of soils in Gera moist Afromontane forest, southwest Ethiopia. *Journal of the Selva Andina Biosphere*, 11, 118-130. https://doi.org/10.36610/j.jsab.2023.110200 118.

Eiki, N., Manyelo, T. G., Hassan, Z. M., et al. (2022). Phenolic composition of ten plant species used as ethnoveterinary medicines in Omusati and Kunene regions of Namibia. *Scientific Reports*, 12(1).

Ekhuemelo, D. O., Amonum, J. I., and Usman, I. A. (2016). Importance of forest and trees in sustaining water supply and rainfall. Nigeria. *Journal of Education, Health and Technology Research (NJEHETR),* APREHET, 274.

Eldeen, I. M. S., Effendy, Mohd. A. W., and Muhammad, T. S. (2016). Ethnobotany: Challenges and future perspectives. *Research Journal of Medicinal Plants*, 10(6), 382–387. https://doi.org/10.3923/rjmp.2016.382.387.

Ellenberg, D., and Mueller-Dombois, D. (1974). Aims and methods of vegetation ecology (Vol. 547). New York: Wiley.

Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., et al. (2017). Trees, forests and water: Cool insights for a hot world. *Global Environmental Change*, 43, 51–61. https://doi.org/10.1016/j.gloenvcha.2017.01.002.

Emad H. E. Yasin, Ahmed A. H. Siddig, and Czimber Kornel. (2024). Forests at the Crossroads: Biodiversity Conservation in the Era of Climate Change. *IntechOpen eBooks* 2024. https://doi.org/10.5772/intechopen.1004224.

Emery, A. R. (200). Integrating Indigenous Knowledge in Project Planning and Implementation. Centre for Traditional Knowledge: Ottawa, Canada.

Endalew, B., Assefa, B., Wondimagegnhu, and Tassie, K. (2020). Willingness to pay for church forest conservation: A case study in northwestern Ethiopia. *Journal of Forest Science*, 66(3), 105-116. https://doi.org/10.17221/154/2019-jfs.

Entrocassi, G. S., Gavilán, R. G., and Sánchez-Mata, D. (2019). Vegetation of Las Yungas (Serranías de Zapla, Jujuy, Argentina): Subtropical mountain forest. *Geobotany Studies*, 1–8. https://doi.org/10.1007/978-3-030-25521-3_1.

Eshete, A., Sterck, F., and Bongers, F. (2011). Diversity and production of Ethiopian dry woodlands explained by climate- and soil-stress gradients. *Forest Ecology and Management*, 261, 1499–1509.

Eshete, M. A., and Molla, E. L. (2021). Cultural significance of medicinal plants in healing human ailments among Guji semi-pastoralist people, Suro Barguda District, Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 17(1), 61. https://doi.org/10.1186/s13002-021-00487-4.

Eshetu, A. A. (2014). Forest resource management systems in Ethiopia: Historical perspective. International Journal of Biodiversity and Conservation, 6(2), 121–131. https://doi.org/10.5897/IJBC2013.0645.

Eshetu, Z., and Högberg, P. (2000). Reconstruction of Forest Site History in Ethiopian highlands based on 13c natural abundance of soils. AMBIO: *A Journal of the Human Environment*, 29(2), 83-89. https://doi.org/10.1579/0044-7447-29.2.83.

Esubalew, E., Giday, K., Hishe, H., and Goshu, G. (2019). Carbon stock of woody species along altitude gradient in Alemsaga Forest, South Gondar, North Western Ethiopia. *Agricultural Journal*. IJOEAR, 5, 13–21.

Ethiopian Biodiversity Institute (EBI). (2015). National biodiversity strategy and action plan 2015–2020. EBI, Addis Ababa, Ethiopia.

Ethiopian Forestry Action Program (EFAP). (1994). The challenge for development. EFAP, Addis Ababa, Ethiopia.

Ethiopian Forestry Action Programme (EFAP). (1994). Volume III: The challenge for development.

Eyasu, G., Tolera, M., and Negash, M. (2020). Woody species composition, structure, and diversity of homegarden agroforestry systems in southern Tigray, Northern Ethiopia. *Heliyon*, 6, e05500. https://doi.org/10.1016/j.heliyon.2020.e05500.

Eycott, A., Watkinson, A., and Dolman, P. (2006). Ecological patterns of plant diversity in a plantation forest managed by clear felling. *Journal of Applied Ecology*, 43(6), 1160-1171. https://doi.org/10.1111/j.1365-2664.2006.01235.x.

Fabricant, D. S., and Farnsworth, N. R. (2001). The value of plants used in traditional medicine for drug discovery. *Environmental Health Perspectives*, 109, 69. https://doi.org/10.2307/3434847.

Fahad, S., Chavan, S. B., Chichaghare, A. R., Uthappa, A. R., Kumar, M., Kakade, V., Pradhan, A., Jinger, D., Rawale, G., Yadav, D. K., et al. (2022). Agroforestry systems for soil health improvement and maintenance. *Sustainability*, 14(22), 14877.https://doi.org/10.3390/su142214877.

Fahrig, L. (2017). Ecological responses to habitat fragmentation per se. Annual Review of Ecology, Evolution, and Systematics, 48(1), 1–23. https://doi.org/10.1146/annurev-ecolsys-110316-022612.

FAO. (2015). Global Forest Resources Assessment 2015: How have the world's forests changed? Food and Agriculture Organization of the United Nations.

Fashing, P. J., Nguyen, N., Demissew, S., Stenseth, N. C., et al. (2022). Ecology, evolution, and conservation of Ethiopia's biodiversity. *Proceedings of the National Academy of Sciences of the United States of America*, 119(50), e2206635119. https://doi.org/10.1073/pnas.2206635119.

Fattani, S., Forka, C.-A., Garcia, M., Huynh, T., Merricks, T., Robinson, M., and Sanders, C. (2021). Soil moisture and porosity affects the abundance and distribution of Ageratum houstonianum. Pursue: *Undergraduate Research Journal*, 4(1), Article 1. Available at https://digitalcommons.pvamu.edu/pursue/vol4/iss1/1 .

FDRE. (2011). Ethiopia's Climate-Resilient Green Economy: Green economy strategy. Available here: http://www.undp.org/content/dam/ethiopia/docs/Ethiopia%20CRGE.pdf.

Federal Democratic Republic of Ethiopia, Ethiopian Statistics Service. (2021). Agricultural sample survey 2021/22 [2014 E.C.]: Volume II: Report on livestock and livestock characteristics (Private peasant holdings). *Ethiopian Statistics Service*. [accessed 2023 Dec 22]. http://www.statsethiopia.gov.et/wp content/uploads/2023/07/6.The_6_2014_AGSS_2014.LIVESTOCK-REPORT_Final-3.pdf.

Fernández-Martínez, M., Vicca, S., Janssens, I., et al. (2015). Correction: Corrigendum: Nutrient availability as the key regulator of global forest carbon balance. *Nature Climate Change*, 5(4), 386. https://doi.org/10.1038/nclimate2587.

Fessehaie, R., and Tessema, T. (2014). Alien plant species invasions in Ethiopia: Challenges and responses. International Workshop on Parthenium Weed in Ethiopia, Addis Ababa.

Feyera, T., Mekonnen, E., Wakayo, B. U., and Assefa, S. (2017). Botanical ethnoveterinary therapies used by agro-pastoralists of Fafan Zone, Eastern Ethiopia. *BMC Veterinary Research*, 13(1).

Feyisa, M., Kassahun, A., and Giday, M. (2021). Medicinal plants used in ethnoveterinary practices in Adea Berga District, Oromia Region of Ethiopia. *Evidence-Based Complementary and Alternative Medicine*, 2021, 1–22.

Feyissa, A., Soromessa, T., and Argaw, M. (2014). Forest Carbon Stocks and Variations along Altitudinal Gradients in Egdu Forest: Implications of Managing Forests for Climate Change Mitigation. *Science, Technology and Arts Research Journal*, 2, 40. https://doi.org/10.4314/star.v2i4.8.

Fisaha, G., Hundera, K., and Dalle, G. (2013). Woody Plants diversity, structural analysis and regeneration status of Wof Washa Natural Forest, north-east Ethiopia. *African Journal of Ecology*, 51(4), 599-610. https://doi.org/10.1111/aje.12085.

Fitsumbirhan, T. (2018, January 5). Medicinal plants in church-based forests of Tahtay Koraro Wereda, Northern Ethiopia [Unpublished MSc. thesis]. Bahir Dar University. DSpace Institution. http://hdl.handle.net/123456789/8398.

Fitzgerald, M., Heinrich, M., and Booker, A. (2020). Medicinal plant analysis: A historical and regional discussion of emergent complex techniques. *Frontiers in Pharmacology*, 10. https://doi.org/10.3389/fphar.2019.01480.

Foltran, E. C., Rocha, J. H. T., Bazani, J. H., Gonçalves, J. L. de M., Rodrigues, M., Pavinato, P., Valduga, G. R., Erro, J., and Garcia-Mina, J. M. (2019). Phosphorus pool responses under different P inorganic fertilizers for a eucalyptus plantation in a loamy Oxisol. *Forest Ecology and Management,* 435, 170-179. https://doi.org/10.1016/j.foreco.2018.10.053.

Food and Agriculture Organization (FAO). (2010). Global forest resources assessment 2010: Country report, Ethiopia. FAO, Rome, Italy.

Food and Agriculture Organization (FAO). (2011). State of the world's forests. FAO, Rome, Italy. ISBN: 978-92-5-106750-5.

Food and Agriculture Organization (FAO). (2012). State of the world's forests 2012. FAO, Rome, Italy.

Food and Agriculture Organization (FAO). (2015). The global forest resources assessment desk reference; FRA country reports. FAO, Rome, Italy.

Food and Agriculture Organization (FAO). (2016). Forestry contribution to national economy and trade in Ethiopia, Kenya, and Uganda. By Kilawe, E. and Habimana, D. Addis Ababa, Ethiopia.

Food and Agriculture Organization of the United Nations. (2021). Soil biodiversity: Keeping the soil alive, protecting the planet. Retrieved from http://www.fao.org/documents/card/en/c/cb1005en.

Freilich, X., Anadón, J., Bukala, J., Calderon, O., Chakraborty, R., and Boissinot, S. (2016). Comparative phylogeography of Ethiopian anurans: Impact of the great rift valley and Pleistocene climate change. *BMC Evolutionary Biology*, 16(1). https://doi.org/10.1186/s12862-016-0774-1.

Friis, I. (1986). The forest vegetation of Ethiopia. Symbolae Botanicae Upsaliensis, 26(2), 31-47.

Friis, I., Demissew, S., and van Breugel, P. (2010). Atlas of the potential vegetation of Ethiopia. Addis Ababa: The Royal Danish Academy of Sciences and Letters.

Friis, I., Thulin, M., Adsersen, H., and Bürger, A. M. (2005). Patterns of plant diversity and endemism in the Horn of Africa. *Biologiske Skrifter,* 55:289–314.

Fullas, F. (2001). Common medicinal plants in perspective. Sioux City, Iowa.

Gabet, E. J., Reichman, O. J., and Seabloom, E. W. (2003). The effects of bioturbation on soil processes and sediment transport. *Annual Review of Earth and Planetary Sciences*, 31, 249–273. https://doi.org/10.1146/annurev.earth.31.100901.141314

Galloway, J. N., Dentener, F. J., Capone, D. G., et al. (2008). Nitrogen cycles: Past, present, and future. *Biogeochemistry*, 70(2), 153–226.

Gama, J. T. (2023). The role of soils in sustainability, climate change, and ecosystem services: Challenges and opportunities. *Ecologies*, 4(3), 552–567.

Garedew, B., and Bizuayehu, B. (2018). A review on ethnobotanical study of traditional medicinal plants used for treatment of liver problems in Ethiopia. *European Journal of Medicinal Plants*, 26(1), 1-18.

Gaya Shivega, W., and Aldrich-Wolfe, L. (2017). Native plants fare better against an introduced competitor with native microbes and lower nitrogen availability. AoB PLANTS, 9(1), plx004. *Advance online publication*. https://doi.org/10.1093/aobpla/pl x004 .

Gebrehiwot, K., Demissew, S., Woldu, Z., Fekadu, M., Desalegn, T., and Teferi, E. (2019). Elevational changes in vascular plants richness, diversity, and distribution pattern in Abune Yosef mountain range, Northern Ethiopia. *Plant Diversity*, 41(4), 220-228. https://doi.org/10.1016/j.pld.2019.06.005.

Gebrehiwot, S., Gessesse, A., and Teketay, D. (2009). Soil organic carbon stocks and their determinants along a land-use gradient in the Ethiopian highlands. *Agriculture, Ecosystems and Environment*, 130(1-2), 111-119.

Gebrelibanos, T., and Assen, M. (2013). Land use/land cover dynamics and their driving forces in the Hirmi watershed and its adjacent agro-ecosystem, highlands of Northern Ethiopia. *Journal of Land Use Science*, 10(1), 81-94. https://doi.org/10.1080/1747423 x.2013.845614.

Gedefaw, M., and Soromessa, T. (2014). Status and woody plant species diversity in Tara Gedam Forest, Northern Ethiopia. *Science, Technology and Arts Research Journal*, 3(2), 113-118. http://dx.doi.org/10.4314/star.v3i2.19

Gedefaw, M., Soromessa, T., and Belliethathan, S. (2014). Forest Carbon Stocks in Woody Plants of Tara Gedam Forest: Implication for Climate Change Mitigation. *Science, Technology and Arts Research Journal*, 3(1), 101-107. https://doi.org/10.4314/star.v3i 1.16

Gentry, A.H. (1988) Changes in plant community diversity and floristic composition on environmental and geographical gradients. *Ann Missouri Bot Gard*, 75:1–34.

Getachew, F., Abdulkadir, A., Lemenih, M., and Fetene, A. (2012). Effects of different land covers on soil physical and chemical properties in Wondo Genet area. *Ethiopia. New York Science Journal*, 5(11), 110-118.

Getnet, A. (2018). Woody species composition, diversity and vegetation structure of Wanzaye dry Afromontane forest, Ethiopia. *Journal of Agriculture and Environmental Research*, 4(4), 1–13. https://doi.org/10.5296/jaer.v4i4.14216

Getnet, S. D., Gelagay, A. A., and Negeri, N. G. (2023). Review of ethnobotanical studies on medicinal plants that used to treat diarrhea and dysentery in Ethiopia. Discovery Phytomedicine - Journal of Natural Product Research and Ethnopharmacology, 9(2). https://doi.org/10.15562/phytomedicine.2022.195

Getnet, T. (1998). Features of the Ethiopian Orthodox Church and the clergy. *Asian and African Studies*, 7(1), 87–104.

Gibbs, H. K., Brown, S., Niles, J. O., and Foley, J. A. (2007). Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Environmental Research Letters*, 2, 045023. https://doi.org/10.1088/1748-9326/2/4/045023.

Giday, M., Asfaw, Z., and Woldu, Z. (2009). Medicinal plants of the Meinit ethnic group of Ethiopia: An ethnobotanical study. *Journal of Ethnopharmacology*, 124(3), 513-521. https://doi.org/10.1016/j.jep.2009.05.009.

Giday, M., Asfaw, Z., and Woldu, Z. (2010). Ethnomedicinal study of plants used by Sheko ethnic group of Ethiopia. *Journal of Ethnopharmacology*, 132(1), 75–85.

Giday, M., Asfaw, Z., Woldu, Z., and Teklehaymanot, T. (2009). Medicinal plant knowledge of the Bench ethnic group of Ethiopia: An ethnobotanical investigation. *Journal of Ethnobiology and Ethnomedicine*, 5(1). https://doi.org/10.1186/1746-4269-5-34.

Gil, L., Tadesse, W., Tolosana, E., and López, R. (2010). Eucalyptus species management, history, status, and trends in Ethiopia. Ethiopian Institute of Agricultural Research (EIAR).

Gimay, M., Lulekal, E., Bekele, T., and Demissew, S. (2021). Use and management practices of medicinal plants in and around mixed woodland vegetation, Tigray Regional State, Northern Ethiopia. *Ethnobotanical Research and Applications*, 21. https://doi.org/10.32859/era.21.43.1-26.

Girma, A., Soromessa, T., and Bekele, T. (2014). Forest carbon stocks in woody plants of Mount Zequalla Monastery and its variation along altitudinal gradient: Implications for managing forests for climate change mitigation. *Science, Technology and Arts Research Journal*, 3(2), 132. https://doi.org/10.4314/star.v3i2.17.

Gizaw, S., Woldehanna, M., Anteneh, H., et al. (2021). Animal health service delivery in crop-livestock and pastoral systems in Ethiopia. *Frontiers in Veterinary Science*, 8.

Gonfa, N., Tulu, D., Hundera, K., and Raga, D. (2020). Ethnobotanical study of medicinal plants, its utilization, and conservation by indigenous people of Gera District, Ethiopia. *Cogent Food and Agriculture*, 6(1), 1852716. https://doi.org/10.1080/23311932.2020.1852716.

Gotelli, N. J., and Colwell, R. K. (2001). Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters*, 4(4), 379–391. https://doi.org/10.1046/j.1461-0248.2001.00230.x.

Gougoulias, C., Clark, J. M., and Shaw, L. J. (2014). The role of soil microbes in the global carbon cycle: Tracking the below-ground microbial processing of plant-derived carbon for manipulating carbon dynamics in agricultural systems. Journal of the Science of Food and Agriculture, 94(12), 2362-2371. https://doi.org/10.1002/jsfa.657.

Granier, A., Ceschia, E., Damesin, C., Dufrêne, E., Epron, D., Gross, P., Lebaube, S., Le Dantec, V., Le Goff, N., Lemoine, D., Lucot, E., Ottorini, J. M., Pontailler, J. Y., and Saugier, B. (2000). The carbon balance of a young beech forest. *Functional Ecology,* 14, 312–325. https://doi.org/10.1046/j.1365-2435.2000.00448.x.

Grieg-Gran, M., Bass, S., and Booker, F. (2015). The role of forests in a green economy Transformation in Africa. www.unep.org/publications.

Griffiths, H. M., Ashton, L. A., Parr, C. L., and Eggleton, P. (2021). The impact of invertebrate decomposers on plants and soil. *New Phytologist*, 231(6), 2142–2149. https://doi.org/10.1111/nph.17553

Grime, J. P. (1973). Control of species density in herbaceous vegetation. Journal of Environmental Management, 1(2), 151–167. https://doi.org/10.1016/S0301-4797(73)80067-3 Gurib-Fakim, A. (2006). Medicinal plants: Traditions of yesterday and drugs of tomorrow. *Molecular Aspects of Medicine*, 27(1), 1-93. https://doi.org/10 .1016/j.mam.2005.07.008.

Haile, A. A. (2022). Ethnobotanical study of medicinal plants used by local people of Mojana Wadera woreda, North Shewa Zone, Amhara Region, Ethiopia. *Asian Journal of Ethnobiology,* 5(1). https://doi.org/10.13057/asianjethnobiol/y050104.

Haile, M., Teketay, D., and Gessesse, A. (2012). Soil fertility and land use dynamics in the Ethiopian highlands: A review. *Journal of Soil Science and Plant Nutrition*, 12(2), 281-302.

Hansson, K., Laclau, J.-P., Saint-André, L., Mareschal, L., van der Heijden, G., Nys, C., Nicolas, M., Ranger, J., and Legout, A. (2020). Chemical fertility of forest ecosystems. Part 1: Common soil chemical analyses were poor predictors of stand productivity across a wide range of acidic forest soils. *Forest Ecology and Management*, 461, 117843. https://doi.org/10.1016/j.foreco.2019.117843.

Hao, D.-C. (2019). Genomics and evolution of medicinal plants. *Ranunculales medicinal plants* (pp. 1–33). https://doi.org/10.1016/b978-0-12-814232-5.00001-0.

Harper, K. A., Macdonald, S. E., Burton, P. J., Chen, J., Brosofske, K. D., Saunders, S. C., Euskirchen, E. S., Roberts, D., Jaiteh, M. S., and Esseen, P.-A. (2005). Edge Influence on Forest Structure and Composition in Fragmented Landscapes. *Conservation Biology*, 19, 768–782. https://doi.org/10.1111/j.1523-1739.2005.00045.x.

Harris, N. L., Gibbs, D. A., Baccini, A., Birdsey, R. A., De Bruin, S., Farina, M. ... and Tyukavina, A. (2021). Global maps of twenty-first century forest carbon fluxes. *Nature Climate Change*, 11(3),234-240.https://doi.org/10.1038/s41558-020-00976-6

Hassan, H., Murad, W., Tariq, A., and Ahmad, A. (2014). Ethnoveterinary study of medicinal plants in Malakand Valley, District Dir (Lower), Khyber Pakhtunkhwa, Pakistan. *Irish Veterinary Journal*, 67(1).

Hassan, R., Scholes, R., and Ash, N. (2005). Ecosystems and human well-being: Volume 1, current state and trends. Washington: Island Press.

Hassanali, A., Wycliffe Wanzala, Zessin, K.-H., Kyule, N. M., Baumann, M., and Mathias, E. (2005). Ethnoveterinary Medicine: A Critical Review of its Evolution, Perception, Understanding and the Way Forward. *Livestock Research for Rural Development*, 17(11).

Hatten, J., and Liles, G. (2019). A 'healthy' balance – The role of physical and chemical properties in maintaining forest soil function in a changing world. In D. L. Karlen (Ed.), Developments in Soil Science (Vol. 36, pp. 373–396). Elsevier. https://doi.org/10.1016/B978-0-444-63998-1.00015-X.

Haugo, R. D., Hall, S. A., Gray, E. M., Gonzalez, P., and Bakker, J. D. (2010). Influences of climate, fire, grazing, and logging on woody species composition along an elevation gradient in the eastern Cascades, Washington. *Forest Ecology and Management*, 260(12), 2204-2213. https://doi.org/10.1016/j.foreco.2010.09.021.

