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Forest and Landscape Restoration Opportunities in the Western Catchment of Lake Ziway, Central Rift Valley, Ethiopia

Technical Report

September 2023

Awdenegest Moges, Getahun Yakob, Rediet Girma, Tirusew Teshale, Wolde Mekuria and Alemseged Tamiru Haile

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Front cover photograph: Wolde Mekuria

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Contents

List of Tables

List of Figures

Abstract

Forest and landscape restoration measures could address landscape degradation, increase ecosystem services, and improve livelihoods. However, mapping potential areas for forest and landscape restoration measures and identifying enabling and constraining factors is crucial for effective implementation. This study was conducted in the western catchment of Lake Ziway, Central Rift Valley, Ethiopia, to identify potential forest and landscape restoration options, map potential areas, assess the benefits and cost of options, and investigate success and failure factors for implementing interventions. The study adopted the Restoration Opportunities Assessment Methodology (ROAM), which enables selecting and mapping forest and landscape restoration options. Data were collected using field surveys, key informant interviews, focus group discussion and literature reviews. We also employed GIS and remote sensing methods to characterize the long-term land use and land-cover dynamics and changes in the status of land degradation. Cost–benefit analysis was conducted to assess the economic viability of identified restoration options. The results suggested that over the last 20 years (2002 to 2022), the western catchment of Lake Ziway experienced severe forest and landscape degradation due to anthropogenic and climatic factors, resulting in multiple environmental and socioeconomic consequences. This study identified seven context-specific forest and landscape restoration measures to address the problem. They vary in cost, trajectory and specific economic and social outcomes. Most options were economically viable with additional environmental and social benefits. For example, the benefit of carbon sequestration for home garden agroforestry was estimated at USD 27,032.5 ha^{-1} over 20 years. It was also found that a considerable portion of the catchment area was potentially suitable for agroforestry practices (40%), particularly for scattered trees on farmlands. However, the potential areas suitable for full afforestation or reforestation and tree buffers are smaller (6%). Integrating multiple forest and landscape restoration measures in the catchment could maximize the environmental and socioeconomic outcomes. Opportunities to effectively implement and scale up the identified forest and landscape restoration options include the availability of adequate active labor, the diverse benefits of measures, and the existence of supporting policies and strategies, multiple potential financing mechanisms and active development of governmental and non-governmental organizations. However, the absence of guidelines for implementing legal issues, weak coordination among responsible institutions, and inadequate finance and incentives have been identified as major constraints to scale up forest and landscape restoration measures. The findings of this study may serve as a guide for the planning, design and implementation of restoration measures in the study catchment and similar future projects in other catchments.

Keywords: carbon sequestration, cost–benefit analyses, ecosystem service, land degradation and restoration, Restoration Opportunities Assessment Methodology, success and failure factors.

1. Introduction

Human activities such as agricultural expansion and land-use and land-cover changes, together with global environmental changes have impacted forest landscapes and the services they provide (Gibbs and Salmon 2015; Brondizio et al. 2019). The negative consequences of forest and landscape degradation are worse in developing countries due to the heavy dependence of communities on forest resources for their livelihoods (Orsi and Geneletti 2010; Sabogal et al. 2015).

Forest and landscape degradation is considered a serious problem in all 12 basins of Ethiopia (Hurni et al. 2010). It has resulted in reduced agricultural productivity (Lemenih et al. 2004; Nyssen et al. 2004), increased siltation of reservoirs (Nigussie et al. 2017) and reduced the quality and quantity of water resources (Wassie 2020) and economic returns (Hurni et al. 2015). Like other basins in the country, forest and landscape degradation is an environmental, hydrological and economic problem in the Central Rift Valley, a subbasin of the Ethiopian Rift Valley Lakes Basin (Ayalew et al. 2022). This can be attributed to both anthropogenic and climatic drivers, including agricultural land expansion and intensification, land use and land conversion, and weather extremes (Elias et al. 2019; Desta and Fetene 2020; Mesfin et al. 2020; Mekuria et al. 2021).