Hazrat, A., Shah, H., Bibi, H., and Sher, K. (2020). Ethnobotanical uses of medicinal plants in Tehsil Utman Khel District Bajaur, Khyber Pakhtunkhwa, Pakistan. Journal of Weed Science Research, 27(2), 287–298. doi:10.28941/pjwsr.v26i3.845.

He, Z., Sun, H., Peng, et al. (2020). Colonization by native species enhances the carbon storage capacity of exotic mangrove monocultures. *Carbon Balance and Management* , 15, 28. https://doi.org/10.1186/s13021-020-00165-0.

Hedberg, I., Kelbessa, E., Edwards, S., Demissew, S., and Persson, E. (2006). Flora of Ethiopia and Eritrea: Vol. 5, Gentianaceae to Cyclocheilaceae. Addis Ababa and Uppsala: The National Herbarium, Addis Ababa University.

Hegde, R., and Enters, T. (2000). Forest products and household economy: A case study from Mudumalai Wildlife Sanctuary, Southern India. *Environmental Conservation*, 27(3), 250–259.

Heilmayr, R., Echeverría, C., Fuentes, R., and Lambin, E. F. (2016). A plantation-dominated forest transition in Chile. *Applied Geography*, 75, 71-82. https://doi.org/10.1016/j.apg eog.2016.07.014.

Heinrich, M., Ankli, A., Frei, B., Weimann, C., and Sticher, O. (1998). Medicinal plants in Mexico: Healers' consensus and cultural importance. *Social Science and Medicine*, 47, 1863-1875.

Hending, D., Heriniaina Randrianarison, Niaina Nirina Mahefa Andriamavosoloarisoa, Ranohatra-Hending, C., Holderied, M. W., McCabe, G., and Cotton, S. (2023). Forest fragmentation and its associated edge-effects reduce tree species diversity, size, and structural diversity in Madagascar's transitional forests. *Biodiversity and Conservation*, 32, 3329–3353. https://doi.org/10.1007/s10531-023-02657-0.

Hill, A. F. (1989). Economic botany: A text book of useful plants and plant products (2nd ed.). McGraw-Hill Book Company, Inc.

Hishe, H., Oosterlynck, L., Giday, K., De Keersmaecker, W., Somers, B., and Muys, B. (2021). A combination of climate, tree diversity and local human disturbance determine the stability of dry Afromontane forests. *Forest Ecosystems*, 8(1). https://doi.org/10.1186/s4066.

Hong Yan Liu, Huang, N., Zhao, C., and Jin Hua Li. (2023). Responses of carbon cycling and soil organic carbon content to nitrogen addition in grasslands globally. *Soil Biology and Biochemistry*, 186, 109164-109164. https://doi.org/10.1016/j.soilbio.2023.109164

Horel, Á., Zsigmond, T., Farkas, C., Gelybó, G., Tóth, E., Kern, A., and Bakacsi, Z. (2022). Climate change alters soil water dynamics under different land cover types. *Sustainability*, 14(7), 3908. https://doi.org/10.3390/su14073908.

Hosseinzadeh, S., Jafarikukhdan, A., Hosseini, A., and Armand, R. (2015). The application of medicinal plants in traditional and modern medicine: a review of Thymus vulgaris. *International Journal of Clinical Medicine*, 6(9), 635–642.

Houghton, R. A., Goodall, J. L., and He, X. (2015). Changes in carbon content of terrestrial biota and soils between 1860 and 1980: A net release of CO2 to the atmosphere. *Ecological Applications*, 25(1), 236-249.

Hu, W., Drewry, J., Beare, M., Eger, A., and Müller, K. (2021). Compaction induced soil structural degradation affects productivity and environmental outcomes: A review and New Zealand case study. *Geoderma*, 395, 115035. https://doi.org/10.1016/j.geoderma.2021.115035.

Hunde, D., Asfaw, Z., and Kelbessa, E. (2006). Use of traditional medicinal plants by people of 'Boosat' sub- district, central Eastern Ethiopia. *Ethiopian Journal of Health Sciences*, 16(2), 141–155.

Hurni, H. (1985). Soil erosion in Ethiopia: A country profile. *Mountain Research and Development*, 5(1), 1-22.

Husen, A., Mishra, V. K., Semwal, K., and Kumar, D. (2012). Biodiversity status in Ethiopia and challenges. *In Environmental Pollution and Biodiversity* (Vol. 1, pp. 31-79). Discovery Publishing House Pvt Ltd.

Hussein, A. (2023). Impacts of Land cover and Land Cover Change on Vegetation Diversity of Tropical Highland in Ethiopia. *Applied and Environmental Soil Science*, 2023. https://doi.org/10.1155/2023/2531241.

Institute of Biodiversity Conservation. (2005). National biodiversity strategy and action plan (Vol. 115). Government of the Federal Democratic Republic of Ethiopia.

IFAD, E. (2016). The biodiversity advantage: Global benefits from smallholder actions. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3671519.

Imhoff, M., Bounoua, L., Ricketts, T., et al. (2004). Global patterns in human consumption of net primary production. *Nature*, 429, 870–873. https://doi.org/10.1038/nature02619.

Intergovernmental Panel on Climate Change (IPCC). (2021). Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press*. https://doi.org/10.1017/9781009157896

Intergovernmental Panel on Climate Change. (2022). Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, and B. Rama, Eds.). *Cambridge University Press*. https://doi.org/10.1017/9781009325844.

Iordăchescu, G., and Vasile, M. (2023). Forests of fear: Illegal logging, criminalization, and violence in the Carpathian Mountains. *Annals of the American Association of Geographers*, 113(9), 2108-2125. https://doi.org/10.1080/24694452.2023.2209631.

Johan, P. D., Ahmed, O. H., Omar, L., and Hasbullah, N. A. (2021). Phosphorus transformation in soils following co-application of charcoal and wood ash. *Agronomy*, 11(10), 2010.

Jolly, D., Bonnefille, R., and Buchet, G. (1997). Vegetation dynamics in central Africa since 18,000 yr BP: Pollen records from the interlacustrine highlands of Burundi, Rwanda and western Uganda. *Journal of Biogeography*, 24(4), 492-512. https://doi.org/10.1046/j.1365-2699.1997.00136.x.

Joshi, R. K., and Garkoti, S. C. (2023). Influence of vegetation types on soil physical and chemical properties, microbial biomass and stoichiometry in the central Himalaya. *CATENA*, 222, 106835. https://doi.org/10.1016/j.catena.2022.106835.

Kabir, M. G., Wang, Y., Abuhena, M., Azim, M. F., Al-Rashid, J., Rasul, N. M., Mandal, D., and Maitra, P. (2023). A bio-sustainable approach for reducing Eucalyptus tree-caused agricultural ecosystem hazards employing Trichoderma bio-sustained spores and mycorrhizal networks. *Frontiers in Microbiology*, 13, 1071392. https://doi.org/10.3389/fmicb.2022.1071392.

Kabir, M., Habiba, U. E., Khan, W., Shah, A., Rahim, S., de los Rios-Escalante, P. R., Farooqi, Z.-U.-R., Ali, L., and Shafiq, M. (2023). Climate change due to increasing concentration of carbon dioxide and its impacts on the environment in the 21st century: A mini review. *Journal of King Saud University Science*. https://doi.org/10.1016/j.jksus.2023.102693

Kafy, A. A., Saha, M., Fattah, M. A., Rahman, M. T., Duti, B. M., Rahaman, Z. A. ... and Sattar, G. S. (2023). Integrating forest cover change and carbon storage dynamics: Leveraging Google Earth Engine and invest model to inform conservation in hilly regions. *Ecological Indicators*, 152, 110374. https://doi.org/10.1016/j.ecolind.2023.110374

Kan, S., Chen, B., and Chen, G. (2023). Globalization of forest land use: Increasing threats on climate vulnerable regions. *Land Use Policy*, 132, 106798. https://doi.org/10.1016/j.landusepol.2023.106798.

Kassa, G., Molla, E., and Abiyu, A. (2020). Effects of Eucalyptus tree plantations on soil seed bank and soil physicochemical properties of Qimbaba forest. *Cogent Food and Agriculture*, 5. https://doi.org/10.1080/23311932.2019.1711297

Kassa, G.M., Teka, AL., and Melese, G.T. (2025). Plant community and structural pattern analyses ofAbraham Sacred Forest in Amhara Regional State,northwest Ethiopia. *PLOS ONE*, 20(1): e0317245.https://doi.org/10.1371/journal.pone.0317245.

Kassa, H., Dondeyne, S., Poesen, J., Frankl, A., and Nyssen, J. (2017). Impact of deforestation on soil fertility, soil carbon and nitrogen stocks: the case of the Gacheb catchment in the White Nile Basin, Ethiopia. *Agriculture, Ecosystems and Environment*, 247, 273–282. https://doi.org/10.1016/j.agee.2017.06.034.

Kassa, Z., Asfaw, Z., and Demissew, S. (2020). An ethnobotanical study of medicinal plants in Sheka Zone of Southern Nations Nationalities and Peoples Regional State, Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 16(1), 7. https://doi.org/10.118 6/s13002-020-00369-9.

Kassaye, K., Amberbir, A., Getachew, B., and Mussema, Y. (2007). A historical overview of traditional medicine practices and policy in Ethiopia. *Ethiopian Journal of Health Development*, 20(2). https://doi.org/10.4314/ejhd.v20i2.10023.

Kassaye, M., Derebe, Y., Kibrie, W., Debebe, F., Emiru, E., Gedamu, B., and Tamir, M. (2024). The effects of environmental variability and forest management on natural forest carbon stock in northwestern Ethiopia. *Ecology and Evolution*, 14(6), e11476. https://doi.org/10.1002/ece3.11476.

Kasu, H. B. (2022). Impact of deforestation in Ethiopia. *Journal of the Selva Andina Biosphere*, 10, 86–95. https://doi.org/10.36610/j.jsab.2022.100200086x.

Kebede, H., Melaku, A., and Kebede, E. (2014). Constraints in animal health service delivery and sustainable improvement alternatives in North Gondar, Ethiopia. *Onderstepoort Journal of Veterinary Research*, 81(1).

Kefalew, A., Asfaw, Z., and Kelbessa, E. (2015). Ethnobotany of medicinal plants in Ada’a District, East Shewa Zone of Oromia Regional State, Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 11(1). https://doi.org/10.1186/s13002-015-0014-6.

Kelbessa, E., Demissew, S., Woldu, Z., and Edwards, S. (1992). Some threatened endemic plants of Ethiopia. In S. Edwards and Z. Asfaw (Eds.), *The status of some plants in parts of tropical Africa* (pp. 35-55). NAPRECA, No. 2. Botany 2000, East and Central Africa.

Kent, M. (2012). Vegetation description and data analysis. A practical approach. John Wiley and Sons.

Kent, M., and Coker, P. (1992). Vegetation description and analysis: a practical approach. Wiley.

Kewessa, G., Dejene, T., Alem, D., Tolera, M., and Martín-Pinto, P. (2022). Forest type and site conditions influence the diversity and biomass of edible macrofungal species in Ethiopia. *Journal of Fungi*, 8(10), 1023. https://doi.org/10.3390/jof81023

Kidane, L., Gebremedhin, G., and Beyene, T. (2018). Ethnobotanical study of medicinal plants in Ganta Afeshum District, Eastern Zone of Tigray, Northern Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 14, 64. https://doi.org/10.1186/s13002-018-0266-z.

Kidane, Y., Hoffmann, S., Jaeschke, A., Beloiu, M., and Beierkuhnlein, C. (2022). Ericaceous vegetation of the Bale Mountains of Ethiopia will prevail in the face of climate change. *Scientific Reports*, 12(1). https://doi.org/10.1038/s41598-022-05846-z

Kifle, E. T., Khamzina, A., Son, Y., Noulèkoun, F., Abdelkadir, A., and Tadesse, W. (2022). Woody species composition, diversity, structure and uses of selected church forests in central Ethiopia. In A. Khamzina and Y. Son (Eds.), *State of the art in Ethiopian church forests and restoration options* (pp. 205-223). Springer International Publishing. https://doi.org/10.1007/978-3-030-86626-6_11.

Kifle, T. E., Noulèkoun, F., Son, Y., and Khamzina, A. (2022). Woody species diversity, structural composition, and human use of church forests in central Ethiopia. *Forest Ecology and Management*, 506, 119991. https://doi.org/10.1016/j.foreco.2021.119991

Kindie, B., Tamiru, C., and Abdala, T. (2021). Ethnobotanical study of medicinal plants and conservation status used to treat human and livestock ailments in Fadis District, eastern Ethiopia. *International Journal of Homeopathy and Natural Medicine*, 7(1), 7. https://doi.org/10.11648/j.ijhnm.20210701.12.

Klepeis, P., Orlowska, I., Kent, E., Cardelús, C., Scull, P., Wassie, A., Eshete, A., and Woods, C. (2016). Ethiopian Church Forests: A hybrid model of protection. *Human Ecology*, 44(6), 715-730. https://doi.org/10.1007/s10745-016-9868-z.

Kokwaro, J. (2009). Medicinal plants of East Africa. University of Nairobi Press.

Koricho, H., Shumi, G., Gebreyesus, T., Song, S., and Fufa, F. (2020). Woody plant species diversity and composition in and around Debre Libanos church forests of North Shoa Zone of Oromiya, Ethiopia. *Journal of Forestry Research*. https://doi.org/10.1007/s11676-020-01241-4.

Körner, C. (2007). The use of 'altitude' in ecological research. *Trends in Ecology and Evolution*, 22(11), 569-574. https://doi.org/10.1016/j.tree.2007.09.006.

Kothandaraman, S., Dar, J. A., Sundarapandian, S., Dayanandan, S., and Khan, M. L. (2020). Ecosystem-level carbon storage and its links to diversity, structural and environmental drivers in tropical forests of Western Ghats, India. *Scientific Reports*, 10. https://doi.org/10.1038/s41598-020-70313-6.

Kothari, C. R. (2004). Research Methodology: Methods and Techniques; 2nd Revised Edition; New Age International (P) Ltd. New Delhi; Pp 175-183.

Krakowska-Sieprawska, A., Kiełbasa, A., Rafińska, K., Ligor, M., and Buszewski, B. (2022). Modern methods of pre-treatment of plant material for the extraction of bioactive compounds. *Molecules*, *27*(3), 730.

Kumar, A., Patil, M., Kumar, P., et al. (2024). Determinants of plant species richness along elevational gradients: Insights with climate, energy, and water–energy dynamics. *Ecological Processes*, *13*, 86. https://doi.org/10.1186/s13717-024-00563-z.

Kumeh, E. M., and Ramcilovic-Suominen, S. (2023). Is the EU shirking responsibility for its deforestation footprint in tropical countries? Power, material, and epistemic inequalities in the EU's global environmental governance. *Sustainable Science*. https://doi.org/10.1007/s11625-023-01302-7.

Lal, R. (1986). Principles of soil science. John Wiley and Sons.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, 304(5677), 1623–1627. https://doi.org/10.1126/science.1097396.

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, *7*(5), 5875-5895.

Larkins, A., Temesgen, W., Chaters, G., et al. (2023). Attributing Ethiopian animal health losses to high-level causes using expert elicitation. *Preventive Veterinary Medicine*, 221, 106077.

Laurance, W. F., Goosem, M., and Laurance, S. G. W. (2009). Impacts of roads and linear clearings on tropical forests. *Trends in Ecology and Evolution*, 24(12), 659–669. https://doi.org/10.1016/j.tree.2009.06.009

Laurance, W. F., Sayer, J., and Cassman, K. G. (2014). Agricultural expansion and its impacts on tropical nature. *Trends in Ecology and Evolution*, 29, 107–116. https://doi.org/10.1016/j.tree.2013.12.001.

Lawal, I. O., Rafiu, B. O., Ale, J. E., Majebi, O. E., and Aremu, A. O. (2022). Ethnobotanical survey of local flora used for medicinal purposes among indigenous people in five areas in Lagos State, Nigeria. *Plants*, 11(5), 633. https://doi.org/10.3390/plants11050633.

Leadley, P., Pereira, H. M., Alkemade, R., Fernandez-Manjarrés, J. F., Proença, V., Scharlemann, J. P. W., and Walpole, M. J. (2010). Biodiversity scenarios: Projections of 21st-century change in biodiversity and associated ecosystem services. Convention on Biological Diversity.

Legese, D., and Roba, A. D. (2021). The Effect of Population Dynamics on Forest Cover in Daro Lebu Wereda, West Hararghe Zone, Oromia Region, Ethiopia. *International Journal of Research Granthaalayah*, 9(3), 78-96. https://doi.org/10.29121/granthaalayah.v9.i3.2021.3761

Leite, F. P., Silva, I. R., Novais, R. F., Barros, N. F. D., and Neves, J. C. L. (2010). Alterations of soil chemical properties by eucalyptus cultivation in five regions in the Rio Doce Valley. *Revista Brasileira de Ciência do Solo*, 34(3), 821-831.

Lemenih, M., and Teketay, D. (2004). Restoration of native forest flora in the degraded highlands of Ethiopia: Constraints and opportunities. *SINET: Ethiopian Journal of Science*, *27*(1), 75–90. https://doi.org/10.4314/sinet.v27i1.18225

Lemessa, D., Mewded, B., and Alemu, S. (2022). Woody species composition and recruitment structures of four common species in an arid and semi-arid ecosystem of Ethiopia. *Journal of Global Ecology and Environment*, *14*(2), 18-27. https://doi.org/10.56557/jogee/2022/v14i27419.

Lemi, T., Guday, S., Fantaye, Y., Eshete, A., and Hassen, N. (2023). Woody species composition, structure, and diversity of Dindin Natural Forest, south east of Ethiopia. *International Journal of Forestry Research*, 2023, 1-13. https://doi.org/10.1155/2023/5338570.

Li, D. P., and Wu, Z. J. (2008). [Impact of chemical fertilizers application on soil ecological environment]. *Ying Yong Sheng Tai Xue Bao*, 19(5), 1158-1165. [PMID: 18655608].

Liang, J., Reynolds, T., Wassie, A., Collins, C., and Wubalem, A. (2016). Effects of exotic Eucalyptus spp. plantations on soil properties in and around sacred natural sites in the northern Ethiopian Highlands. *AIMS Agriculture and Food*, 1(2), 175-193. https://doi.org/10.3934/agrfood.2016.2.175

Lin, B. B., Macfadyen, S., Renwick, A. R., and Cunningham, S. A. (2013). Maximizing the environmental benefits of carbon farming through ecosystem service delivery. *BioScience*, 63(10), 793–803. https://doi.org/10.1525/bio.2013.63.10.6

Linder, H. P., and Verboom, G. A. (2015). The evolution of regional species richness: The history of the southern African flora. *Annual Review of Ecology, Evolution, and Systematics*, 46(1), 393–412. https://doi.org/10.1146/annurev-ecolsys-112414-054322.

Loretta, G., Garrett, A.-K., Byers, A., Chen, C., Lan, Z., Bahadori, M. M., and Wakelin, S. A. (2024). The hidden depths of forest soil organic carbon chemistry in a pumice soil. *Geoderma Regional*. https://doi.org/10.1016/j.geodrs.2024.e00760

Lulekal, E., Asfaw, Z., Kelbessa, E., and Van Damme, P. (2013). Ethnomedicinal study of plants used for human ailments in Ankober District, North Shewa Zone, Amhara Region, Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 9(1). https://doi.org/10.1186/1746-4269-9-63.

Lulekal, E., Kelbessa, E., Bekele, T., and Yineger, H. (2008). An ethnobotanical study of medicinal plants in Mana Angetu District, southeastern Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 4(1). https://doi.org/10.1186/1746-4269-4-10.

Lulekal, E., Rondevaldova, J., Bernaskova, E., Cepkova, J., Asfaw, Z., Kelbessa, E., Kokoska, L., and Van Damme, P. (2014). Antimicrobial activity of traditional medicinal plants from Ankober District, North Shewa Zone, Amhara Region, Ethiopia. *Pharmaceutical Biology*, 52(5), 614-620.

Luo, Y., Su, B. O., Currie, W. S., Dukes, J. S., Finzi, A., Hartwig, U., ... and Field, C. B. (2004). Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. Bioscience, 54(8), 731-739.https://doi.org/10.1641/0006-3568(2004)054[0731:pnloer]2.0.co;2

Lyu, Q., Liu, J., Liu, J., Luo, Y., Chen, L., Chen, G., Zhao, K., Chen, Y., Fan, C., and Li, X. (2021). Response of plant diversity and soil physicochemical properties to different gap sizes in a Pinus massoniana plantation. *PeerJ*, 9, e12222. https://doi.org/10.7717/ peerj.12222.

Ma, R., Hu, F., Liu, J., et al. (2020). Shifts in soil nutrient concentrations and C:N:P stoichiometry during long-term natural vegetation restoration. *PeerJ*, 2020:1–20. https://doi.org/10.7717/peerj.8382.

Maarel, E., and Franklin, J. (Eds.). (2013). Vegetation ecology (2nd ed.). Wiley-Blackwell.

Macía, M. J., García, E., and Vidaurre, P. J. (2005). An ethnobotanical survey of medicinal plants commercialized in the markets of La Paz and El Alto, Bolivia. *Journal of Ethnopharmacology, 97(*2), 337–350. https://doi.org/10.1016/j.jep.2004.11.022.

Magnago, L. F. S., Rocha, M. F., Meyer, L., Martins, S. V., and Meira-Neto, J. A. A. (2015). Microclimatic conditions at forest edges have significant impacts on vegetation structure in large Atlantic forest fragments. *Biodiversity and Conservation*, *24*(9), 2305–2318. https://doi.org/10.1007/s10531-015-0961-1

Magurran, A. E. (1988). Ecological diversity and its measurement. Chapman and Hall.

Magurran, A. E. (2004). Measuring Biological Diversity. Blackwell Publishing, Oxford.

Mammo, S., Kebin, Z., Chimidi, A., and Ibrahim, H. (2019). Soil Quality Analysis for Sustainability of Forest Ecosystem: The Case of Chilimo-Gaji Forest, West Shewa Zone, Ethiopia. *Journal of Environment and Earth Science*, 9. https://doi.org/10.7176/ jees/9-3-01.

Manaye, A., Tesfamariam, B., Tesfaye, M., and Worku, A. (2021). Tree diversity and carbon stocks in agroforestry systems in northern Ethiopia. *Carbon Balance and Management*, 16, 1–18. https://doi.org/10.1186/s13021-021-00174-7.

Mandal, M., and Chatterjee, N. (2021). Estimation of forest ecosystem quality using GIS tool in Panchet forest division, West Bengal, India. In *Forest resources, resilience and conflicts* (pp. 203-213). https://doi.org/10.1016/B978-0-12-822931-6.00015-0.

Maquere, V., Laclau, J.-P., Bernoux, M., Saint-Andre, L., Gonçalves, J. L. M., Cerri, C. C., Piccolo, M. C., and Ranger, J. (2008). Influence of land cover (savanna, pasture, Eucalyptus plantations) on soil carbon and nitrogen stocks in Brazil. *European Journal of Soil Science*, 59, 863-877. https://doi.org/10.1111/j.1365 2389.2008.01059. x

Mariotti, B., Yasutomo Hoshika, Cambi, M., Marra, E., Feng, Z., Paoletti, E., and Marchi, E. (2020). Vehicle-induced compaction of forest soil affects plant morphological and physiological attributes: A meta-analysis. *Forest Ecology and Management*, 462, 118004–118004. https://doi.org/10.1016/j.foreco.2020.118004

Marschner, H., 2011. Marschner's Mineral Nutrition of Higher Plants. Academic Press, London, UK.

Martin, G. J. (1995). Ethnobotany: A method manual. 'People and Plants' Conservation Manual. Chapman and Hall.

Matawal, D. S., and Maton, D. J. (2013). Climate change and global warming: Signs, impact and solutions. *International Journal of Environmental Science and Development*, *4*(1), 62. https://doi.org/10.7763/ijesd.2013.v4.305.

Matthews, E. (1983). Global vegetation and land use: New high-resolution data bases for climate studies. *Journal of Climate and Applied Meteorology*, 22(3), 474-487. https://doi.org/10.1175/1520-0450(1983)022<0474:gvalun>2.0.co;2

McMahon, D. E., Vergütz, L., Valadares, S. V., Silva, I. R., and Jackson, R. B. (2019). Soil nutrient stocks are maintained over multiple rotations in Brazilian Eucalyptus plantations. *Forest Ecology and Management*, 448, 364-375. https://doi.org/10.1016/j.foreco.2019.06.027

Meaza, G., Tadesse, B., Maria, A. S., Piero, B., and Gidey, Y. (2015). Traditional medicinal plants used by Kunama ethnic group in Northern Ethiopia. *Journal of Medicinal Plants Research*, 9(15), 494–509. https://doi.org/10.5897/jmpr2014.5681

Megersa, M., and Tamrat, N. (2022). Medicinal plants used to treat human and livestock ailments in Basona werana district, North Shewa Zone, Amhara Region, Ethiopia. *Evidence-Based Complementary and Alternative Medicine*, 2022, 1–18. https://doi.org/10.1155/2022/5242033.

Megersa, M., Nedi, T., and Belachew, S. (2023). Ethnobotanical study of medicinal plants used against human diseases in Zuway Dugda District, Ethiopia. *Evidence-Based Complementary and Alternative Medicine*, 2023, 1-22. https://doi.org/10.1155/2023/5545294.

Mekonen, A., Gebreslassie, B. H., Wassie, W. A., and Tsegay, B. A. (2019). Review: Church forests the green spots of Ethiopian highlands. *Asian Journal of Forestry*, 3. https://doi.org/10.13057/asianjfor/r00300201.

Mekonnen, A. B. (2019). Distribution and ecological impact of exotic woody plant species inside sacred groves of Northwestern Ethiopia. *Biodiversity and Conservation*, 28(11), 2845–2859. https://doi.org/10.1007/s10531-019-01799-4

Mekonnen, A. B., Mohammed, A. S., and Demissew, A. (2023). Species diversity, structure, and regeneration status of woody plants in Saleda Yohans Church Forest, South Wollo, Ethiopia. *Science*, 2023, 1–11. https://doi.org/10.1155/2023/3853463.

Mekonnen, A. B., Mohammed, A. S., and Tefera, A. K. (2022). Ethnobotanical study of traditional medicinal plants used to treat human and animal diseases in Sedie Muja District, South Gondar, Ethiopia. *Evidence-Based Complementary and Alternative Medicine*, 2022, 1–22. https://doi.org/10.1155/2022/7328613.

Mekonnen, A. B., Wassie, W. A. (2023). Floristic composition, structure, and regeneration status of woody plants in Wonjeta St Micheal Church Forest, Northwestern Ethiopia. *Scientifica, 2023,* 1–10. https://doi.org/10.1155/2023/4061029.

Mekonnen, A. B., Wassie, W. A., Ayalew, H., and Gebreegziabher, B. G. (2022). Species composition, structure, and regeneration status of woody plants and anthropogenic disturbances in Zijje Maryam Church Forest, Ethiopia. *Science*, 2022, 1–14. https://doi.org/10.1155/2022/8607003

Mekonnen, D., Eshetu, A., and Zeryehun, T. (2017). Prevalence of bovine trypanosomosis in Dembecha woreda Amhara Region, Northwest Ethiopia. *Journal of Veterinary Science and Technology*, 8(1). https://doi.org/10.4172/2157-7579.1000413.

Mekonnen, T., Ayele, B., and Ashagrie, Y. (2015). Woody plant species diversity, structure and regeneration status of Wuynwuha natural forest, North West Ethiopia. *Asian Journal of Ethnopharmacology and Medical Foods*, 1(1), 7–9.

Mekuanent, T., Zebene, A., and Solomon, Z. (2015). Ethnobotanical study of medicinal plants in Chilga District, Northwestern Ethiopia. *Journal of Natural Remedies*, 15(2), 88. https://doi.org/10.18311/jnr/2015/476.

Mekuria, W., Diyasa, M., Tengberg, A., and Haileslassie, A. (2021). Effects of long-term land use and land cover changes on ecosystem service values: An example from the Central Rift Valley, Ethiopia. *Land*, 10(12), 1373. https://doi.org/10.3390/land101213 73.

Melkie, A. (2020). Review of opportunities, challenges, and future directions of forestry development and conservation in Ethiopia. *Agricultural Research and Technology: Open Access Journal*, 24(5), 556-286. https://doi.org/10.19080/ARTOAJ.2020.24.556 286.

Mengistu, K. D., Soromessa, T., and Eshete, A. (2021). Carbon Storage of Selected Church Forests in Northern Ethiopia: Implication for Climate Change Mitigation. *Research Square*. https://doi.org/10.21203/rs.3.rs-864594/v1.

Mengistu, T., and Dereje, T. (2021). Impact of land cover types and soil depths on selected soil physicochemical properties in Fasha District, Konso Zone, Southern Ethiopia. *Journal of Soil Science and Environmental Management*, 12(1), 10-16. https://doi.org/ 10.5897/jssem2020.0815.

Mequanint, F., Wassie, A., Aynalem, S., Adgo, E., Nyssen, J., and Frankl, A., et al. (2020). Biodiversity conservation in the church forests of north-west Ethiopia: Diversity and community structure of woody species. *Global Ecology and Conservation*, 24, e01377. https://doi.org/10.1016/j.gecco.2020.e01377.

Meragiaw, M., Woldu, Z., Martinsen, V., and Singh, B. R. (2021). Carbon stocks of above- and belowground tree biomass in Kibate Forest around Wonchi Crater Lake, Central Highlandof Ethiopia. *PLOS ONE*, 16, e0254231. https://doi.org/10.1371/journal.pone. 0254231.

Mesfin, F., Seta, T., and Assefa, A. (2014). An ethnobotanical study of medicinal plants in Amaro woreda, Ethiopia. *Ethnobotanical Research and Applications*, 12, 341. https://doi.org/10.17348/era.12.0.341-354.

Meunpong, P., Wachrinrat, C., Thaiutsa, B., Kanzaki, M., and Meekaew, K. (2010). Carbon pools of indigenous and exotic tree species in a forest plantation, Prachuap Khiri Khan, Thailand. *Kasetsart Journal of Natural Science,* 44(6), 1044–1057.

Mewded, B., Negash, M., and Awas, T. (2019). Woody species composition, structure, and environmental determinants in a moist evergreen Afromontane forest, southern Ethiopia. *Journal of Forestry Research*, 31(4), 1173-1186. https://doi.org/10.1007/s11676-019-00894-0.

Michalzik, B., Kalbitz, K., Park, J. H., Solinger, S., and Matzner, E. (2001). Fluxes and concentrations of dissolved organic carbon and nitrogen: A synthesis for temperate forests. *Biogeochemistry,* 52, 173–205.

Ministry of Environment, Forest and Climate Change (MEFCC). (2018). National Forest Sector Development Programme, Ethiopia. Volume I: Situation Analysis.

Miripanah, Z., Tavakoli, M., Rostaminya, M., and Naderi, M. (2019). Carbon sequestration via afforestation as a sustainable action to mitigate climate change in Western Iran. *Natural Resources Forum*, 43(3), 194-202. https://doi.org/10.1111/1477-8947.12185.

Misganaw, M., Asfaw, Z., and Argaw, M. (2016). The status of ethnobotanical knowledge of medicinal plants and the impacts of resettlement in Delanta, Northwestern Wello, Northern Ethiopia. *Evidence-Based Complementary and Alternative Medicine*, 2016, 1-24. https://doi.org/10.1155/2016/5060247.

Misganaw, M., Seboka, N., and Mulatu, A. (2021). Documentation of traditional knowledge associated with medicinal animals in West Gojjam Zone of Amhara Region, Ethiopia. *American Journal of Life Sciences*, 9(3), 45. https://doi.org/10.11648/j.ajls.20210903.12.

Mittelbach, G. G., Steiner, C. F., Scheiner, S. M., Gross, K. L., Reynolds, H. L., Waide, R. B., ... & Gough, L. (2001). What is the observed relationship between species richness and productivity? Ecology, 82(9), 2381–2396. https://doi.org/10.1890/0012-9658(2001)082[2381:WIOTOR]2.0.CO;2.

Moges, A., and Moges, Y. (2020). Ethiopian common medicinal plants: Their parts and uses in traditional medicine - ecology and Quality Control. *Plant Science - Structure, Anatomy, Physiology of Plants Culture Vivo Vitro*. https://doi.org/10.5772/intechopen.86202.

Molla, E., Getnet, K., and Mekonnen, M. (2022). Land cover change and its effect on selected soil properties in the northwest highlands of Ethiopia. *Heliyon*, 8, e10157. https://doi.org/10.1016/j.heliyon.2022.e10157

Mondo, J. M., Chuma, G. B., Muke, M. B., Fadhili, B. B., Kihye, J. B., Matiti, H. M., ... and Balezi, A. Z. (2024). Utilization of non-timber forest products as alternative sources of food and income in the highland regions of the Kahuzi-Biega National Park, eastern Democratic Republic of Congo. *Trees, Forests and People*, 16, 100547. https://doi.org/10.1016/j.tfp.2024.100547

Montagnini, F., Haines, B., and Swank, W. T. (1991). Soil-solution chemistry in black locust, pine/mixed-hardwoods, and oak/hickory forest stands in the southern Appalachians, USA. *Forest Ecology and Management*, 40, 199–208.

Morales-Hidalgo, D., Oswalt, S. N., and Somanathan, E. (2015). Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment 2015.*Forest Ecology and Management*, 352, 68–77. https://doi.org/10.1016/j.foreco.2015.06.011 .

Mori, S. A., Lertzman, P. K., Gustafsson, L., and Cadotte, M. (2016). Biodiversity and ecosystem services in forest ecosystems: A research agenda for applied forest ecology. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.12669.

Motbainor, A., Worku, A., and Kumie, A. (2016). Level and determinants of food insecurity in East and West Gojjam zones of Amhara Region, Ethiopia: A community-based comparative cross-sectional study. *BMC Public Health*, 16, Article 3186. https://doi.org/10.1186/s12889-016-3186-7.

Mucheye, G., and Yemata, G. (2020). Species composition, structure and regeneration status of woody plant species in a dry Afromontane forest. Northwestern Ethiopia. Cogent Food and Agriculture, 6(1), 1823607. https://doi.org/10.1080/23311932.2020.182360 7.

Mulugeta, L., and Teketay, D. (2005). Restoration of native forest flora in the degraded highlands of Ethiopia: Constraints and opportunities. *SINET: Ethiopian Journal of Science*, 27(1), 75–90. https://doi.org/10.4314/sinet.v27i1.18225.

Muluneh, M. G., Feyissa, M. T., and Wolde, T. M. (2021). Effect of forest fragmentation and disturbance on diversity and structure of woody species in dry afromontane forests of northern Ethiopia. *Biodiversity and Conservation*, 30(6), 1753-1779. https:// doi.org/10.1007/s10531-021-02167-x.

Mwakalukwa, E., Meilby, H., and Treue, T. (2014). Floristic composition, structure, and species associations of dry miombo woodland in Tanzania. *ISRN Biodiversity*, *2014*, 1–15. https://doi.org/10.1155/2014/153278

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A., and Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403(6772), 853–858. https://doi.org/10.1038/35002501.

Naeem, S., Bunker, D. E., Hector, A., Loreau, M., and Perrings, C. (2009). Biodiversity, ecosystem functioning and human wellbeing: An ecological and economic perspective. Oxford University Press.

Najmi, A., Javed, S. A., Al Bratty, M., and Alhazmi, H. A. (2022). Modern approaches in the discovery and development of plant-based natural products and their analogues as potential therapeutic agents. *Molecules*, 27(2), 349.

Naveh, Z. (1994). From biodiversity to ecodiversity: A landscape-ecology approach to conservation and restoration. *Restoration Ecology*, 2(3), 180-189. https://doi.org/10.1 111/j.1526-100x.1994.tb00065.x.

Neelamegam, R. (2016). Woody species composition and diversity analysis in the S.T. Hindu College campus located at Nagercoil, Kanniyakumari District, Tamil Nadu, India. *International Journal of Pure and Applied Bioscience*, 4(6), 193-203. https://doi.org/10.18782/2320-7051.2411.

Nesibu, Y., Belay, G., and Tesfaye, G. (2019). Species diversity, population structure, and regeneration status of woody species on Yerer Mountain Forest, Central Highlands of Ethiopia. *Tropical Plant Research*, 6(2), 206-213. https://doi.org/10.22271/tpr.2019.v6.i2.030.

Netsanet, G., Tulu, D., Hundera, K., and Raga, D. (2020). Ethnobotanical study of medicinal plants, its utilization, and conservation by indigenous people of Gera district, Ethiopia. *Cogent Food and Agriculture*, 6(1), 1852716. https://doi.org/10.1080/23311932.2020.1852716.

Neudertová, K., Hellebrandová, V., Fadrhonsová, V., and Šrámek, V. (2024). Aggregated database of forest soil chemical properties in the Czech Republic based on surveys from 2000 to 2020. *Annals of Forest Science*. https://doi.org/10.1186/s13595-024-01225-y.

Neuschulz, E., Mueller, T., Schleuning, M., et al. (2016). Pollination and seed dispersal are the most threatened processes of plant regeneration. *Scientific Reports*, 6, Article 29839. https://doi.org/10.1038/srep29839.

Newton, A., Evans, P., Watson, S., Ridding, L., Brand, S., and McCracken, M., et al. (2021). Ecological restoration of agricultural land can improve its contribution to economic development. *PLOS ONE*, 16(3), e0247850.https://doi.org/10.1371/journal.pone.0247850.

Ngarivhume, T., van't Klooster, C. I. E. A., de Jong, J. T. V. M., and Van der Westhuizen, J. H. (2015). Medicinal plants used by traditional healers for the treatment of malaria in the Chipinge District in Zimbabwe. *Journal of Ethnopharmacology*, 159, 224–237. https://doi.org/10.1016/j.jep.2014.11.011.

Ni, J. (2003). Plant functional types and climate along a precipitation gradient in temperate grasslands, northeast China and southeast Mongolia. *Journal of Arid Environments*, 53(4), 501–516. https://doi.org/10.1006/jare.2002.1063.

Ni, J., Cheng, Y., Wang, Q., Ng, C. W. W., and Garg, A. (2019). Effects of vegetation on soil temperature and water content: Field monitoring and numerical modeling. *Journal of Hydrology*, 572, 1054-1065. https://doi.org/10.1016/j.jhydrol.2019.02.009.

Nigussie, A., Bezie, Y., Fentahun, M., Alemayehu, A., and Amsalu, G. (2018). Use and conservation of medicinal plants by indigenous people of Gozamin Wereda, East Gojjam Zone of Amhara Region, Ethiopia: An ethnobotanical approach. *Evidence-Based Complementary and Alternative Medicine*, 1-23.https://doi.org/10.1155/2018/2973513.

Nunes, L. J. R., Meireles, C. I. R., Pinto Gomes, C. J., and Almeida Ribeiro, N. M. C. (2020). Forest contribution to climate change mitigation: Management oriented to carbon capture and storage. *Climate*, 8(2), 21. https://doi.org/10.3390/cli8020021.

Oda, B. K., Lulekal, E., Warkineh, B., Asfaw, Z., and Debella, A. (2024). Ethnoveterinary medicinal plants and their utilization by indigenous and local communities of Dugda District, Central Rift Valley, Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 20(1).

Odukoya, J. O., Odukoya, J. O., Mmutlane, E. M., and Ndinteh, D. T. (2022). Ethnopharmacological study of medicinal plants used for the treatment of cardiovascular diseases and their associated risk factors in sub-Saharan Africa. *Plants*, 11(10), 1387. https://doi.org/10.3390/plants11101387.

Oljirra, A. (2019). The causes, consequences, and remedies of deforestation in Ethiopia. *Journal of Degraded and Mining Land Management*, 6(3), 1747-1754. https://doi.org/ 10.15243/jdmlm.2019.063.1747.

Orlowska, I., and Klepeis, P. (2018). Ethiopian church forests: A socio-religious conservation model under change. *Journal of Eastern African Studies*, 12(4), 674-695. https://doi.o rg/10.1080/17531055.2018.1519659.

Osman, A., Sbhatu, D. B., and Giday, M. (2020). Medicinal plants used to manage human and livestock ailments in Raya Kobo District of Amhara Regional State, Ethiopia. *Evidence Based Complementary and Alternative Medicine*, 1-19. https://doi.org/10.11 55/2020/1329170.

Osman, K. T. (2013). Nutrient dynamics in forest soil. In *Forest soils* (pp. 85–103). Springer. https://doi.org/10.1007/978-3-319-02541-4_6.

Ostrowska, A., and Porębska, G. (2015). Assessment of the C/N ratio as an indicator of the decomposability of organic matter in forest soils. *Ecological Indicators*, 49, 104–109. https://doi.org/10.1016/j.ecolind.2014.09.044.

Oteng Mintah, S., Asafo-Agyei, T., Archer, M.-A., Atta-Adjei Junior, P., Boamah, D., Kumadoh, D.,Agyare, C. (2019). Medicinal Plants for Treatment of Prevalent Diseases. *IntechOpen*. doi: 10.5772/intechopen.82049.

Özkan, U., and Gökbulak, F. (2017). Effect of vegetation change from forest to herbaceous vegetation cover on soil moisture and temperature regimes and soil water chemistry. *CATENA*, 149, 158–166. https://doi.org/10.1016/j.catena.2016.09.017.

Pagliai, M., Vignozzi, N., and Pellegrini, S. (2004). Soil structure and the effect of management practices. *Soil and Tillage Research*, 79, 131-143. https://doi.org/10.101 6/j.still.2004.07.002.

Palombo, A. E. (2011). Traditional medicinal plant extracts and natural products with activity against oral bacteria: Potential application in the prevention and treatment of oral diseases. *Evidence-Based Complementary and Alternative Medicine*, 2011, 680354.

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., ... and Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *science*, 333(6045), 988-993. https://doi.org/10.1126/science.1201609.

Pankhurst, R. (1927). An introduction to the medical history of Ethiopia. The Red Sea Press, Inc.

Panwar, V. P. (2013). Litter fall, nutrient return, and soil fertility under Albizia chinensis: An agroforestry tree species. *Annals of Forest Science, 21*(2), 148–160. https://doi.org/10.1007/s13595-013-0279-9

Papageorgiou, D., Bebeli, P. J., Panitsa, M., and Schunko, C. (2020). Local knowledge about sustainable harvesting and availability of wild medicinal plant species in Lemnos Island, Greece. *Journal of Ethnobiology and Ethnomedicine*, 16(1).

Paritsis, J., and Aizen, M. A. (2008). Effects of exotic conifer plantations on the biodiversity of understory plants, epigeal beetles and birds in Nothofagus dombeyi forests. *Forest Ecology and Management*, 255(56), 1575-1583. https://doi.org/10.1016/j.foreco.2007.11.015.

Passalacqua, N. G., De Fine, G., and Guarrera, P. M. (2006). Contribution to the knowledge of the veterinary science and of the Ethnobotany in Calabria region (southern Italy). *Journal of Ethnobiology and Ethnomedicine*, 2(1), 52. https://doi.org/10.1186/1746-4269-2-52.

Pearson, R. H. T., Brown, L. S., and Bridsey, A. R. (2007). Measurement guidelines for the sequestration of forest carbon. U.S. Department of Agriculture, Forest Service, Northern Research Station.