The western catchment of Lake Ziway, the subcatchment of the Central Rift Valley and the study area, has experienced serious forest and landscape degradation (Mekuria et al. 2021) and expansion of intensive irrigated farming close to the freshwater ecosystems. The expansion of agricultural land at the expense of forest and shrublands, especially in the upstream parts of the catchment, has increased the vulnerability of soils to water erosion (Bunta and Abate 2021), decreased ecological functions and productivity (Desta and Fetene 2020) and affected hydrological processes (Ayalew et al. 2022). This has resulted in water stress, particularly in the first irrigation season (October–January) (Teferi et al. 2022).

In response to these problems, the Ethiopian government, in collaboration with donors and local communities, has implemented multiple initiatives (Vinceti et al. 2020). In 2016, the country pledged to restore 15 million hectares of degraded land as part of the African Forest and Landscape Restoration Initiative (AFR100) (Kassa et al. 2022). The AFR100 is a country-led effort to bring 100 million hectares of land in Africa into restoration by 2030. It contributes to the Bonn Challenge, the African Resilient Landscapes Initiative, the African Union Agenda 2063, the Sustainable Development Goals (e.g., SDG15, land for life) and other targets (https://afr100.org/). The country also plans to manage seven million hectares of forests and woodlands as part of its Climate Resilient Green Economy Strategy enacted in 2011. The strategy aims to build a carbon-neutral economy by 2030. It also aims to guide and support initiatives that would enable the country to better adapt to the impacts of climate variability and change (Jones and Carabine 2013). The government-initiated watershed development activities in the 1970s. Community-based watershed development activities were started in 2005 to improve agricultural productivity by restoring degraded landscapes (Desta et al. 2005).

The urgent need for enhanced food and water security and more secure livelihoods among rural and urban communities and the growing demand for forest products and bioenergy all underline the need to massively scale up current efforts toward forest and landscape restoration. Restoring degraded forests and landscapes could be a win for livelihoods, particularly for people living in rural areas, as it would have multiple benefits and outcomes (Cohen-Shacham et al. 2016; Abraham and Nadew 2018; Gromko et al. 2019). In this context, a holistic approach is needed that provides both social and ecological benefits while building social, human, natural, physical and financial capitals. Forest and landscape restoration (FLR) is recommended as one of several approaches supporting multiple benefits under the nature-based solutions movement (Cohen-Shacham et al. 2016). FLR potentially offers multiple benefits including the transformation of large areas of degraded and deforested land into resilient, multifunctional assets that contribute to local and national economies, sequester significant amounts of carbon, strengthen food and clean water supplies and safeguard biodiversity (Chazdon and Brancalion 2019). In Ethiopia, the concept of FLR is understood to include activities that restore ecological and productive functions of degraded forests and agricultural landscapes along the forest-farm continuum to better support human well-being now and in the future (Kassa et al. 2017). The most important state-led FLR initiatives include engaging communities in the management of state-owned natural forests through participatory forest management, assisting natural regeneration in degraded lands by excluding human and animal interference by establishing exclosures and mobilizing communities to engage in soil and water conservation works and tree planting campaigns through programs such as the sustainable land management programs (SLM I and II), the recent Green Legacy Initiative and the Climate Action through Landscape Management. This study was conducted in the western catchment of Lake Ziway, Central Rift Valley, Ethiopia to identify forest and landscape restoration options, map potential areas, assess the costs and benefits of restoration options, investigate success and failure factors for implementing FLR options and identifying stakeholders. The study assumed that identifying potential areas for FLR measures, context-specific interventions, costs and benefits, success and failure factors, and capitalizing on existing experiences would support effective planning, design, implementation, and monitoring and evaluation.

2. Materials and Methods

2.1. Study Area

The study was conducted in the western catchment of Lake Ziway, which covers an area of about 3,000 km^2 in the Central Rift Valley of Ethiopia (Figure 1). More than 75% (2,318 km^2) of the catchment drains directly into the Meki River, which originates from the Gurage highlands and then drains into Lake Ziway (Figure 1). Twenty-nine percent of the catchment lies within the Oromia Region, but about 71% is in the Southern Nations, Nationalities, and Peoples Region (SNNPR). It shares four zones,[1] two from Oromia (East and Southwest Shoa) and two from SNNPR (Gurage and Siltie).