Peters, D. H., Garg, A., Bloom, G., Walker, D. G., Brieger, W. R., and Rahman, M. H. (2008). Poverty and access to health care in developing countries. *Annals of the New York Academy of Sciences*, 1136, 161–171. https://doi.org/10.1196/annals.1425.011.

Petrovska, B. (2012). Historical review of medicinal plants' usage. *Pharmacognosy Reviews*, 6(11), 1. https://doi.org/10.4103/0973-7847.95849.

Phondani, P. C., Maikhuri, R. K., and Kala, C. P. (2010). Ethnoveterinary uses of medicinal plants among traditional herbal healers in Alaknanda catchment of Uttarakhand, India. *African Journal of Traditional, Complementary and Alternative Medicines*, *7*(3).

Pichi-Sermolli, R. (1957). Una Carta Geobotanica Dell'africa Orientale (Eritrea, Ethiopia, Somalia). *Webbia*, 13(1), 15–132. https://doi.org/10.1080/00837792.1957.10669673.

Pillay, R., Venter, M., Aragon-Osejo, J., González-Del-Pliego, P., Hansen, A. J., Watson, J. E., and Venter, O. (2022). Tropical forests are home to over half of the world's vertebrate species. *Frontiers in Ecology and the Environment*, 20(1), 10–15. https://doi.org/10.1002/fee.2420.

Plugge, D., Baldauf, T., and Kohl, M. (2011). Reduced Emissions from Deforestation and Forest Degradation (REDD): Why a Robust and Transparent Monitoring, Reporting and Verification (MRV) System is Mandatory. In *InTech eBooks*. https://doi.org/10.5772/24701.

Poore, M. E. D., and Fries, C. (1985). The ecological effects of Eucalyptus (FAO Forestry Paper No. 59). Food and Agriculture Organization of the United Nations.

Procheș, Ș., and Ramdhani, S. (2023). Ancient plant lineages endemic to Africa and its islands: An analysis on the distribution and diversity. *Diversity*, 15(9), 1000. https://doi.org/10.3390/d15091000.

Psistaki, K., Tsantopoulos, G., and Paschalidou, A. K. (2024). An overview of the role of forests in climate change mitigation. *Sustainability*, 16(14), 6089. https://doi.org/10.3390/su16146089.

Pugh, T. A. M., Lindeskog, M., Smith, B., Poulter, B., Arneth, A., Haverd, V., and Calle, L. (2019). Role of forest regrowth in global carbon sink dynamics. *Proceedings of the National Academy of Sciences*, 116, 4382-4387. https://doi.org/10.1073/pnas.1810512116.

Pulrolnik, K., Barros, N. F. de, Silva, I. R., Novais, R. F., and Brandani, C. B. (2009). Carbon and nitrogen stocks in labile and stable fractions of soil organic matter under eucalyptus, pasture, and cerrado in the Jequitinhonha Valley – MG. *Revista Brasileira de Ciência do Solo*, 33, 1125–1136.

Ramage, M., Burridge, H. C., Wicher, M., and Fereday, G. (2017). The wood from the trees: The use of timber in construction. *Renewable and Sustainable Energy Reviews*, 68, 333–359. https://doi.org/10.1016/j.rser.2016.09.107.

Razafindratsima, O. H., Brown, K. A., Carvalho, F., Johnson, S. E., Wright, P. C., and Dunham, A. E. (2017). Edge effects on components of diversity and above-ground biomass in a tropical rainforest. *Journal of Applied Ecology*, 55, 977–985. https://doi.org/10.1111/1365-2664.12985.

Reddi, L. N., Jain, A. K., and Yun, H.B. (2012). Soil materials for earth construction: Properties, classification, and suitability testing. In *Modern earth buildings: Materials, engineering, constructions and applications* (pp. 155–171). Woodhead Publishing. https://doi.org/10.1533/9780857096166.2.155.

Redding, T. E., Hope, G. D., Fortin, M.-J., Schmidt, M. G., and Bailey, W. G. (2003). Spatial patterns of soil temperature and moisture across subalpine forest-clearcut edges in the southern interior of British Columbia. *Canadian Journal of Soil Science*, 83(2), 121–130.

Regassa, A. (2023). Conversion in land-use alter soil physiochemical properties in the highland of western Ethiopia. *Research Design*, 3(4), Article 16. https://doi.org/10.11648/j.rd.20230403.16.

Reigosa, M. J., and González, L. (2006). Forest ecosystems and allelopathy. In M. J. Reigosa, N. Pedrol, & L. González (Eds.), Allelopathy: A physiological process with ecological implications (pp. 451–463). Dordrecht: Springer. https://doi.org/10.1007/1-4020-4280-9_20.

Ren, G., Yang, X., Wang, X., Zhang, Y., and Li, S. (2020). Comparative study of main meteorological factors inside and outside the forest of Xianweng Mountain National Forest Park. *IOP Conference Series: Earth and Environmental Science*, 508, 012111. https://doi.org/10.1088/1755-1315/508/1/012111.

Reynolds, T. W., Collins, C. D., Wassie, A., Liang, J., Briggs, W., Lowman, M., Sisay, T. S., and Adamu, E. (2017). Sacred natural sites as mensurative fragmentation experiments in long inhabited multifunctional landscapes. *Ecography*, 40(2), 144-157. https://doi.org/10.1111/ecog.02950.

Reynolds, T., Stave, K., Sisay, T., and Eshete, A. (2017). Changes in community perspectives on the roles and rules of church forests in northern Ethiopia: Evidence from a panel survey of four Ethiopian Orthodox communities. *International Journal of the Commons*, *11*(1), 355. https://doi.org/10.18352/ijc.707.

Reynolds, T., Tegegne, S., Lowman, M., & Wassie, A. (2015). Sacred natural sites provide ecological libraries for landscape restoration and institutional models for biodiversity conservation. Retrieved from https://sustainabledevelopment.un.org/content/documents/614059 Sacred%20natural%20sites%20provide%20ecological%20libraries%20for%20landscape%20restoration%20and%20institutional%20models%20for%20biodi.pdf

Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J., and Hirota, M. M. (2009). The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation*, 142(6), 1141–1153. https://doi.org/10.1016/j.biocon.2009.02.021.

Robinson, L. (2015). How churches are the gatekeepers of Ethiopia's forests. Available at: http://magazine.africageographic.com/weekly/issue-43/ethiopias-church-forests/. Accessed on 25.07.2016.

Robledo, C. (2005). Adaptation of forest ecosystems and the forest sector to climate change. FAO Series Forests and Climate Change Working Paper No. 2.

Rodríguez-Loinaz, G., Amezaga, I., and Onaindia, M. (2013). Use of native species to improve carbon sequestration and contribute towards solving the environmental problems of the timberlands in Biscay, northern Spain. *Journal of Environmental Management*, 120, 18–26. https://doi.org/10.1016/j.jenvman.2013.01.032.

Romha, G., Dejene, T. A., Telila, L. B., and Bekele, D. F. (2015. Ethnoveterinary medicinal plants: Preparation and application methods by traditional healers in selected districts of southern Ethiopia. *Veterinary World*, 8(5), 674–684.

Ross, I. A. (Ed.). (2005). Medicinal plants of the world (Vol. 3): Chemical constituents, traditional and modern medicinal uses (pp. 110–132). Humana Press Inc.

Ruelle, M. L., Kassam, K. A., and Asfaw, Z. (2017). Human ecology of sacred space: Church forests in the Highlands of northwestern Ethiopia. *Environmental Conservation*, 45(3), 291–300. https://doi.org/10.1017/s0376892917000534.

Ruwanza, S. (2019). The edge effect on plant diversity and soil properties in abandoned fields targeted for ecological restoration. *Sustainability*, 11(1), 140. https://doi.org/10.3390/su11010140.

Ryu, H., Coscieme, L., Droste, N., Ghosh, S., Nilsson, L., Rana, S., and Shrestha, U. (2020). Assessing Nature's Contributions to People. *Frontiers For Young Minds*, **8**. https://doi.org/10.3389/frym.2020.00098.

Sahle, M., Saito, O., and Reynolds, T. W. (2021). Nature's contributions to people from church forests in a fragmented tropical landscape in southern Ethiopia. *Global Ecology and Conservation*, 28, e01671. https://doi.org/10.1016/j.gecco.2021.e01671.

Salazar, M. P., Lozano, L. A., Villarreal, R., Bellora, G. L., Alejandra, C., Nirvana Churquina, Polich, N. G., and Soracco, C. G. (2024). Soil water repellency under Eucalyptus stands of different age and its relationship with soil hydrological function and soil organic matter. *CATENA*, 246, 108441-108441. https://doi.org/10.1016/j.catena.2024.108441.

Salazar, S., Sanchez, L. E., Galindo, P., and Santa-Regina, I. (2010). Above-ground tree biomass equations and nutrient pools for a paraclimax chestnut stand and for a climax oak stand in the Sierra de Francia Mountains, Salamanca, Spain. *Scientific Research and Essays*, 5(11), 1294–1301.

Sánchez González, A., and Lopez-Mata, L. (2005). Plant species richness and diversity along an altitudinal gradient in the Sierra Nevada, Mexico. *Diversity and Distributions*, 11(6), 567–575. https://doi.org/10.1111/j.1366-9516.2005.00186.x.

Sandewall, M., and Gebrehiwot, M. (2015). An approach for assessing changes of forest land use, their drivers, and their impact to society and environment. In J. P. Díaz (Ed.), *Forests and global change* (pp. 1–14). InTech. https://doi.org/10.5772/61074.

Sayer, A. J., Harcourt, S. C., and Collins, M. N. (1992). The conservation atlas of tropical forests Africa. IUCN.

Schlesinger, W. H., and Bernhardt, E. S. (2013). Biogeochemistry: An analysis of global change. Elsevier/Academic Press.

Schoonover, J. E., and Crim, J. F. (2015). An introduction to soil concepts and the role of soils in watershed management. *Journal of Contemporary Water Research and Education*, 154, 21–47.

Schulte-Uebbing, L., and de Vries, W. (2018). Global-scale impacts of nitrogen deposition on tree carbon sequestration in tropical, temperate, and boreal forests: A meta-analysis. *Global Change Biology*, 24, e416–e431. https://doi.org/10.1111/gcb.13862.

Scotton, M., and Andreatta, D. (2021). Anti-erosion rehabilitation: Effects of revegetation method and site traits on introduced and native plant cover and richness. *Science of The Total Environment*, 776, 145915. https://doi.org/10.1016/j.scitotenv.2021.145915

Scull, P., Cardelús, C. L., Klepeis, P., Woods, C. L., Frankl, A., and Nyssen, J. (2017). The resilience of Ethiopian church forests: Interpreting aerial photographs, 1938–2015. *Land Degradation and Development*, 28, 450–458. https://doi.org/10.1002/ldr.2633

Sekucia, F., Dlapa, P., Kollár, J., Cerdá, A., Hrabovský, A., and Svobodová, L. (2020). Land-use impact on porosity and water retention of soils rich in rock fragments. *CATENA*, 195, 104807. https://doi.org/10.1016/j.catena.2020.104807

Sewagegn, G. B. (2024). Comparative analysis of church, community, and national park forests in biomass carbon stock and climate change mitigation in Ethiopia: A review. *International Journal of Forest Research*, 2024, 11, 6481157. https://doi.org/10.1155/ijfr/648115

Sewagegn, G. B., Abate, D. F., and Gebremariam, G. Y. (2022). Woody species diversity and carbon stock of church forests along age gradient in Dangila District, Awi-Zone, Ethiopia. *Heliyon*, 8, e10491. https://doi.org/10.1016/j.heliyon.2022.e10491.

Sewagegn, G. B., and Abate, D. F. (2024). Church forests diversity and biomass carbon stock along urbanization continuum in Dangila District, Awi-Zone, Ethiopia. *International Journal of Forest Research*, *2024*, Article 6635230. https://doi.org/10.1155/2024/663 5230.

Seyoum, G., and Zerihun, G. (2014). An ethnobotanical study of medicinal plants in Debre Libanos Wereda, Central Ethiopia. *African Journal of Plant Science*, 8(7), 366–379. https://doi.org/10.5897/ajps2013.1041.

Sgarlata, T., Gabriele, M., Maié, T., de Zoeten, R., and Rasteiro, L., and Chikhi, L. (2022). On the genetic consequences of habitat contraction: Edge effects and habitat loss. *bioRxiv*. https://doi.org/10.1101/2022.10.25.513679.

Shaheb, M. R., Venkatesh, R., and Shearer, S. A. (2021). A review on the effect of soil compaction and its management for sustainable crop production. *Journal of Biosystems Engineering*, 46, 417–439. https://doi.org/10.1007/s42853-021-00117-7.

Shahi, N., Bhusal, P., Paudel, G., and Kimengsi, J. N. (2022). Forest People nexus in changing livelihood contexts: Evidence from community forests in Nepal. *Trees, Forests and People*, 8, 100223. https://doi.org/10.1016/j.tfp.2022.100223

Shivanna, K. R. (2022). Climate change and its impact on biodiversity and human welfare. Proceedings of the Indian National Science Academy, 88(1), 160-171. https://doi.org/ 10.1007/s43538-022-00073-6.

Shrestha, S., and Medley, K. (2017). Integrating ecological and ethnobotanical knowledge to promote collaborative conservation planning in the Nepal Himalaya. *Mountain Research and Development*, 37(1), 97-107. https://doi.org/10.1659/mrd-journal-d-15-00081.1.

Siddique, Z., Ahmed, H. M., Hussein, K. N., Hassan, K. I., and Meena, B. I. (2022). Herbal medicinal uses and their practices in human health care and livestock from District Haripur, Khyber Pakhtunkhwa, Pakistan. *Veterinary Medicine and Science*, 8(6), 2683–2695. https://doi.org/10.1002/vms3.948.

Simegn, T. Y., Soromessa, T., and Bayable, E. (2014). Forest carbon stocks in lowland area of Simien Mountains National Park: Implication for climate change mitigation. *Science, Technology and Arts Research Journal*, 3(3), 29-36. https://doi.org/10.4314/s tar.v3i3.5.

Simegniew, B. Y., Kitaw, S. L., Alemayehu, Y. A., and Mengesha, N. M. (2017). Ethnobotanical study of medicinal plants used to treat human diseases in Enarj Enawga District, East Gojjam Zone, Amhara Region, Ethiopia. *Journal of Medicinal Plant Studies*, 1(1), 1006.

Simin, T., Davie-Martin, C. L., Petersen, J., Høye, T. T., and Rinnan, R. (2022). Impacts of elevation on plant traits and volatile organic compound emissions in deciduous tundra shrubs. *Science of The Total Environment*, 837, 155783. https://doi.org/10.1016/j.scitotenv.2022.155783

Singh, S., Malik, Z. A., and Sharma, C. M. (2016). Tree species richness, diversity, and regeneration status in different oak (Quercus spp.) dominated forests of Garhwal Himalaya, India. *Journal of Asia Pacific Biodiversity*, 9(3), 293-300. https://doi.org/10.1016/j.japb.2016.06.002.

Sintayehu, D. W. (2018). Impact of climate change on biodiversity and associated key ecosystem services in Africa: A systematic review. *Ecosystem Health and Sustainability*, 4(9), 225–239. https://doi.org/10.1080/20964129.2018.1530054.

Siraj, M. (2019). Forest carbon stocks in woody plants of Chilimo-Gaji Forest, Ethiopia: Implications of managing forests for climate change mitigation. *South African Journal of Botany*, 127, 213–219. https://doi.org/10.1016/j.sajb.2019.09.003.

Sitotaw, T. M., Willemen, L., Meshesha, D. T., and Nelson, A. (2022). Sacred church forests as sources of wild pollinators for the surrounding smallholder agricultural farms in Lake Tana Basin, Ethiopia. *Ecological Indicators*, 137,108739. https://doi.org/10.1016/j.ecolind.2022.108739.

Smith, P., Cotrufo, M. F., Rumpel, C., Paustian, K., Kuikman, P. J., Elliott, J. A., ... and Scholes, M. C. (2015). Biogeochemical cycles and biodiversity as key drivers of ecosystem services provided by soils. *Soil*, 1(2), 665-685.https://doi.org/10.5194/soil-1-665-2015.

Sollins, P., and McCorison, F. M. (1981). Nitrogen and carbon solution chemistry of an old-growth coniferous forest watershed before and after cutting. *Water Resources Research*, 17, 1409–1418.

Solomon, D., Teketay, D., and Gessesse, A. (2014). Soil properties and plant diversity along an altitudinal gradient in the Bale Mountains, Ethiopia. *Journal of Mountain Science*, 11(1), 127-139.

Solomon, N., Hishe, H., Annang, T., Pabi, O., Asante, I., and Birhane, E. (2018). Forest cover change, key drivers, and community perception in Wujig Mahgo Waren Forest of Northern Ethiopia. *Land*, 7(1), 32. https://doi.org/10.3390/land7010032.

Song, Q., Qin, F., He, H., Wang, H., and Yu, S. (2018). Allelopathic potential of rain leachates from Eucalyptus urophylla on four tree species. *Agroforestry Systems*, 93(4), 1307–1318. https://doi.org/10.1007/s10457-018-0240-8.

Song, Z., Seitz, S., Li, J., Goebes, P., Schmidt, K., Kühn, P., Shi, X., and Scholten, T. (2019). Tree diversity reduced soil erosion by affecting tree canopy and biological soil crust development in a subtropical forest experiment. *Forest Ecology and Management, 444*(2), 69–77. https://doi.org/10.1016/j.foreco.2019.04.015.

Soumare, A., Manga, A., Fall, S., Hafidi, M., Ndoye, I., and Duponnois, R. (2014). Effect of Eucalyptus camaldulensis amendment on soil chemical properties, enzymatic activity, Acacia species growth and roots symbioses. *Agroforestry Systems*, 89, 97–106. https://doi.org/10.1007/s10457-014-9744-z.

Stephenson, N., Das, A., Condit, R., et al. (2014). Rate of tree carbon accumulation increases continuously with tree size. *Nature*, 507, 90–93. https://doi.org/10.1038/nature12914

Stewart, P., & Globig, S. (Eds.). (2011). Photosynthesis: Genetic, environmental and evolutionary aspects. *Apple Academic Press*. https://doi.org/10.1201/b13160.

Sutton-Grier, A. E., and Sandifer, P. A. (2018). Conservation of wetlands and other coastal ecosystems: A commentary on their value to protect biodiversity, reduce disaster impacts, and promote human health and well-being. *Wetlands*, 39. https://doi.org/10.1007/s13157-018-1039-0.

Swaminathan, C., Devi, N., and Pandian, K. (2021). Soil organic matter decomposition—Roles, factors, and mechanisms. In *Latest Trends in Soil Sciences* (Vol. 1, pp. 61–91). Integrated Publications. https://doi.org/10.22271/int.book.33

Tadele, D., Lulekal, E., Damtie, D., and Assefa, A. (2014). Floristic diversity and regeneration status of woody plants in Zengena Forest, a remnant montane forest patch in northwestern Ethiopia. *J. Forestry Res*., 25(2), 329-336.https://doi.org/10.1007/s11676-013-0420-3.

Tadesse Kifle, E. (2020). Physico-chemical characteristics of the soils in three church forest of central Ethiopia. *Research in Ecology,* 2. https://doi.org/10.30564/re.v2i4.2368.

Tadesse, A., Tsegay, B. A., and Telake, B. B. (2019). Ethnoveterinary medicinal plants in rural settings of Bahir Dar District, Ethiopia. *Ethiopian Journal of Science and Technology,* 11(3), 223.

Tadesse, E. (2020). Local perceptions on the status, values and conservation and ethnobotanical implications of medicinal and multipurpose plants in and around selected church forests in Central Ethiopia. *Research in Ecology*, 2(3). https://doi.org/10.30564/re.v2i3.2367.

Tadesse, S. A., and Tafere, S. M. (2017). Local people's knowledge on the adverse impacts and their attitudes towards growing Eucalyptus woodlot in Gudo Beret Kebele, Basona Worena district, Ethiopia. *Ecological Processes*, 6(37). https://doi.org/10.1186/s13717-017-0105-5.

Tadesse, T. (2008). The value of some forest ecosystem services in Ethiopia. In *Proceedings of a workshop on Ethiopian forestry at crossroads: The need for a strong institution* (pp. 83–98). Forum for Environment, Addis Ababa, Ethiopia.

Tahir, M., Asnake, H., Beyene, T., Van Damme, P., and Mohammed, A. (2023). Ethnobotanical study of medicinal plants in Asagirt District, northeastern Ethiopia. *Trop Med Health,* 51(1). https://doi.org/10.1186/s41182-023-00493-0.

Takele, A., Lakew, H. B., and Kabite, G. (2022). Does the recent afforestation program in Ethiopia influence vegetation cover and hydrology? A case study in the upper Awash basin, Ethiopia. *Heliyon,* 8(6), e09589. https://doi.org/10.1016/j.heliyon.2022.e09589

Tamiru, B., Soromessa, T., Warkineh, B., Legesse, G., and Belina, M. (2021). Woody species composition and community types of Hangadi Watershed, Guji Zone, Ethiopia. *BMC Ecol. Evol.,* 21(1), 225. https://doi.org/10.1186/s12862-021-01949-9.

Tariq, A., Mussarat, S., Adnan, M., et al. (2014). Ethnoveterinary study of medicinal plants in a tribal society of Sulaiman Range. *The Scientific World Journal,* 2014, 1–10.

Tebekew, F. A., Tadesse, T. B., Alemu, D. A., and Ayalew, A. A. (2024). Soil physicochemi cal properties variation under annual crop and coffee land cover in the Chentale watershed, upper Blue Nile basin, Ethiopia. *Applied and Environmental Soil Science,* 2024, 1–11. https://doi.org/10.1155/2024/2921614.

Tebkew, M., and Atinkut, H. B. (2022). Impact of forest decentralization on sustainable forest management and livelihoods in East Africa. *Trees For. People,* 10(4), 100346. https://doi.org/10.1016/j.tfp.2022.100346.

Tefera, B. N., and Kim, Y.-D. (2019). Ethnobotanical study of medicinal plants in the Hawassa Zuria District, Sidama Zone, southern Ethiopia. *J Ethnobiol Ethnomed., 15*(1). https://doi.org/10.1186/s13002-019-0302-7.

Tefera, T., and Yihune, M. (2019). Ethnobotanical study on medicinal plants used by indigenous people in Tenta District, South Wollo, Ethiopia. *Journal of Medicinal Plants Research,* 13(2), 47–54. https://doi.org/10.5897/jmpr2018.6599.

Tegegne, E., Alemu Gelaye, K., Dessie, A., Shimelash, A., Asmare, B., Deml, Y. A., Lamore, Y., Temesgen, T., Demissie, B., and Teym, A. (2022). Spatio-Temporal Variation of Malaria Incidence and Risk Factors in West Gojjam Zone, Northwest Ethiopia. *Environ. Health Insights,* 16, 117863022210957. https://doi.org/10.1177/11 786302221095702.

Teketay, D., and Bekele, T. (1995). Floristic composition of Wof Washa natural forest, central Ethiopia: Implication for the conservation of biodiversity. *Feddes Repertorium,* 106(1-2), 127-147.

Tekle, Y. (2015). Medicinal plants in the ethnoveterinary practices of Bensa Woreda, Southern Ethiopia. *OALib,* 2(1), 1–12.

Teku, D., Abebe, A., and Fetene, M. (2024). Ethiopian Orthodox Tewahedo Church sacred forests as sanctuaries for endangered species: Key roles, challenges, and prospects. *Sustainable Environment,* 10(1), Article 2391614. https://doi.org/10.1080/27658511.2 024.2391614

Telo da Gama, J. (2023). The role of soils in sustainability, climate change, and ecosystem services: Challenges and opportunities. *Ecologies,* 4(3), 552-567. https://doi.org/10.33 90/ecologies4030036

Temesgen, D., and Serekebirhan, T. (2019). Woody species diversity and carbon stock estimation of Dorze Ayira natural forest, Gamo zone, Southern Ethiopia. *OMO Int. J. Sci.*, 2(1), 31-44. https://doi.org/10.59122/1341494

Terefe Tolossa, and Feyera Senbeta. (2018). The extent of soil organic carbon and total nitrogen in forest fragments of the central highlands of Ethiopia. *Journal of Ecology and Environment*, 42. https://doi.org/10.1186/s41610-018-0081-4.

Tesfaye, A., Anjulo, A., Fekadu, A., Beyene, K., Girma, A., Gemeda, B., et al. (2022). Ethnopharmacological investigations of *Moringa stenopetala* Bak. Cuf. and its production challenges in southern Ethiopia. *PLOS ONE*, 17(9), e0274678. https://doi.org/10.1371/journal.pone.0274678.

Tewolde, M. (1991). Diversity of Ethiopian flora. In J. M. Engels, J. G. Hawkes, and M. Worede (Eds.), *Plant genetic resources of Ethiopia* (pp. 75–81). Cambridge University Press.

Thomas, G., Sucher, R., Wyatt, A., and Jiménez, I. (2022). Ex situ species conservation: Predicting plant survival in botanic gardens based on climatic provenance. *Biological Conservation*, 265, 109410. https://doi.org/10.1016/j.biocon.2021.109410.

Thorn, S., Seibold, S., Leverkus, A. B., Michler, T., Müller, J., Noss, R. F., Stork, N., Vogel, S., and Lindenmayer, D. B. (2020). The living dead: Acknowledging life after tree death to stop forest degradation. *Front. Ecol. Environ.*, 18, 505-512. https://doi.org/10 .1002/fee.2252.

Tichy, J., and Novak, J. (1998). Extraction, assay, and analysis of antimicrobials from plants with activity against dental pathogens (Streptococcus spp.). *The Journal of Alternative and Complementary Medicine*, 4(1), 39–45.

Tilahun, T. (2018). Medicinal plants used in the treatment of livestock diseases in Berbere district of Bale zone, Oromia region, Ethiopia. *Journal of Medicinal Plants Research*, 12(20), 270–277. https://doi.org/10.5897/jmpr2018.6598

Tilman, D., Wedin, D., and Knops, J. (1996). Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature*, 379(6567), 718-720. https://doi.org/10.1 038/379718a0

Togola, A.,Austarheim,I.,Theïs,A.,Diallo, D., and Paulsen, B. S. (2008). Ethnopharmacologic -al uses of *Erythrina senegalensis*: A comparison of three areas in Mali, and a link between traditional knowledge and modern biological science. *J. Ethnobiol. Ethnomed.*, 4(1). https://doi.org/10.1186/1746-4269-4-6.

Tola, F. K. (2023). Drivers of Forest cover changes in and around Jorgo Wato Forest, West Wallagga, Oromia, Ethiopia. *Heliyon, 9*, e19053. https://doi.org/10.1016/j.heliyon.202 3.e19053

Tolessa, T., and Senbeta, F. (2018). The extent of soil organic carbon and total nitrogen in forest fragments of the central highlands of Ethiopia. *Journal of Ecology and Environment*, 42, 1–8. https://doi.org/10.1186/s41610-018-0081-4

Tolossa, K., Debela, E., Athanasiadou, S., et al. (2013). Ethno-medicinal study of plants used for treatment of human and livestock ailments by traditional healers in South Omo, Southern Ethiopia. *J Ethnobiol Ethnomed.,* 9, 32. https://doi.org/10.1186/1746-4269-9-32.

Tona, B. (2016). Review on woody plant species of Ethiopian high forests. *Journal of Resources Development and Management,* 27. ISSN 2422-8397.

Toraño Caicoya, A., Biber, P., Poschenrieder, W., Schwaiger, F., and Pretzsch, H. (2018). Forestry projections for species diversity-oriented management: An example from Central Europe. Ecological Processes, 7(1). https://doi.org/10.1186/s13717-018-0135-7.

Trotter, R. T., and Logan, M. H. (1986). Informant census: A new approach for identifying potentially effective medicinal plants. In L. N. Etkin (Ed.), *Plants in indigenous medicine and diet* (pp. 91–112). Redgrave.

Trotter, R. T., and Logan, M. H. (2019). Informant Consensus: A new approach for identifying potentially effective medicinal plants. In Plants Indig Med Diet (pp. 91–112). https://doi.org/10.4324/9781315060385-6.

Tuasha, N., Fekadu, S., and Deyno, S. (2023). Prevalence of herbal and traditional medicine in Ethiopia: A systematic review and meta-analysis of 20-year studies. *Syst. Rev., 12*(1). https://doi.org/10.1186/s13643-023-02398-9.

Tufa, T. B., Gurmu, F., Beyi, A. F., et al. (2018). Veterinary medicinal product usage among food animal producers and its health implications in Central Ethiopia. *BMC Veterinary Research,* 14(1).

Tura, T. (2011). Estimation of carbon stock in church forests: Implications for managing church forests for carbon emission reduction. [Unpublished thesis]. Addis Ababa University.

Turner, M. G. (2010). Disturbance and landscape dynamics in a changing world. *Ecology,* 91(10), 2833–2849. https://doi.org/10.1890/10-0097.1.

Turner, N. (2000). Ethnobotany: Future direction for the new millennium. *Manitoba Anthropology Student's Journal,* 16, 15–18.

Turner, N. (2014). Ancient pathways, ancestral knowledge: ethnobotany and ecological wisdom of indigenous peoples of northwestern North America (Vol. 74). McGill-Queen's University Press. https://hdl.handle.net/2027/heb33492.0001.001.

Ugulu, I. (2012). Fidelity level and knowledge of medicinal plants used to make therapeutic Turkish baths. *Studies on Ethno-Medicine,* 6(1).

UNDP. (2021). *Climate Change Adaptation in Ethiopia*. United Nations Development Programme. https://www.undp.org/ethiopia/climate-change-adaptation-ethiopia.

UNEP. (2006). *Africa environment outlook 2* (pp. 226–259). Division of Early Warning and Assessment (DEWA); Progress Press Ltd.

UNFCCC. (2002). Report of the Conference of the Parties on its seventh session, held at Marrakesh from 29 October to 10 November 2001 (FCCC/CP/2001/13/Add.1). UNFCCC. http://unfccc.int/resource/docs/cop7/13a01.pdf

UNFCCC. (2002). Report of the Conference of the Parties on its seventh session, held at Marrakesh from 29 October to 10 November 2001 (FCCC/CP/2001/13/Add.1). http://unfccc.int/resource/docs/cop7/13a01.pdf.

United Nations Framework Convention on Climate Change (UNFCCC). (2002). Report of the Conference of the Parties on its seventh session, held at Marrakesh from 29 October to 10 November 2001: Addendum. Part Two: Action taken by the Conference of the Parties. Volume I (FCCC/CP/2001/13/Add.1). United Nations.

Van Leeuwen, M., and Nieuwenhuis, M. (2010). Retrieval of forest structural parameters using LiDAR remote sensing. *European Journal of Forest Research*, 129, 749–770. https://doi.org/10.1007/s10342-010-0381-4.

Van Wyk, B.-E., and Gorelik, B. (2017). The history and ethnobotany of Cape Herbal Teas. *S. Afr. J. Bot.*, 110, 18–38. https://doi.org/10.1016/j.sajb.2016.11.011.

Van, C.-D. P., and Alonso, Á. (2023). Above and belowground carbon stock of pine plantations and native oak forests coexisting in central Spain. *New For.*, 55. https://doi.org/10.1007/s11056-023-10011-z.

Vigo, C. N., Oclocho-Garcia, F. E., Daniel Iliquín Trigoso, and Oliva-Cruz, M. (2024). Influence of *Eucalyptus globulus* plantations on soil characteristics at different altitudinal levels. *Trees Forests and People*, 18, 100677-100677. https://doi.org/10.10 16/j.tfp.2024.100677.

Vitasse, Y., Signarbieux, C., and Fu, Y. H. (2017). Global warming leads to more uniform spring phenology across elevations. *Proc. Natl. Acad. Sci.*, 115, 1004-1008. https://doi.org/10.1073/pnas.1717342115.

Vitousek, P. M., and Howarth, R. W. (1991). Nitrogen limitation on land and in the sea: How can it occur? *Biogeochemistry*, 13(2), 87-115. https://doi.org/10.1007/BF00002772.

Vitousek, P. M., and Sanford, R. L. (1986). Nutrient cycling in moist tropical forest. *Annual Review of Ecology and Systematics*, 17, 137–167.

Walter, R., Gratzer, G., and Wangdi, K. (2002). Cattle grazing in the conifer forests of Bhutan. *Mt.Res.Dev*, *22*(4), 368-374.https://doi.org/10.1659/02764741(2002)022[036 8: CGITCF] 2.0.CO; 2.

Wang, S., Fu, B. J., Gao, G. Y., Yao, X. L., and Zhou, J. (2012). Soil moisture and evapotranspiration of different land cover types in the Loess Plateau, China. *Hydrology and Earth System Sciences*, 16, 2883–2892. https://doi.org/10.5194/hess-16-2883-2012.

Wassie, A. (2002). Opportunities, constraints and prospects of EOTC in conserving forest resources: The case of churches in South Gonder, Northern Ethiopia (Unpublished MSc thesis). *Swedish University of Agricultural Sciences*, Skinnskatterberg, Sweden.

Wassie, A. (2007). Ethiopian church forests: Opportunities and challenges for restoration (PhD thesis). Wageningen University, PUDOC, Wageningen, the Netherlands. ISBN: 978-90-8504-768-; 204 pp.

Wassie, A., and Teketay, D. (2006). Soil seed banks in church forests of northern Ethiopia: Implications for the conservation of woody plants. *Flora - Morphology, Distribution, Functional Ecology of Plants*, 201(1), 32–43.

Wassie, A., and Teketay, D. (2006). Soil seed banks in church forests of northern Ethiopia: Implications for the conservation of woody plants. *Morphol. Distrib. Funct. Ecol Plants*, 201(1), 32–43. https://doi.org/10.1016/j.flora.2005.04.002.

Wassie, A., Sterck, F. J., and Bongers, F. (2010). Species and structural diversity of church forests in a fragmented Ethiopian highland landscape. *J. Veg. Sci.*, 21(5), 938-948. https://doi.org/10.1111/j.1654-1103.2010.01202.x.

Wassie, A., Sterck, F. J., Teketay, D., and Bongers, F. (2009). Tree regeneration in church forests of Ethiopia: Effects of microsites and management. *Biotropica*, 41(1), 110–119. https://doi.org/10.1111/j.1744-7429.2008.00449.x

Wassie, A., Sterck, F., and Bongers, F. (2010). Species and structural diversity of church forests in a fragmented Ethiopian highland landscape. *Journal of Vegetation Science*, 21, 938–948. https://doi.org/10.1111/j.1654-1103.2010.01202.x

Wassie, S. B. (2020). Natural resource degradation tendencies in Ethiopia: A review. *Environ. Syst. Res.*, 9(1). https://doi.org/10.1186/s40068-020-00194-1.

Wassie, S. M., Aragie, L. L., Taye, B. W., and Mekonnen, L. B. (2015). Knowledge, attitude, and utilization of traditional medicine among the communities of Merawi Town, Northwest Ethiopia: a cross-sectional study. *Evidence-Based Complementary and Alternative Medicine*, 2015, 1–7.

Weckmüller, H., Barriocanal, C., Maneja, R., and Boada, M. (2019). Factors affecting traditional medicinal plant knowledge of the Waorani, Ecuador. *Sustainability*, 11(16), 4460. https://doi.org/10.3390/su11164460.

Weil, R. R., and Brady, N. C. (2017). The nature and properties of soils (15th ed.). Pearson.

Welz, A. N., Emberger-Klein, A., and Menrad, K. (2018). Why people use herbal medicine: Insights from a focus-group study in Germany. *BMC Complementary and Alternative Medicine*, 18, 92. https://doi.org/10.1186/s12906-018-2160-6.

White, D. A., Ren, S., Mendham, D. S., Balocchi-Contreras, F., Silberstein, R. P., Meason, D., Iroumé, A., and Ramirez de Arellano, P. (2022). Is the reputation of *Eucalyptus* plantations for using more water than *Pinus* plantations justified? *Hydrol. Earth Syst. Sci.*, 26(20), 5357–5371. https://doi.org/10.5194/hess-26-5357-2022.

WHO. (2002). Traditional medicine strategy 2002-2005 (WHO/EDM/TRM/2002.1). Geneva, Switzerland.

WHO. (2009). Monographs on selected medicinal plants (Vol. 4). Geneva.

Willmer, J. N. G., Püttker, T., and Prevedello, J. A. (2022). Global impacts of edge effects on species richness. *Biological Conservation*, 272, 109654. https://doi.org/10.1016/j.biocon.2022.109654.

Wirabuana, P. Y. A. P., Sadono, R., & Matatula, J. (2022). Competition influences tree dimension, biomass distribution, and leaf area index of Eucalyptus urophylla in dryland ecosystems at East Nusa Tenggara. *Agriculture and Forestry,* 68(1), 191-206. https://doi.org/10.17707/AgricultForest.68.1.12.

Witharana, L., Chen, D., Curio, J., & Burman, A. (2025). Traditional ecological knowledge in High Mountain Asia: A pathway to climate resilience in agriculture amidst changing climates. *Advances in Climate Change Research,* 16(1), 167–182. https://doi.org/10.1016/j.accre.2025.01.009.

Wolde, A. (2023). Review on selected church forests of Ethiopia: Implications for plant species conservation and climate change mitigation. *International Journal of Forestry Research,* 2023, 1–14. https://doi.org/10.1155/2023/7927301.

Woldearegay, M., Woldu, Z., and Lulekal, E. (2018). Species diversity, population structure and regeneration status of woody plants in Yegof dry Afromontane forest, north eastern Ethiopia. *Eur. J. Adv. Res. Biol. Life Sci.,* 6(4), 20–34.

Woldemariam, G., Demissew, S., and Asfaw, Z. (2021). An ethnobotanical study of traditional medicinal plants used for human ailments in Yem ethnic group, South Ethiopia. *Ethnobot Res Appl.,* 22. https://doi.org/10.32859/era.22.09.1-15.

Woldemedhin, T. T., and Teketay, D. (2016). Forest conservation tradition of the Ethiopian Orthodox Tewahido Church: A case study from West Gojjam Zone, north-western Ethiopia. *Symbolae Botanicae Upsalienses,* 38, 57–73. Uppsala. ISBN 978-91-554-9608-1.

Woods, C. L., Bitew Mekonnen, A., Baez-Schon, M., Thomas, R., Scull, P., Abraha Tsegay, B., and Cardelús, C. L. (2020). Tree community composition and dispersal syndrome vary with human disturbance in sacred church forests in Ethiopia. *Forests,* 11(10), 1082. https://doi.org/10.3390/f11101082.

Woods, C., Cardelus, C., Scull, P., Wassie, A., Baez, M., and Klepeis, P. (2017). Stone walls and sacred forest conservation in Ethiopia. *Biodiversity and Conservation,* 26, 209–221.

Workayehu, B., Fitamo, D., Kebede, F., Birhanu, L., and Fassil, A. (2022). Floristic composition, diversity, and vegetation structure of woody species in Kahitassa Forest, northwestern Ethiopia. *Int. J. For. Res.,* 2022, 1-12. https://doi.org/10.1155/2022/7653465.

Worku, C. (2023). Determinants of food security status of household in West Gojjam Zone, Ethiopia. *Food Sci. Nutr.,* 11(10), 5959–5966. https://doi.org/10.1002/fsn3.3527

World Bank. (2008). *A country study on the economic impacts of climate change (Environment and Natural Resource Management Report Series No. 46946-ET).* World Bank Sustainable Development Department, Africa Region. Washington, D.C.

Wubetie, K. C., Alemayehu, A., & Melaku, E. (2025). Identification of direct and indirect drivers of land use and land cover changes from agriculture to Eucalyptus plantation using the DPSIR framework in Sinan and Mecha Districts of Northwestern Ethiopia. *Trees, Forests and People,* 19, 100759. https://doi.org/10.1016/j.tfp.2024.100759.

Wubu, K. A., Ngatie, A. H., Haylie, T. A., and Osman, A. D. (2023). Ethnobotanical study of traditional medicinal plants in Kebridehar and Shekosh districts, Korahi Zone, Somali Region, Ethiopia. *Heliyon,* 9(12), e22152. https://doi.org/10.1016/j.heliyon.2023.e22152.

Wuenscher, R., Unterfrauner, H., Peticzka, R., and Zehetner, F. (2015). A comparison of 14 soil phosphorus extraction methods applied to 50 agricultural soils from Central Europe. *Plant, Soil and Environment,* 61(2), 86-96. https://doi.org/10.17221/932/2014-pse.

Xi, J., Shao, Y., Li, Z., Zhao, P., Ye, Y., Li, W., et al. (2021). Distribution of woody plant species among different disturbance regimes of forests in a temperate deciduous broad-leaved forest. *Frontiers in Plant Science,* 12. https://doi.org/10.3389/fpls.2021.618524.

Xiong, Y., and Long, C. (2020). An ethnoveterinary study on medicinal plants used by the Buyi people in Southwest Guizhou, China. *Journal of Ethnobiology and Ethnomedicine,* 16(1), 46. https://doi.org/10.1186/s13002-020-00396-y.

Xu, B. C., Gichuki, P., Shan, L., and Li, F. M. (2006). Aboveground Biomass Production and Soil Water Dynamics of Four Leguminous Forages in Semiarid Region, Northwest China. *South African Journal of Botany,* 72, 507-516. https://doi.org/10.1016/j.sajb.2006.01.005.

Yahya, N., Kebede, G., Getachew, M., and Eshete, A. (2022). Land use land cover changes and forest fragmentation on the surrounding of selected church forests in Ethiopia. In *State of the art in Ethiopian church forests and restoration options* (pp. 31–51). https://doi.org/10.1007/978-3-030-86626-6_3.

Yasuhiro, K., Hirofumi, M., and Kihachiro, K. (2004). Effects of topographic heterogeneity on tree species richness and stand dynamics in a subtropical forest in Okinawa Island, Southern Japan. *J. Ecol.,* 92(2), 230-240. https://doi.org/10.1111/j.0022-0477.2004.00875.x.

Yebirzaf, Y., Esubalew, T., and Workinesh, T. (2019). The dynamics of medicinal plants utilization practice nexus its health and economic role in Ethiopia: A review paper. *Int J Biodivers Conserv.,* 11(1), 31–47. https://doi.org/10.5897/ijbc2018.1201.

Yemata, G., and Haregewoien, G. (2022). Floristic Composition, structure and regeneration status of woody plant species in northwest Ethiopia. [1] *Trees, For. People,* 9, 100291. https://doi.org/10.1016/j.tfp.2022.100291.

Yigeremu, A., and Woldearegay, M. (2022). Woody species diversity, composition, and regeneration status of Abbo Sacred Forest, southern Ethiopia. *Scientific World J.,* 2022, 1–10. https://doi.org/10.1155/2022/9112578.

Yigezu, G. (2021). The challenges and prospects of Ethiopian agriculture. *Cogent Food and Agriculture*, 7(1), 1923619.

Yilma, G., and Derero, A. (2020). Carbon stock and woody species diversity patterns in church forests along church age gradient in Addis Ababa, Ethiopia. *Urban Ecosystems, 23*(5), 971-983. https://doi.org/10.1007/s11252-020-00961-z.

Yimam, A., Mekuriaw, A., Assefa, D., and Bewket, W. (2024). Effect of *Eucalyptus globulus* plantations on soil physicochemical properties in the upper Blue Nile, Ethiopia. *Applied and Environmental Soil Science*, 2024, 1-12. https://doi.org/10.1155/2024/88 11109.