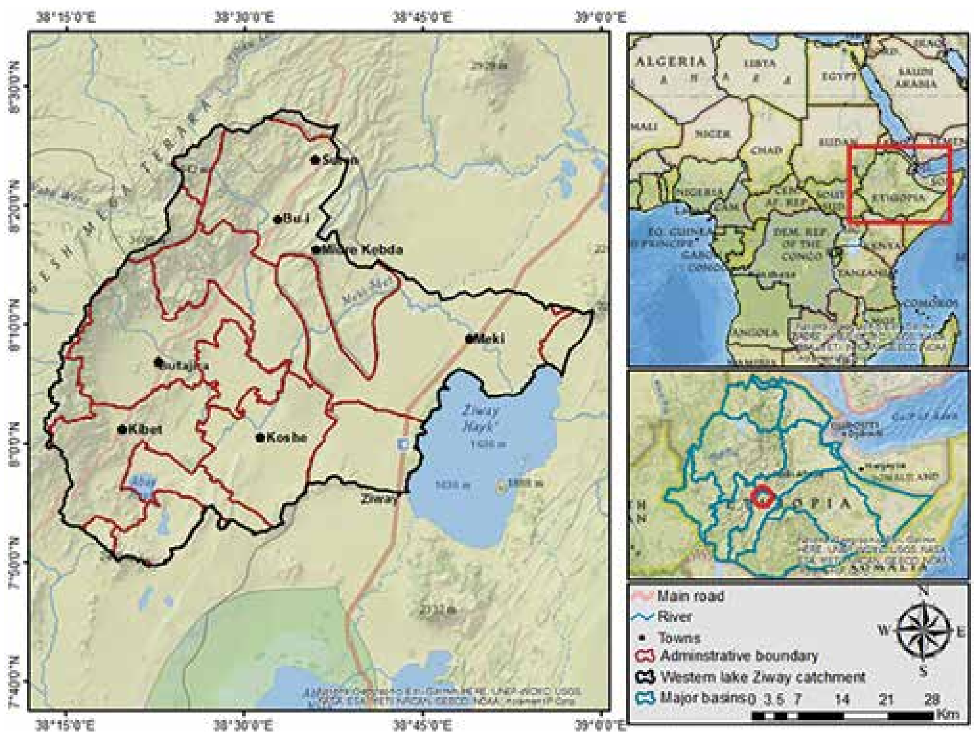


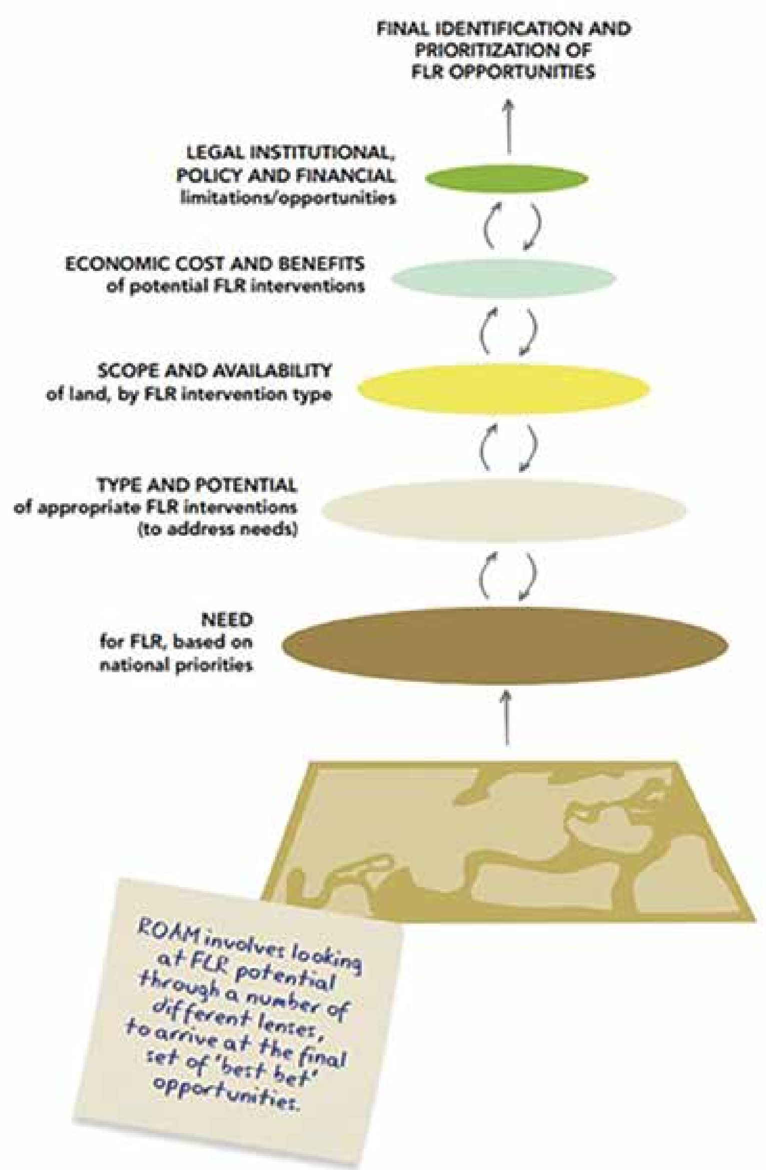
FIGURE 1. Location of the study area.
Source: Author's creation.