Yineger, H., Kelbessa, E., Bekele, T., and Lulekal, E. (2007). Ethnoveterinary medicinal plants at Bale Mountains National Park, Ethiopia. *Journal of Ethnopharmacology,* 112(1), 55–70.

Yirsaw, E., and Nigussie, W. (2024). Land use/land cover change modeling and evaluating the spatiotemporal dynamics of highland bamboo species in the southern highland of Ethiopia. *J. Indian Soc. Remote Sens.* https://doi.org/10.1007/s12524-023-01799-6.

Yitaferu, B., Abewa, A., and Amare, T. (2013). Expansion of *Eucalyptus* Woodlots in the Fertile Soils of the Highlands of Ethiopia: Could It Be a Treat on Future Cropland cover? *Journal of Agricultural Science,* 5. https://doi.org/10.5539/jas.v5n8p97.

Yohannis, S., Asfaw, Z., and Kelbessa, E. (2018). Ethnobotanical study of medicinal plants used by local people in Menz Gera Midir District, North Shewa Zone, Amhara Regional State, Ethiopia. *Journal of Medicinal Plants Research,* 12(21), 296-314. https://doi.org/10.5897/jmpr2018.6616.

Younes, N., Yebra, M., Boer, M. M., Griebel, A., and Nolan, R. H. (2024). A review of leaf-level flammability traits in eucalypt trees. *Fire*, 7(183). https://doi.org/10.3390/fire70 60183.

Yu, Z., Guoyi, Z., Liu, L., Manzoni, S., Ciais, P., Goll, D., Peñuelas, J., Sardans, J., Wang, W., Zhu, J., Li, L., Yan, J., Liu, J., and Tang, X. (2021). Natural forests promote phosphorus retention in soil. *Global Change Biology*, 28, 1678–1689. https://doi.org/10.1111/gcb.15996.

Yusuf, H. A., Oludipe, J. J., Adeoye, O. O., and Olorunfemi, I. E. (2019). Carbon Stocks in Aboveground and Belowground Biomass of Sub-Humid Tropical Forest in Southwestern Nigeria. *OALib*, 06, 1–12. https://doi.org/10.4236/oalib.1105588.

Zaman, S., Siddiquee, S., and Katoh, M. (2011). Species composition and forest structure in tropical moist deciduous forest of Bangladesh: A case study in Thakurgaon. *Arabian Journal of Geosciences,* 4(7–8), 1315–1321. https://doi.org/10.1007/s12517-010-0235-x.

Zechmeister-Boltenstern, S., Keiblinger, K. M., Mooshammer, M., Peñuelas, J., Richter, A., Sardans, J., and Wanek, W. (2015). The application of ecological stoichiometry to plant–microbial–soil organic matter transformations. *Ecological Monographs,* 85, 133–155. https://doi.org/10.1890/14-0777.1.

Zegeye, H., Teketay, D., and Kelbessa, E. (2011). Diversity and regeneration status of woody species in Tara Gedam and Abebaye forests, northwestern Ethiopia. *J. For. Res.,* 22(3), 315–328. https://doi.org/10.1007/s11676-011-0176-6.

Zegeye, M. B., Fikire, A. H., and Assefa, A. B. (2022). Impact of agricultural technology adoption on food consumption expenditure: evidence from rural Amhara region, Ethiopia. *Cogent Economics and Finance,* 10(1).

Zemede Asfaw, K. Zewude, and Demissew, S. (2020). An ethnobotanical study of medicinal plants in Sheka Zone of Southern Nations Nationalities and Peoples Regional State, Ethiopia. *Journal of Ethnobiology and Ethnomedicine,* 16(1). https://doi.org/10.1186/s13002-020-0358-4.

Zerabruk, S., and Yirga, G. (2012). Traditional knowledge of medicinal plants in Gindeberet district, Western Ethiopia. *S. Afr. J. Bot.,* 78, 165-169. https://doi.org/10.1016/j.sajb.2011.06.006.

Zhang, C., and Fu, S. (2009). Allelopathic effects of eucalyptus and the establishment of mixed stands of eucalyptus and native species. *Forest Ecology and Management,* 258, 1391–1396. https://doi.org/10.1016/j.foreco.2009.06.045.

Zhang, J., Onakpoya, I. J., Posadzki, P., and Eddouks, M. (2015). The safety of herbal medicine: From prejudice to evidence. *Evid Based Complement Alternat Med.,* 2015, 1–3. https://doi.org/10.1155/2015/316706.

Zhang, L., Qi, S., Li, P., and Zhou, P. (2024). Influence of stand and environmental factors on forest productivity of *Platycladus orientalis* plantations in Beijing’s mountainous areas. *Ecological indicators,* 158, 111385-111385. https://doi.org/10.1016/j.ecolind.2023.111385.

Zhao, W., Cao, X., Li, J., Xie, Z., Sun, Y., and Peng, Y. (2023). Novel Weighting Method for Evaluating Forest Soil Fertility Index: A Structural Equation Model. *Plants,* 12, 410. https://doi.org/10.3390/plants12020410.

Zhu, W., Zhou, O., Sun, Y., Li, X., Di, N., Li, D., Yilihamu, G., Wang, Y., Fu, J., Xi, B., and Jia, L. (2023). Effects of stand age and structure on root distribution and root water uptake in fast-growing poplar plantations. *Journal of Hydrology,* 616, 128831. https://doi.org/10.1016/j.jhydrol.2022.128831.

Zwartendijk, B. W., Van Meerveld, H. J., Ghimire, C. P., Bruijnzeel, L. A., Ravelona, M., and Jones, J. P. G. (2017). Rebuilding Soil Hydrological Functioning after Swidden Agriculture in Eastern Madagascar. *Agriculture, Ecosystems and Environment,* 239, 101-111. https://doi.org/10.1016/j.agee.2017.01.002.

APPENDICES

Appendix 1: List of Published and unpublished Manuscripts

Ayele, A., Seid, A., Mekonnen, A. B., Wassie, W. A., Yemata, G., Yihune, E., Mekuriaw, A., and Shimeles, L. (2024). Woody species diversity, structure and regeneration status of the church forests in West Gojjam Zone, Northwestern Ethiopia. *Trees, Forests and People*, 16, 100570. https://doi.org/10.1016/j.tfp.2024.100570

Ayele Haile, A., Seid, A., Mekonnen, A. B., Adnew, W., Yemata, G., Yihune, E., and Mekuriaw, A. (2024). Estimation of carbon stocks of woody plant species in church forests of West Gojjam zone, Northwestern Ethiopia: Implications for climate change mitigation. *Trees, Forests and People*, 18, 100704. https://doi.org/10.1016/j.tfp.2024.100704

Haile, A. A., Seid, A., Mekonnen, A. B., Wassie, W. A., Yemata, G., Yihune, E., and Mekuriaw, A. (2025). Human disturbances and their impact on woody species diversity in sacred church forests in West Gojjam Zone, Northwestern Ethiopia. *Trees, Forests and People*, 19, 100776. https://doi.org/10.1016/j.tfp.2025.100776

Soil Fertility and Ecosystem Integrity in Wst Gojjam Zone Selected Church Forests: Effects of Eucalyptus Plantation and Edge Disturbance.

Ayele, A. H., Seid, A., Mekonnen, A. B., Adnew, W. W., and Yemata, G. (2024). Ethnobotanical study of the traditional use of medicinal plants used for treating human diseases in selected districts of West Gojjam zone, Amhara Region, Ethiopia. *Phytomedicine Plus*, 4(3), 100620. https://doi.org/10.1016/j.phyplu.2024.100620

Abebe Ayele, Ali Seid, Amare B. Mekonnen, Wubetie Adnew, Getahun Yemata (2025). Ethnoveterinary practices of medicinal plants in Selected Districts of West Gojjam Zone, North Western Ethiopia. *Journal of Ethnobotany Research and Applications*. https://doi.org/10.32859/era.31.74.1-20.

Ayele Haile, A., Tsegay, B. A., Seid, A., Adnew, W., and Moges, A. (2022). A review on medicinal plants used in the management of respiratory problems in Ethiopia over a twenty-year period (2000–2021). *Evidence-Based Complementary and Alternative Medicine*. https://doi.org/10.1155/2022/2935015

Appendix 2. Checklists of data sheets for Ecological and Ethnobotanical data

I. Ecological data

Complete this form for each plot in the church forest.

Church forests Name _______Longitude_______ Latitude_______ Elevation______

Name of collector (s) ____________________________________ Date____________

Plot Number_____________

Size in hectare_________

Size of Church Forest: Large_______ Medium________ Small___________

Distance: Near_______Far________

Table 1: Complete this form for the overall plot (DBH= diameter at breast height; IVI= Important value index; AGB= above ground biomass)

Botanical name	No trees	No. of plot in which sp. Occur	Mean DBH (cm)	Mean Height (m)	Frequ-ency	Relative density	IVI	Mean AGB/tree (ton ha^{-1})

II. Ethnobotanical data collection through semi-structured interview questions employing in the church community and study districts.

A. General information on respondents

1. Date…………2. Name of kebele…………………….3. Collection No…………

4. Name of respondent……………5. Gender………….. 6. Age…………7. Occupation……… 8 Marital Status…………. 9. Religion: Orthodox…………..Protestant……… Muslim………..Others………………

10. Educational status: illiterate ……… Literate ………

B. Information related to the medicinal use of the plants

1. List the major types of human and livestock diseases in your locality?
2. How do you treat human and livestock diseases in traditional way?
3. Local name of plants……… ……
4. Family name……… ……………Scientific name……………. fill by researcher
5. Habitat of plant (wild, home garden, both wild and home garden, cultivated, everywhere or others)
6. Habit of the plant: Tree……..Shrub……Climber………Herb……… epiphyte… liana………
7. Which parts of medicinal plants used to treat human/livestock diseases? Leaves…Roots……Stems……barks……flowers……seeds……latexes…whole plants…… etc.
8. How do you prepare the medicine? Crushing…………powdering………..boiling……..… chewing…concoction…grinding…chopping….squeezing……decoction……heating…cooking……smoking….
9. How plant parts are condition during the preparation of medicine? Fresh…… dry……both fresh and dry…………
10. What ingredients are adding other than plants during the preparation of medicine? ………
11. Plants used to treat human health problems.

Local names of plants	Habit	Habitat	preparation	Application	Dosage	Side effect	Antidote	collection number

12. Plants used to treat livestock health problems.

Local names of plants	Habit	Habitat	preparation	Application	Dosage	Side effect	Antidote	collection number

13. Are there any side effects of medicines? If yes what is the antidote?
14. How medicines are administered? Oral……Dermal……Nasal……Eye….Ear…others…
15. How do you determine the dose? ……………………………….
16. Does the dose differ among males, females, children, elders, pregnant women? Mention any noticeable adverse/side effect (s) …………………………….
17. How is the knowledge on the medicinal plants passed to the next generation (Oral, document form)? ……………………………………….
18. To whom do you share your knowledge? …………………………
19. Which plant species is selected by the local communities for different purposes? ……………
20. Which seasons are preferred for collection of medicinal plants? Wet…….dry……....both seasons……
21. How much the traditional medicine is accepted by the community you live in (Acceptance, no acceptance, I don’t know)? ………………..
    21.1. If not accepted why? ……………
    21.2. If it is accepted why? (Effectiveness of traditional medicine, the cheapness of traditional medicine, lack of access to modern medicine, all of the above, other reasons, I don’t know) ………
22. Is there any taboos related to the collection of medicinal plants? ……
23. What are the threats of medicinal plants in your local area? ……………..
24. How do you conserve medicinal plants? ……………..

Checklist semi-structered interview question for selected key informants (traditional healers)

1. Which medicinal plants are most preferred to prepare medicine in your area?

No	Name of plant species	Respondents						Total	Rank
		R1	R2	R3	R4	…….			
1									
2									
3									
4									
5									
6									

2. Which plants are used as multipurpose?

No	Name of plant species	Uses						Total	Rank
		U1	U2	U3	U4	…….			
1									
2									
3									
4									

Note: U1, U2… = Use of that particular plant species beyond medicinal value

Appendix 3. Site location and details obtained from GPS data and survey observations

Study sites code	Elevation	Elevation Zone	Size (Ha)	Latitude	Longitude	Wall
S1	1835	Montane	2.77	11.613	37.280	No
S2	1824	Montane	2.99	11.661	37.277	No
S3	1918	Montane	6.16	11.695	37.498	No
S4	2115	Upper Montane	1.99	11.433	37.163	No
S5	2141	Upper Montane	50.11	11.388	37.157	No
S6	2038	Montane	3.11	11.353	36.923	No
S7	1967	Montane	5.9	11.410	37.011	NO
S8	1973	Montane	4.69	11.363	36.966	Yes
S9	1960	Montane	2.98	11.401	37	No
S10	2392	Upper Montane	15.67	11.241	37.537	NO
S11	2350	Upper Montane	3.12	11.220	37.512	No
S12	2425	Upper Montane	7.73	11.198	37.499	NO
S13	2945	Upper Montane	5.26	10.854	37.640	No
S14	2636	Upper Montane	6.13	10.893	37.681	NO
S15	2560	Upper Montane	4.88	10.884	37.662	NO
S16	2653	Upper Montane	12.38	10.947	37.097	NO
S17	2723	Upper Montane	4.4	10.993	37.207	Yes
S18	2265	Upper Montane	3.89	10.584	37.48	No
S19	2233	Upper Montane	9.94	10.575	37.528	NO
S20	2497	Upper Montane	3.21	10.606	37.501	Yes
S21	2096	Montane	3.79	10.546	37.506	Yes
S22	2045	Montane	5.52	10.612	37.428	No
S23	1912	Montane	5.46	10.692	37.240	No
S24	1899	mon tane	4.89	10.672	37.24	No
S25	2072	Montane	1.98	10.626	36.914	No
S26	2033	Montane	3.86	10.620	36.987	No

Appendix 4. List of woody species found in the 26 church forests with their respective Relative Dominance (RDO), Relative Density (RD), Importance value indices (IVI).

Scientific Name	Family Name	Relative Dominance	Relative density	Relative Frequency	IVI
Gardenia ternifolia subsp. *jovis-tonantis* (Welw.) Verdc.	Rubiaceae	2.290	0.272	0.949	3.511
Vachellia abyssinica (Hochst. ex Benth.) Kyal. & Boatwr.	Fabaceae	0.978	1.905	1.008	3.891
Vachellia nilotica (L.) P.J.H. Hurter & Mabb.	Fabaceae	0.406	0.459	1.242	2.107
Capparis tomentosa L.	Capparidaceae	0.074	1.667	1.167	2.907
Olinia rochetiana A. Juss.	Oliniaceae	0.016	0.068	0.767	0.851
Acanthus polystachius Del.	Acanthaceae	0.027	0.833	0.867	1.728
Albizia schimperiana Oliv.	Fabaceae	3.404	6.276	1.600	11.279
Salix mucronata subsp. *subserrata* (Willd.) R.H. Archer & Jordaan	Salicaceae	0.064	0.017	0.426	0.507
Apodytes dimidiata E. Mey. ex Arn.	Icacinaceae	1.412	0.323	0.742	2.477
Oldeania alpina (K. Schum.) Stapleton	Poaceae	0.092	1.088	1.704	2.885
Allophylus abyssinica (Hochst) Radlkofer	Sapindaceae	0.090	0.017	0.365	0.472
Arundo donax L.	Poaceae	0.033	0.017	0.426	0.476
Barleria eranthemoides R. Br. ex C.B. Clarke.	Acanthaceae	0.017	0.085	0.852	0.954
Bersama abyssinica Fresen. subsp. Abyssinica.	Melianthaceae	0.062	1.939	1.427	3.428
Borassus aethiopum Mart.	Arecaceae	0.500	0.034	0.426	0.960
Brucea antidysenterica J. F. Mill.	Simaroubaceae	0.084	0.714	1.298	2.096
Buddleja polystachya Fresen.	Loganiaceae	0.928	1.156	1.072	3.156
Cajanus cajan (L.) Millsp.	Fabaceae	0.037	0.034	0.426	0.497
Calpurnia aurea subsp. *aurea* (Ait.) Benth.	Fabaceae	0.066	6.667	1.668	8.400
Carica papaya L.	Caricaceae	9.752	0.017	0.426	10.195
Carissa spinarum L.	Apocynaceae	0.122	3.146	1.591	4.858
Celtis africana Burm.	Ulmaceae	0.558	0.153	0.913	1.624

Citrus aurantiifolia (Christm.) Swingle.	Rutaceae	0.133	0.051	0.383	0.567
Citrus aurantium L.	Rutaceae	0.062	0.085	0.393	0.541
Citrus sinensis (L.) Osb.	Rutaceae	0.122	0.051	0.852	1.025
Clausena anisata (Willd.) Benth.	Rutaceae	0.035	2.993	1.397	4.425
Clematis simensis Fresen.	Ranunculaceae	0.043	0.425	0.660	1.128
Rotheca myricoides (Hochst.) Steane & Mabb.	Lamiaceae	0.074	0.187	0.716	0.977
Coffea arabica L.	Rubiaceae	0.027	4.660	1.454	6.141
Clutia abyssinica Jaub. & Spach.	Euphorbiaceae	0.177	0.051	0.426	0.654
Cordia africana Lam.	Boraginaceae	1.186	3.197	1.321	5.704
Crateva adansonii DC.	Capparidaceae	0.470	1.224	0.904	2.598
Croton macrostachyus Del.	Euphorbiaceae	0.787	5.068	1.596	7.450
Hesperocyparis lusitanica (Mill.) Bartel.	Cupressaceae	1.385	1.241	1.162	3.788
Cyanotis parasitica Hochst. ex Hassk.	Commeliaceae	0.094	0.119	0.568	0.781
Pavetta crystalensis S. E. Dawson	Rubiaceae	0.066	0.085	1.278	1.429
Diospyros abyssinica (Hiern) F. White.	Ebenaceae	1.288	0.136	1.704	3.128
Discopodium penninervium Hochst.	Solanaceae	0.004	0.068	0.852	0.924
Dodonaea viscosa subsp. Angustifolia	Sapindaceae	0.021	1.156	1.111	2.289
Dombeya torrida (J. F. Gmel.) P.Bamps.	Sterculiaceae	0.424	1.565	0.997	2.986
Dovyalis abyssinica (A. Rich.) Warb.	Flacourtiaceae	0.057	0.238	0.852	1.147
Dracaena steudneri Engl.	Dracaenaceae	2.028	0.289	0.639	2.956
Ekebergia capensis Sparrm.	Meliaceae	0.136	0.425	0.716	1.277
Embelia schimperi Vatke.	Myrsinaceae	0.162	0.085	0.465	0.712
Entada abyssinica Steud.ex A. Rich.	Fabaceae	0.026	0.051	0.852	0.929
Erythrina abyssinica Lam. ex DC.	Fabaceae	0.338	0.204	0.852	1.395
Erythrococca bongensis Pax.	Euphorbiaceae	0.128	0.034	0.852	1.014
Eucalyptus camaldulensis Dehnh.	Myrtaceae	0.751	6.769	1.855	9.374
Corymbia citriodora (Hook.) K.D.Hill & L.A.S.Johnson.	Myrtaceae	0.721	0.102	0.852	1.675
Euclea racemosa Murr.	Ebenaceae	0.477	0.204	0.983	1.664

Euphorbia abyssinica Gmel.	Euphorbiaceae	1.594	2.007	0.791	4.392
Euphorbia tirucalli L.	Euphorbiaceae	0.912	0.255	0.852	2.019
Ficus glumosa Del.	Moraceae	2.006	0.034	0.426	2.466
Ficus sur Forssk.	Moraceae	2.802	0.153	0.511	3.466
Ficus thonningii Blume.	Moraceae	0.342	0.918	0.871	2.132
Ficus vasta Forssk.	Moraceae	24.384	0.578	0.631	25.593
Galiniera saxifraga (Hochst.) Bridson.	Rubiaceae	0.114	0.204	1.136	1.454
Grevillea robusta A.Cunn. ex R.Br.	Proteaceae	0.295	2.415	1.335	4.045
Melia azedarach L.	Meliaceae	0.884	0.136	1.704	2.724
Grewia ferruginea Hochst.ex A.Rich.	Tiliaceae	0.292	1.327	1.203	2.821
Hagenia abyssinica (Bruce) J.F.Gmelin.	Rosaceae	1.202	0.272	1.065	2.539
Hibiscus macranthus Hochst. ex A. Rich.	Malvaceae	0.021	0.085	0.767	0.873
Indigofera prieureana Guill & Perr.	Oleaceae	0.045	0.255	0.673	0.973
Jasminum abyssinicum Hochets. Ex DC.	Oleaceae	0.018	0.051	0.730	0.799
Juniperus procera Hochst. ex. Endl.	Cupressaceae	4.013	6.463	1.757	12.233
Justicia schimperiana (Hochst. ex Nees) T. Anders.	Acanthaceae	0.042	1.667	1.046	2.754
Maesa laceolata Forssk.	Myrsinaceae	0.031	0.136	0.511	0.678
Malus sylvestris Miller.	Rosaceae	0.367	0.017	0.426	0.810
Myrsine africana L.	Myrsinaceae	0.051	0.068	0.404	0.523
Gymnosporia arbutifolia (A. Rich.) Wilczek.	Celastraceae	0.033	1.054	1.123	2.210
Gymnosporia obscura (A.Rich.) Loes.	Celastraceae	0.053	0.051	0.730	0.834
Millettia ferruginea (Hochst.) Bak	Asteraceae	0.831	2.500	1.613	4.944
Mimusops kummel Bruce ex. DC.	Sapotaceae	7.072	0.884	1.399	9.355
Morella salicifolia (Hochst. ex A. Rich.) Verdc. & Polhill.	Myricaceae	0.073	0.136	0.639	0.848
Myrtus communis Tarentina.	Myrtaceae	0.046	0.034	0.320	0.400
Eucalyptus globulus Labill.	Myrtaceae	1.655	1.020	1.491	4.166
Olea europaea subsp. *cuspidata* (Wall. & G.Don) Cif.	Oleaceae	2.233	5.833	1.731	9.797

Osyris lanceolata Hochst. & Steud.	Santalaceae	0.050	0.391	0.755	1.196
Loeseneriella africana (Willd.) N. Hallé.	Celastraceae	0.033	0.085	0.568	0.686
Persea americana Mill.	Lauraceae	0.188	0.051	0.393	0.632
Phytolacca dodecandra L'Her.	Phytolaccaceae	0.031	0.119	0.710	0.860
Piper nigrum L.	Piperaceae	0.678	0.085	0.426	1.189
Afrocarpus falcatus (Thunb.) C.N.	Podocarpaceae	7.426	0.510	1.189	9.125
Premna schimperi Engl.	Lamiaceae	0.033	0.034	0.256	0.322
Prunus africana (Hook.f.) Kalkm.	Rosaceae	3.279	1.259	0.800	5.338
Prunus persica L.	Rosaceae	0.489	0.017	0.426	0.932
Psidium guajava L.	Myrtaceae	0.254	0.068	0.409	0.731
Pterolobium stellatum (Forssk.) Brenan.	Fabaceae	0.025	0.153	0.639	0.817
Rhamnus prinoides L'Herit.	Rhamnaceae	0.018	0.102	0.710	0.830
Rhus vulgaris Meikle.	Anacardiaceae	0.095	2.415	1.470	3.980
Ricinus communis L.	Euphorbiaceae	0.046	0.068	0.538	0.652
Ritchiea albersii Gilg.	Capparidaceae	0.626	0.255	0.852	1.733
Rosa abyssinica Lindley.	Rosaceae	0.049	0.357	0.738	1.145
Rubus rosifolius Sm.	Rosaceae	0.019	0.085	1.278	1.382
Rumex nervosus Vahl.	Polygonaceae	0.001	0.068	0.511	0.580
Salix mucronata subsp. *subserrata*. (Willd.) Cufod.	Salicaceae	0.012	0.051	0.320	0.383
Astropanax abyssinicum (Hochst. ex A. Rich.) Seem.	Araliaceae	0.548	0.289	0.994	1.831
Scolopia theifolia Gilg.	Flacourtiaceae	0.254	0.068	0.852	1.174
Senna didymobotrya (Fresen.) H.S.Irwin & Barneby.	Fabaceae	0.055	0.051	0.479	0.585
Senna singueana (Del.) Lock.	Fabaceae	0.482	0.017	0.426	0.925
Sesbania sesban (L.)'Merr.	Fabaceae	0.055	0.051	0.426	0.532
Sida tenuicarpa Vollesen.	Malvaceae	0.021	0.051	0.852	0.924
Solanecio gigas Vatke.	Asteraceae	0.041	0.187	0.852	1.080
Stereospermum kunthianum L.	Bignoniaceae	0.090	0.017	1.118	1.226

Syzygium guineense (Wild.) DC.	Myrtaceae	0.708	0.629	0.601	1.939
Tamarindus indica L.	Fabaceae	0.025	0.085	0.426	0.537
Vepris nobilis Mziray.	Rutaceae	0.266	0.510	1.022	1.798
Urera hypselodendron (A. Rich.) Wedd.	Urticaceae	0.060	0.153	0.852	1.066
Vernonia auriculifera Hien.	Asteraceae	0.043	2.449	1.278	3.770
Baccharoides schimperi (DC.) Isawumi, El-Ghazaly & B. Nord.	Asteraceae	0.155	2.602	1.186	3.943
Ziziphus mauritiana Lam.	Rhamnaceae	0.203	0.459	1.704	2.366

Appendix 5. List of 26 church forests in West Gojjam zone with their diversity metrics

		Diversity metrics							
No.	Church Forest Name	Raw Shannon diversity	Adjusted shannon diversity	evenness	Total frequency	Basal area	Density per hectare	Species richness	No. plots
1	Wegelsa arbayitu ensesa	2.68	2.68	0.85	8.16	11.9	925	23	6
2	Atangusa Mariam	1.73	1.73	0.6	6.6	1.058	1083.3	17	6
3	Gonbat saint Mikael	2.64	2.26	0.85	14.28	1.67	1078.57	21	7
4	Merawi Kidane Mihret	3.11	2.67	0.8	14.42	3.9	807.14	44	7
5	Tiemt bata lemariam	3.47	1.30	0.91	16.93	0.8	1001.56	45	16
6	Gedema Mariam	3.37	3.37	0.91	15.33	0.8	687.5	39	6
7	Care Qusquam	2.76	2.76	0.79	11.16	0.92	779.16	32	6
8	Abchikili Mariam	3.28	3.28	0.93	18.5	0.53	995.83	32	6
9	Care Aregawi	3.3	3.30	0.96	14.33	0.71	583.33	32	6
10	Weneba Mikael	2.44	1.63	0.76	10	0.33	1065	26	9
11	Ambatna Mariam	2.3	1.38	0.95	8	0.26	595.8	12	10

12	Korch silassie	2.5	2.50	0.78	11.66	0.23	1600	27	6
13	Aynaba qusquam	2.54	2.54	0.82	8	0.38	687.5	22	6
14	Gebatsiyon Mariam	2.39	2.39	0.78	8.166	0.72	670.83	21	6
15	Debre mihret Mesk kidanemihret	0.99	0.99	0.5	3.5	0.24	575	7	6
16	Gundil mikael	2.4	2.40	0.9	6.83	0.13	933.33	13	6
17	Sangeb Mikael	2.1	2.10	0.79	7.5	0.22	679.16	16	6
18	Seqela Mariam	2.12	2.12	0.76	6.67	0.49	725	22	6
19	Seregela Mariam	2.58	2.58	0.87	10.66	0.69	1212.5	19	6
20	Godber medhaniyalem	2.38	2.38	0.87	8.16	0.4	783.3	21	6
21	Lejet Kidanemihret	2.78	2.78	0.87	11.33	0.51	745.83	25	6
22	Angot Mikael	2.6	2.60	0.88	10.33	0.37	841.66	21	6
23	Guay Mikael	2.99	2.99	0.91	11.5	0.37	733.3	26	6
24	Qerer Qusquam	1.95	1.95	0.7	7.16	0.4	641.66	15	6
25	Boldin Arbayitu ensesa	2.86	2.86	0.91	11.16	0.69	775	25	6
26	Arbagel Mariam	2.29	2.29	0.82	7.33	0.55	745.83	16	6

Appendix 6. List of church forests with different carbon pools

No.	Church Forest Name	Different carbon pools in ton ha^{-1}							
		AGB	**AGC**	**BGB**	**BGC**	%C	SOC	**TC**	**Co2 equivalence**
1	Wegelsa arbayitu ensesa	48.16	24.08	12.04	6.02	65.15	6.47	36.57	134.22
2	Atangusa Mariam	19.85	9.92	4.96	2.48	47.15	5.10	17.50	64.24
3	Gonbat saint Mikael	26.25	13.12	6.56	3.28	62.36	7.36	23.76	87.21
4	Merawi Kidane Mihret	8.95	4.48	2.24	1.12	63.88	6.43	12.03	44.15
5	Tiemt bata lemariam	8.61	4.30	2.15	1.08	89.81	9.72	15.10	55.43
6	Gedema Mariam	19.96	9.98	4.99	2.49	48.67	5.59	18.06	66.28
7	Care Qusquam	34.91	17.46	8.73	4.36	96.33	9.72	31.54	115.77
8	Abchikili Mariam	28.14	14.07	7.04	3.52	103.94	10.53	28.12	103.21
9	Care Aregawi	32.14	16.07	8.03	4.02	89.99	9.53	29.61	108.69
10	Weneba Mikael	25.70	12.85	6.43	3.21	65.02	7.93	23.99	88.05
11	Ambatna Mariam	26.46	13.23	6.62	3.31	35.24	3.46	20.00	73.39
12	Korch silassie	8.07	4.03	2.02	1.01	29.56	3.82	8.86	32.51
13	Aynaba qusquam	31.95	15.97	7.99	3.99	80.11	8.33	28.29	103.84
14	Gebatsiyon Mariam	47.23	23.62	11.81	5.90	31.43	3.70	33.22	121.92
15	Debre mihret Mesk kidanemihret	99.00	49.50	24.75	12.38	38.53	5.20	67.08	246.17
16	Gundil mikael	30.22	15.11	7.55	3.78	55.77	6.47	25.36	93.07
17	Sangeb Mikael	33.00	16.50	8.25	4.12	70.98	8.68	29.31	107.55
18	Seqela Mariam	37.13	18.57	9.28	4.64	60.84	7.40	30.61	112.34
19	Seregela Mariam	29.54	14.77	7.39	3.69	53.24	5.87	24.33	89.31

20	Godber medhaniyalem	26.40	13.20	6.60	3.30	43.86	5.39	21.89	80.33
21	Lejet Kidanemihret	39.62	19.81	9.90	4.95	56.28	5.96	30.72	112.73
22	Angot Mikael	46.37	23.18	11.59	5.80	75.80	8.73	37.71	138.40
23	Guay Mikael	42.88	21.44	10.72	5.36	23.07	2.65	29.45	108.07
24	Qerer Qusquam	45.47	22.73	11.37	5.68	49.43	5.21	33.63	123.42
25	Boldin Arbayitu ensesa	49.23	24.61	12.31	6.15	44.11	4.67	35.43	130.04
26	Arbagel Mariam	57.42	28.71	14.36	7.18	32.96	3.66	39.56	145.17

APPENDIX 7. List of medicinal plants used to treat human diseases in the West Gojjam zone (compiled data from Dembecha, South achefer, and Sekela districts) note: G.F.. = growth forms, C.No. = collection number

. *Scientific name*	Local name	G.F.	Plant part	Diseases treated	Mode of preparation of remedies	Route	C.No.
Vachellia abyssinica (Hochst. ex Benth.) Kyal. & Boatwr	Girar	Tree	Seed	Syphilis	The seed powder will be mixed with water and then drunk.	Oral	AA45
Achyranthes aspera L.	Telenj	Herb	leaves	Nose bleeding	Fresh leaves are squeezed and added to nostrils.	Nasal	
			Leaves	Nose bleeding	Fresh leaves will be crushed and sniffed.		AA99
Vachellia nilotica (L.) P.J.H. Hurter & Mabb	Cheba	Tree	Leaves and roots	Cough	The extracts of leaf and root will be given to the patient until recovery.	Oral	AA22
			Stem	Tonsillitis	The stem will be chewed and washed in the mouth with its juice.	Oral	
Vachellia etbaica (Schweinf.) Kyal.&Boatwr	Dere/qer eta	Tree	Seed and leaves	Dandruff	The leaves and seed are crushed and mixed with butter then the infected part of the body is smeared	Dermal	AA15

Acokanthera schimperi (A. DC.) Schweinf.	Merenz	Tree	Leaves	Liver Problem	Powdered leaves will be mixed with honey and then swallowed it.	Oral	AA39
			Leaves	Tonsillitis	Leaves will be crushed and boiled and then drunk the filtrated.		
Acmella caulirhiza DDel.	Yemdir berbere	Herb	Flowers	Toothache	Put and hold on your teeth.	Oral	AA52
Allium sativum L.	Nech shinkurt	Herb	Seed	Fever	The seed will be crushed and mixed with one glass of boiled water then drunk the filtrated by adding honey.	Oral	AA77
			Seed	Common cold	Seed of *allium sativum and* juice of *Citrus aurantiifolia* will be boiled and drunk with honey	Oral	
			Seed	Evile eye	The seed will be pounded and then sniffed every morning.	Nasal	
			Seed	Warts	The fresh pounded seed will be applied to affected body.	Dermal	
			Seed	Diarrhea	The seed is chewed and swallowed	Oral	
Allium cepa L.	Key shinkurt	Herb	Seed	Cancer	The extracted seed juice of onion will be mixed with honey and drunk for seven days in the morning.	Oral	AA8
Aloe adigratana Reynolds.	Eret	Herb	Leaves	Fire burn	Take leaves and break them and apply the jelly on affected part.	Dermal	AA6
				Skin rash	Apply jelly to the affected part of the body for three consecutive days.		
				Warts	The leaves jelly part will be applied to the affected body.		
Artemisia abyssinica Sch.Bip.exA.R.	Chikugn	Herb	Leaves	Cough	The fresh leaves will be crushed and boiled in water and then drunk by adding honey.	Oral	AA101
Asparagus africanus Lama.	Yeset Kest	Herb	Root	Warts	The root powder will be applied to the affected part	Dermal	AA92
Bidens pilosa L.	chigogot	Herb	leaves	Eye problem	The squeezed leaf juice is added to the diseased eye at night	Eye	AA252
			root	Diarrhea	The root is pounded and mixed with water then drink	Oral	

Bidens macroptera (Sch.-Bip. ex Chiov.)	Adey abeba	Herb	Flowers	Skin burn	The powder of the flower will be mixed with butter and then applied to the affected part.	Dermal	AA211
Brassica nigra (L.) Koch.	Sinafch	Herb	Seed	Wound	The seed is pounded and mixed with Vaseline and creamed onto the wound.	Dermal	AA66
			Seed	Asthma	Massage the chest with its oil of *Brassica nigra*.		
Brucea antidysenterica J. F. Mill.	Abalo	Shrub	Leaves and fruits	Wound	Powdered leaves of *Brucea antidysenterica* and fruits will be mixed with butter and then applied to the wound.	Dermal	AA25
			Bark	Diarrhea	The bark powder will be mixed with milk and then drunk.	Oral	
Buddleja polystachya Fresen.	Anfar	Shrub	Root and bark	Snake preventation	The root and bark will be tied on the neck.	Neck	AA33
			leaves	Skin cancer	Leaves are dried and mixed with butter then smeared on the affected part.	Dermal	
Calpurnia aurea subsp. *aurea* (Ait.) Benth.	Digita	Shrub	leaves	Snake bite	The leaf of Calpurnia aurea will be crushed and mixed with water and then drunk.	Oral	AA88
			leaves	Jaundice	Take the boiled steam of *Calpurnia aurea.*	Nasal	
			Leaf and root	Diarrhea	The leaf and root will be crushed then enter the boiled water then drunk the juice part at the morning before food	Oral	
Carica papaya L.	Papaya	Tree	Fruit	Heartburn	Eat fruit in the morning for seven days	Oral	AA109
			Fruit	Kidney problem	The juice of *Carica papaya* will be drunk in the morning on an empty stomach.		
			Bark	Skin rash	The affected part will be creamed by the outer skin of *Carica papaya*.	Dermal	
Carissa spinarum L.	Agam	Shrub	leaves and bark	Headache	The leaves and bark is boiled and then the decoction will be drunk by adding honey.	Oral	AA222
Catha edulis (Vahl) Forssk. ex Endl.	Chat	Shrub	leaves	Cough	The leaves will be cocked like tea and drunk by adding honey.	Oral	AA157
			Root	Evile eye	The root will be tied on the neck.	Neck	

Centella asiatica (L.) Urban.	Etse leul/yayt joro	Herb	Leaves and roots	Wound	The leave and root powder are applied to the wound.	Dermal	AA111
Cicer arietinum L.	Shimbra	Herb	Seed	Snake bite	The seed powder of Cicer arietinum is mixed with Sesamum angustifolium, baked, and then eaten.	Oral	
Cissampelos mucronata A. Rich.	Engocht hareg/et se eyesus	Clim b er	Roots	Rabies	Roots of *Cissampelos mucronata*, *Solanum anguivi*, *Cucumis ficifolius* and *Phytolacca dodecandara* will be powdered, mixed with milk and drunk.	Oral	AA153
Citrus limon (L.) Burm.f.	Lomi	Shrub	Fruit	Common cold	Three spoons of *Citrus limon* will be mixed with honey and drunk.	Oral	AA189
Citrus sinensis (L.) Osb.	Birtukan	Tree	Fruit	Asthma	The juice *of Citrus sinensis* will be boiled and drunk.	Oral	AA177
Citrus medica L.	Tringo	Tree	Fruit	Bronchitis	Fruit of *Citrus medica* will be mixed with black goat bile and eat.	Oral	AA165
Clausena anisata (Wild.).Benth.	Limch	Shru b	Fruit	Ascaris	The fresh fruit will be prepared, mixed with honey and ate.	Oral	AA131
			Bark	Jaundice	Fresh stem is peeled and tied on the head.	Dermal	
Clematis hirsuta Perr. & Guill.	Azo hareg	Clim b er	Stem	Swelling of leg	The fresh stem will be fired and gently applied on swelling part.	Dermal	AA126
Rotheca myricoides (Hochst.) Steane & Mabb	Misirich	Herb	leaves	toothache	The leaves will be hold on diseased tooth.	Oral	AA243
Clutia lanceolata Jaub. & Spachs.	feyefeji	Herb	Whole parts	Cancer	Taken some parts from all parts of plant and powdered it and mixed with butter then applied on affected part.	Dermal	AA219
Coffea arabica L.	Buna	Shru b	Seed	Wound	The roasted coffee powder will be mixed with butter and applied on wound.	Dermal	AA55
				Diarrhea	The roasted seed powder will be mixed with honey an ate at empty stomach	Oral	

Cordia Africana Lam.	Wanza	Tree	Fruit	Ascaris	The fruit *Cordia africana* is ate at the morning at empty stomach	Oral	AA34
			Bark	Diarrhea	The crushed bark will be mixed with water then drunk at morning		
Crinum abyssinicum Hochst. ex A. Rich.	Yejib Shinkurt	Herb	Root	Arthritis	Powder of *Crinum abyssinicum* and *Allium sativum* will be mixed with Vaseline and creamed on affected area.	Dermal	AA41
Croton macrostachyus Del.	Bisana	Tree	Latex	Ringworms	The latex for is collected and gently applied on the ringworm until recover.	Dermal	AA137
			Bud	Skin rash	The bud is cut and applied the juicy part on the affected part.		
Cucumis ficifolius A.Rich.	Yemidr enbuay	Herb	leaves	Dry cough	Leaves will be crushed, and the decoction is mixed with honey and drunk at morning for seven days.	Oral	AA159
			Root	Diarrhea	Root is dried and pounded then mixed with tella and drunk.		
			Root and leaves	Stomachache	Root and leaf are boiled and drunk the decoction.		
			Stem	Wound	Stem will be fired and put on wound for some seconds.	Dermal	
Cucurbita pepo L.	Duba	Herb	Seed	Tapeworms	The seed will be cocked and ate at morning in empty stomach.	Oral	AA144
Cyathula uncinulata (Schrad.) Schinz.	Yemogn fiqr/beg dzemed	Herb	Leaf	Ear problem	The leaves are crushed and applied juice on will be inserted in ear.	Ear	AA280
Cymbopogon martini (Roxb.) Wats.	Tej sar	Herb	Leaf and root	Stomachache	Root and leaves will be pounded and soaked in water then drunk the decoction.	Oral	AA291
Datura stramonium L.	Atse faris/ astenagir	Herb	Seed	Toothache	Seed is boiled and chewed and hold on diseased	Oral	AA7
			Leaves	Dandruff	Fresh leaves will be crushed and squeezed on head until overcome the result.	Dermal	

Dodonaea viscosa subsp. *angustifolia* (L.f.) J.G.West.	Kitkita	shrub	Leaves	Eczema	Leaves will be rubbed gently on the affected part at morning time.	Dermal	AA17
Dombeya torrida (J. F. Gmel.) P. Bamp.	Wulkifa	shrub	Root	Toothache	The teeth will be brushed by root.	Oral	AA29
Dovyalis abyssinica (A. Rich.) Warb.	Koshm	Shrub	Whole parts	Swelling	Collect parts from the root, leaf, and seed, dry them, pound into powder, mix with butter, and apply to the affected area	Dermal	AA108
Echinops kebericho Mesfin.	Keberch o	Herb	Root and fruit	Sudden illness	Root and fruit will be dried and put on fire then fumigated.	Nasal	AA10
Embelia schimperi Vatke.	Enkoko	shrub	Root	Tapeworm	The root is dried and pounded then mix with water then drunk.	Oral	AA9
			Fruit	Asthma	The fruit will be dried and sniffed.	Nasal	
Erythrina abyssinica Lam. ex DC.	Korch	Tree	Leaves	Eye problem	Small leaves will be crushed and add a drop of juice in the eye.	Eye	AA265
Eucalyptus globulus Labill.	Nech bahirzaf	Tree	Leaves	Common cold	Leaves will be soaked in hot water and sniffed.	Nasal	AA277
Euclea racemosa Murray.	Dedho	Shrub	Leaves	toothache	A fresh leaf is chew.	Oral	AA128
Euphorbia abyssinic a J. F. Gmel.	Qulqual	Tree	Latex	Ascaris	At least 5-7 drops of latex are added on fresh injera, and allow eating for child at morning time before food.	Oral	AA113
			Latex	Wound	Add a drop of latex on wound gently.	Dermal	
Euphorbia tirucalli L.	Qinchib	shrub	Latex and root	Rabies	Root is dried and pounded then mix with 3 drops of latex and drunk at morning before food for seven days.	Oral	AA99
			Root	Jaundice	Root is pounded, mixed with hot coffee and drunk.		
Ficus vasta Forssk.	Warka	Tree	leaves	Tapeworm	Leaves will be crushed and soaked in water then drunk with mixing honey.	Oral	AA88
Foeniculum vulgare Mill.	Insilal	Herb	Root	Stomachach	Root will be chewed for some minutes.	Oral	AA27

Grewia ferruginea Hochst.ex A.Rich.	Lenquata	Shrub	Bark	Tapeworm	Bark is dried and pounded then drunk by mixing water.	Oral	AA37
Guizotia abyssinica (L.f.) Cass.	Nug	Herb	Root	Dysuria	Root will be chewed at nighttime before going to bed.	Oral	AA11
Hagenia abyssinica (Bruce) J.F.Gmelin.	Koso	Tree	Seed	tapeworm	Seed is properly pound and drink with mixing milk.	Oral	AA64
Hordeum vulgare L.	Gebs	Herb	Seed	Tonsillitis	Seven seeds will be pounded and mixed with the *Rhamnus prinoides* leave and soaked in water then drunk the filtrated.	Oral	AA104
Impatiens ethiopica Grey-Wilson.	Ensosla/ girshit	Herb	Root	Arthritis	Roots will be crushed and mixed with water then filtered drunk.	Oral	AA238
Juniperus procera Hochst. ex. Endl.	Tsid	Tree	Seed	Ear problem	Seed is dried and pounded and mixed with water then add small drops into ear.	Ear	AA19
Justicia schimperiana (Hochst.ex Nees). T.Anders.	Sensel/s imiza	Shrub	leaves	Rabies	The leaves of *Justicia schimperiana*, root of *Inula confertiflora* and root of *Cucumis ficifolius* crushed together and allowed to drunk at the morning before food for 3 days.	Oral	AA36
Kalanchoe petitiana A. Rich	Endahul a	Herb	leaves	Swelling	The fresh leave is cut and fired the applied on swelling part.	Dermal	AA97
Lagenaria siceraria (Molina) Standley.	Qil	Herb	leaves	Swelling	Leaves will be fired in hot fire then applied on swelling.	Dermal	AA71
Lepidium sativum L.	Feto	Herb	Seed and leaves	Stomachache	Seed and leaves are pounded the mixed with water then drunk	Oral	AA84
Lobelia rhynchopetalum H emsl.	Jibra	herb	Bark and root	Spiritual illness	The root and bark are dried and put on fire then sniffed during sickness.	Nasal	AA117
Lupins albus L.	Gibto	herb	Seed	Hypertension	Eat raw seed at morning before food.	Oral	AA28
Mangifera indica L.	Mango	tree	leaves	Diabetes	Seven fresh leaves are cut and soaked in boiled water then drunk at the morning. This decreased insulin.	Oral	AA20
Gymnosporia arbutifolia (A. Rich.) Wilczek.	Atat	shrub	Leaves	Tonsillitis	Fresh leaves are crushed and squeezed then drunk.	Oral	AA60

Melia azedarach L.	Mimi	Tree	Leaves	Wound	Leaves are squeezed and creamed on affected part.	Dermal	AA35
			Leaves	Toothache	Leaves will be hold on diseased teeth.	Oral	
Musa acuminata Colla.	Muz	Herb	Fruit	Cough	Eat at morning before food for seven days.	Oral	AA61
Nigella sativa L.	Tikur azmud	Herb	Seed	Vomiting	The seed is pounded and mixed with *Zingiber officinalethen* boiled and drunk.	Oral	AA75
			Seed	Dandruff	The seed is pounded and mixed with *Citrus aurantium* and creamed on affected part	Dermal	
Ocimum lamiifolium Hochst. ex. Benth.	Damakesse	Herb	Leaves	Fever	The leaves will be crushed and added on coffee then drunk.	Oral	AA85
			Leaves	Nose bleeding	The leaves will be squeezed and add a drop into nose.	Nasal	
Olea europaea subsp. cuspidata (Wall. ex G. Don) Cif.	Weyra	Tree	Leaves	Ear problem	The leaves will be squeezed and add a drop until recover.	Ear	AA264
			Stem	Toothache	Always brushed the teeth by stem of *Olea europaea subsp. cuspidata*.	Oral	
Otostegia integrifolia Benth.	Tinjut	Shrub	Root	Lung diseases	Root will be dried and smoked then inhaled through nostril.	Nasal	AA197
Persea americana Mill.	avocado	Tree	Fruit	Anemia	The fruit is eaten at the morning.	Oral	AA207
Phytolacca dodecandra L'Hert.	Mekan endod	Shrub	Root	Jaundice	Roots of *Phytolacca dodecandara*, *Solanum dasyphyllum*, *Verbascum sinaiticum* and *Solanum marginatum* are crushed, fused with half of coca - cola and drunk.	Oral	AA31
			Root	Rabies	Roots are pounded and mixed with water then drunk.	Oral	
Plantago lanceolata L.	Gorteb /yebglat	Herb	leaves	Nose bleeding	The leaves are squeezed and add through nostrils	Nasal	AA81
			leaves	Wound	The leaves are squeezed and add a drop to dry wound.	Dermal	

Podocarpus falcatus (Thunb.) Mirb.	Zigba	Tree	Resin	Eye disease	The resin will be applied on diseased eye.	Eye	AA91
Psidium guajava L.	Zeytuna	Tree	leaves	Toothache	The leaves are held on diseased teeth.	Oral	AA103
Rhamnus prinoides L'Herit	Gesho	Shrub	Fruit and leaves	Tonsillitis	Fruit and leaves are squeezed and mixed with *Kalanchoe Shimperiana* then the filtrate will be drunk.	Oral	AA127
Rosa abyssincia Lindley.	Kega	Shrub	Fruit	Ascaris	The fruit is eaten	Oral	AA78
Salvia rosmarinus Spenn.	Rosmeri	Herb	Leaves	Arthritis	The leaves will be cocked with meat and eaten.	Oral	AA40
Rubus apetalus Poir.	Enjori	Shrub	Fruit	Stomachache	The ripped fruit is eaten.	Oral	AA47
Rumex nepalensis Spreng.	Tult	Herb	Root	Sudden stomachache	The root will be chewed.	Oral	AA79
			Leaves and root	Tonsillitis	Leaves and root will be crushed and mixed with water then drunk.		
			Root	Toothache	Root is crushed and held on diseased tooth.		
			Root	Diarrhea	The crushed root will be mixed with water then drunk the filtrated juice part		
Rumex nervosus Vahl.	Embuacho	Shrub	leaves	Dandruff	Leaves are crushed and rubbed on affected part.	Dermal	AA243
			Leaves	Evil eye	Leaves are crushed and mixed with *Ruta chalepensis* then drunk with coffee.	Oral	
Ruta chalepensis L.	Tenadam	Herb	Leaf and seed	Headache	Leaf and seed are crushed and mixed with coffee then drunk.	Oral	AA86
			Leaves	Common cold	Leaves are inserted in cup of tea and drunk the decoction.		
			Seed	Diarrhea	Seed is pounded and mixed with yogurt and drunk.		
Salvia nilotica Jacq.	Hulegeb	Herb	Leaves	Nose bleeding	Leaves will be crushed and squeezed then insert into nostrils.	Nasal	AA72
			Leaves	Fever	Leaves will be crushed and mixed with *Ocimum lamiifolium* then mixed with coffee and drunk.	Oral	
Schinus molle L.	Quando berbere	Herb	Fruit	Jaundice	Fruit will be dried and mixed with leaf of *Rhus retinorrhoea then boiled and drunk one glass at morning before food.*	Oral	AA67

Sida schimperiana Hochst.ex A. Rich.	Chifrg /gorjejit	Herb	Leaf and root	Wound	Root and leaf will be crushed and mixed with vasiline the creamed on affected part.	Dermal	AA95
Solanum anguivi Lam.	Zerch enbuay	Herb	Leaf and root	Wound	Fresh leaf and root will be crushed and applied on wound.	Dermal	AA181
Solanum marginatum L.f.	Embuay	Shrub	Root	Toothache	Rout is crushed and mixed with water then wash the teeth.	Oral	AA167
Lycopersicon esculentum Mill.	Timatim	Herb	Fruit	Heart	The fruit will be eaten with mixed *Capsicum*	Oral	AA2
			leaves and root	Jaundice	Leaves and root will be mixed with leaf of *Calpurnia aurea* then mixed with water and drunk at morning at empty stomach.		
Syzygium guineense (Wild.) DC.	Doqma	Tree	Bark	Diarrhea	Bark is crushed and mixed with water then drunk the filtrate.	Oral	AA5
Thalictrum rhynchocarpum Dill.A. & Rich	Sirebizu	Herb	Root	Stomachache	Root will be chewed.	Oral	AA105
			Leaves and root	Jaudice	Leaves and root will be mixed with leaf of *Calpurnia aurea* then mixed with water and drunk at morning at empty stomach.	Oral	
Thymus schimperi Ron. (Labiatae).	Tosign	Herb	leaves and root	Hypertension	Leaf and root will be dried and make as tea then drunk at morning before food.	Oral	AA239
			leaves and root	gonorrhea	Dried leaves and root are pounded and drunk with tea.		
Trigonella foenum-graecum L.	Abish	Herb	Seed	Diabetes	Pounded seed is mixed with yogurt and butter then ate for seven days at morning	Oral	AA74
			Seed	Gastritis	Pounded seed is eaten in empty stomach.		
			Seed	Constipation	Seed will be pounded and mixed with water the drunk.		
			Seed	Toothache	Roasted seed is chewed		

Verbena officinalis L.	Atuch	Herb	Whole parts	Diarrhea	whole parts are pounded and mixed with drunk then drunk	Oral	AA58
			Root	Stomachache	Root is chewed during illness.		
			Root and leave	Tonsillitis	Root and leaves are crushed and mixed with water then drunk the filtrated.		
			Root	Diarrhea	The root crushed and mixed with water then drunk the filtrated juice		
Vernonia amygdalina Del.	Girawa	Shrub	Root and leaves	Malaria	Root and leaves are crushed and mixed with water then drunk the filtrated.	Oral	AA4
Withania somnifera (L.) Dunal.	Gizawa	Shrub	Root and leave	Evile eye	Root and leaves are crushed and mixed with coffee then drunk.	Oral	AA262
Zingiber officinale Roscoe.	Zingible	Herb	Wholeparts	Cough	Whole parts are inserted in tea and drunk.	Oral	AA241
			Whole parts	Dandruff	Whole parts are rubbed on affected part.	Dermal	
			Whole Parts	Toothache	Whole parts are crushed and hold on diseased teeth.	Oral	

Appendix 8. List of medicinal plants used to treat livestock diseases in West Gojjam zone (compiled from three districts: Dembecha, South Achefer, and Sekela). G.F. = Growth forms, C.No. = Collection number

Scientific name	Local name	Family	G.f.	Plant part	Disease treated	Mode of preparation of remedies	Route	C.No.
Achyranthes aspera L.	Telenji	Amaranthaceae	Herb	Leaves	Leech	The leaves crushed and mixed with water, added drop wise through nose	Nasal	AA45
Acokanthera schimperi (A. DC.) Schweinf.	Merenz	Apocynaceae	Shrub	Root	Rabies	The root is pounded and the powder mixed with water and then drunk in the morning for seven days for dogs	Oral	AA99
Ajuga integrifolia Buch.-Ham. Ex D. Don.	Armagusa/ etse libawit	Lamiaceae	Herb	Leaves	Black leg	Leaves are crushed, pounded and mixed with water then given to cattle	Oral	AA22
Allium sativum L.	Nechshink urt	Alliaceae	Herb	Seed	Leeches	Seed is crushed and mixed with water and poured into the nose in both openings	Nasal	AA15
Aloe adigratana Reynolds.	Eret	Aloaceae	Herb	Leaves	Cough	The fleshy leaves are soaked in water for one day and drank in the morning	Oral	AA39
Artemisia abyssinica Sch. Bip. ex A. Rich.	Chikugn	Asteraceae	Herb	Root and leaves	Diarrhea	The root and leaves are crushed and mixed with water and then given to goat and sheep until recovery	Oral	AA52
Buddleja polystachya Fresen.	Anfar	Loganiaceae	Shrub	Root and leaves	hemorrho ids	The root and leaves are crushed, mixed with the pounded seed of *Lepidium sativum* and then applied to the affected part with the mixing of aloe sap	Dermal	AA77
Calpurnia aurea subsp. aurea (Ait.) Benth.	Digita	Fabaceae	Shrub	Fruit	Stomach ache	The fruit is crushed, mixed with water and then drank	Oral	AA8
				Leaves	Ecto-parasite	The leaves are crushed and applied on the affected part	Dermal	

Cicer arietinum L.	Shimbira	Fabaceae	Herb	Seed	Leech	The seed is properly pounded and the powder mixed with water then given to cattle	Oral	AA101
Citrus aurantiifolia (Christm.) Swingle.	Lomi	Rutaceae	Shrub	Fruit	Leech	The juice of *Citrus aurantiifolia* is mixed with salt and then added through nostrils	Nasal	AA92
Clausena anisata (Willd.) Benth.	Limich	Rutaceae	Shrub	Root and leaves	Swelling on the body	The root and leaves are crushed and mixed with water, and then the mixture is given to domestic animals to drink	Oral	AA252
Rotheca myricoides (Hochst.) Steane and Mabb.	Misirch	Lamiaceae	Shrub	Leaves	Anthrax	The leaves are crushed and mixed with water and then given to cattle	Oral	AA211
Clutia abyssinica Jaub. & Spach.	Fiyelefeji	Euphorbiaceae	Shrub	Root	Anthrax	The roots of *Thalictrum rhynchocarpum, Dodonaea angustifolia, and Tragia cinerea, Rhus retinorrhoe* are pounded and mixed with ale (tela= local beer) and then given to cattle	Oral	AA66
Combretum collinum Fresen.	Yeqola abalo	Combretaceae	Shrub	Leaves	Diarrhea	The leaves are pounded, mixed with coffee and then given to the cattle	Oral	AA25
				Leaves	Eye disease	The leaves are crushed and a drop of juice applied on diseased eye	Eye	
Croton macrostachyus Del	Misana/bisana	Euphorbiaceae	Tree	Leaves	Bloat	The fresh leaves are pounded and mixed with water and then drank	Oral	AA222
Cucumis pustulatus Naud. ex Hook.f.	Yemidir embuay	Cucurbitaceae	Herb	Root	Diarrhea	The root is crushed and pounded, then mixed with milk and drank	Oral	AA111
				Fruit	Sheep coughing	The fruit is pounded, mixed with hot water and a pinch of salt, then drunk.	Oral	
				Root	Blackleg	The root is pounded and mixed with water then given to cattle	Oral	
Datura stramonium L.	Atsefaris/astenagir	Solanaceae	Herb	Leaves	Wound	The leaves are crushed and applied on affected part	Dermal	AA165

Echinops kebericho Mesfin.	Kebercho	Asteraceae	Shrub	Whole p art	Sudden illness	The whole plant is placed on the fire, then smoke is directed onto the cattle	Nasal	AA34
Dodonaea angustifolia L. f.	Kitkita	Sapindaceae	Shrub	Stem	Broken part	The stem is tied on broken part	Tie	AA41
Erythrina brucei Schweinf.	Korch	Fabaceae	Tree	Bark	Wound	The powdered bark is mixed with Vaseline and applied to the affected area.	Dermal	AA137
				Leaves	Eye diseases	The crushed leaves are dissolved in a solvent, and drops are applied to the diseased eye.	Eye	
Eucalyptus globulus Labill.	Nech bahirzaf	Myrtaceae	Tree	Bark	Mich	The bark is then put on fire and smoked on the cattle	Nasal	AA280
Euphorbia abyssinica Gmel.	Kulkual	Euphorbiaceae	Tree	Milk	Rabies	*Euphorbia abyssinica milk* is given to a mad dog in the morning before food	Oral	AA291
Grewia ferruginea Hochst.ex A.Rich.	Alenquata	Tiliaceae	Shrub	Latex	Diarrhea	Latex is mixed with water and salt, then given to cattle as a drink.	Oral	AA7
Hagenia abyssinica (Bruce ex Steud.) J.F.Gmel.	Kosso	Rosaceae	Tree	Fruit	Stomach ache	The fruit is crushed and mixed with water and then given to the cattle	Oral	AA17
Juniperus procera Hochst. ex Endl.	Yehabesha tsid	Cupressaceae	Tree	Leaves	Leech	The leaves are crushed and mixed with water and then given to cattle through nostril	Nasal	AA29
Justicia schimperiana (Hochst. ex Nees) T. Anders.	Sensel /smiza	Acanthaceae	Shrub	Leaves	Swelling	The leaves are crushed and given to the diseased livestock	Oral	AA108
				Leaves	Coccidio sis	The leaves are crushed and mixed with water and then given to hens by adding injera	Oral	
				Leaf	Rabies	Leaves of *Justicia schimperiana* and *Salix mucronata subsp. subserrata* are crushed, and the juice is given to the dog in the morning before food for three consecutive days.	Oral	

Lagenaria siceraria (Molina) Standley.	Qil	Cucurbitaceae	Herb	Fruit	Anthrax	The fruit is squeezed and mixed with water; then filtrate is administered to the cattle for five consecutive days	Oral	AA265
Lepidium sativum L.	Feto	Brassicaceae	Herb	Seed	Black leg	The seed is pounded, and mixed with water then given to cattle to drink	Oral	AA277
				Seed	Bloating	The crushed seed mixed with water then given to cattle to drunk	Oral	
Maesa lanceolata Forssk.	Qelewa/qilaba	Myrsinaceae	Shrub	Leaves and fruit	Anthrax	The leaves and fruit are crushed, mixed with water and then given to cattle to drunk	Oral	AA113
Nicotiana tabacum L.	Tinbaho	Solanaceae	Herb	Leaves	Leech	The leaves are crushed and mixed with salt and pepper, and then drops are given through nostrils	Nasal	AA10
Ocimum lamiifolium Hochst. Ex Benth.	Damakese	Lamiaceae	Herb	Leaves	Febrile illness	The leaves are crushed and mixed with water and then given to livestock to drink	Oral	AA71
Osyris quadripartita Decn.	Qeret	Santalaceae	Shrub	Leaves	Broken skin	The leaves are tied around the broken part	Tie	AA88
Otostegia integrifolia Bent.	Tinjut	Lamiaceae	Shrub	Leaves	Mich	The leaves are dried, fired, smoked to the cattle	Nasal	AA27
Pergularia daemia (Forssk.) Chiov.	yayit hareg	Asclepiadaceae	Climber	Leaves	Eye disease	The leaves are crushed, and the juice is applied on the diseased eye	Eye	AA56
Phytolacca dodecandra L' Herit.	Mekan endod	Phytolaccaceae	Shrub	Root and leaves	Rabies	The root and leaves are crushed and pounded then given to the dog	Oral	AA64
Plantago lanceolata L.	Gorteb	Plantaginaceae	Herb	Root and leaves	Eye diseases	The root and leaves are crushed and a drop of juice applied on the diseased eye	Eye	AA238
Prunus persica L	Kok	Rosaceae	Tree	Leaves	Sudden illness	The leaves are crushed and soaked with water and then given to cattle	Oral	AA19

Rhamnus prinoides L'Herit.	Gesho	Rhamnaceae	Shrub	leaves	Leech	Fresh leaf, together with *Nicotiana tabacum*, pepper is mixed with water and goat butter, and then given through the nose	Nasal	AA36
Ricinus communis L.	Gulo/chakima	Euphorbiaceae	Shrub	Root	Gastrointestinal disorder	The root is crushed and mixed with water and then given to cattle at the morning	Oral	AA97
Rumex nepalensis spreng.	Tult	Polygonaceae	Herb	Root and leaves	Stomach ache	The root and leaves are crushed and mixed with water and then drunk	Oral	AA84
Rumex nervosus Vahl.	Embuacho	Polygonaceae	Shrub	Leaves	Leech	The crushed leaf is mixed with water then given to cattle	Nasal	AA28
Sida schimperiana Hochst.ex A. Rich.	Chifrg	Malvaceae	Herb	Root	Coccidiosis	The root of *Sida schimperiana* and the leaf of *Catha edulis* are mixed with each other and pounded then mixed with water. The formulation is given with enjera and given to hen	Oral	AA20
Silene macrosolen A.Rich.	Wogert	Caryophyllaceae	Herb	Root and leaves	Sudden illness	The roots and leaves are dried, and the cattle is inhaled as smoke	Nasal	AA60
Solanecio gigas Vatke.	Yeshikokogomen/Boz	Asteraceae	Herb	Leaves	Diarrhea	The leaves are crushed and mixed with water and then given to the cattle	Oral	AA35
				Leaves	Black leg	The leaves are crushed and mixed with water and then given to the cattle	Oral	
Solanum incanum L.	Enbuay	Solanaceae	Shrub	Fruit	Eye diseases	A portion of the fresh fruit is homogenized and applied to the diseased eye of the cattle	Eye	AA75
Solanum anguivi Lam.	Zerch embuay	Solanaceae	Herb	Seed	Tick	The affected part of the body is washed with the juice	Dermal	AA85
Syzygium guineense (Wild.) DC.	Doqma	Myrtaceae	Tree	Bark	Stomach ache	The bark is crushed and mixed with water, and then given to the cattle as a drink	Oral	AA264

Tagetes minuta L.	Gimme/gime	Asteraceae	Herb	Leaves	Black leg	The leaves are crushed and mixed with water and then given to the cattle as a drink	Oral	AA197
Thalictrum rhynchocarpum Dill. & A. Rich.	Sirebizu	Ranunculaceae	Herb	Root and leaves	Anthrax	The root and leaves are crushed and mixed with water, and then given to the cattle as a drink	Oral	AA207
Verbascum sinaiticum Benth.	Yayiya joro/qetetina	Scrophulariaceae	Herb	Leaves	Nose bleeding	The leaves are crushed and the juice is given through nostrils	Nasal	AA61
Vernonia amygdalina Del.	Girawa	Asteraceae	Tree	Leaves	Any wound	The leaves are squeezed and applied to the wound until recovery	Dermal	AA81
Withania somnifera L.	Gizawa	Solanaceae	Shrub	Root and leaves	Spiritual illness	The root and leaves are crushed and mixed with water and then given to the livestock as drinking or smoking, and spraying also recommended	Nasal	AA103
Zingiber officinale Roscoe.	Zingibil	Zingiberaceae	Herb	Stem	Bloating	The stem is crushed and mixed with water and then given to cattle as a drink	Oral	AA127