[1] Zones are divided into woredas (districts).

2.2. Approaches

The study employed an adapted Restoration Opportunity Assessment Methodology (ROAM) (Figure 2). The original methodology has three phases: preparation and planning, data collection and analyses, and results and recommendations (IUCN and WRI 2014). The adapted ROAM used in this study employed five steps. The first step is assessing the need for FLR based on the national priorities and identifying appropriate interventions to address those needs. This is followed by identifying potential areas for implementing the interventions from Step 1. The final two steps focus on assessing the costs and benefits of each intervention and the enabling environments (Figure 2).

Steps in ROAM	Activities to address the Steps in the ROAM



Activities to address the Steps in the ROAM
Final mapping of FLR option in the catchment; Validation workshop conducted in 2023.
Document consultation, KIIs and FGD 2022–2023.
Analysis of inputs and outputs of each potential restoration option. Evaluation of the economic viability using discounted NPV in 20 years. Carbon sequestration estimate based on field measurement of vegetation variables done in 2023.
Catchment characterization and evaluation of the land-use and land-cover dynamics and land degradation in 2023.
Review and analysis of regional and national documents. The options are evaluated with respect to the catchment profile.
Document consultation, expert knowledge, discussions with the community and stakeholders, stratification of the study area in 2023.

FIGURE 2. ROAM approach and activities conducted at each step.
Source: IUCN and WRI, 2014.

2.3. Data Collection

Qualitative Data Collection Methods

The study employed qualitative data collection methods such as key informant interviews (KII) and focus group discussions to gather information. During the entire study, 26 KII and five FGDs (two men-only, one women-only and two mixed) were conducted. The key informants were selected from government and non-governmental organizations using two criteria: expert knowledge and involvement in landscape restoration activities. The key informants had diverse knowledge and expertise on topics of land use and management, forestry and agroforestry, agricultural extension, soil and water conservation and monitoring and evaluation. The participants of the FGDs (men, women and youth) were selected with support from District Agricultural Offices. Each group had 7–12 participants. The FGDs were held at Farmers Training Centers and agricultural bureaus with support from translators, facilitators and note takers.

The KIIs were conducted to (a) assess local community opinions on forest and landscape degradation and restoration efforts; (b) describe the farming systems, major land uses and drivers of land use and land-cover dynamics; (c) identify and prioritize restoration options and assess social and environmental benefits; (d) gain insights into the input and output options for restoration and financing mechanisms; e) better understand the agroecological suitability, institutional responsibility and involvement and the enabling environment for restoration options; and f) investigate success and failure factors, gaps and weaknesses during the implementation of restoration options. KII interviews took 30 minutes to an hour and a half, depending on the informant.

FGDs were conducted to complement the data gathered through KIIs and gather additional data on (a) the availability of water resources that support the implementation of FLR measures, (b) productivity of lands and land-use and land-cover dynamics, (c) protected and National Forest Priority Areas, (d) criteria for prioritizing restoration options, (e) ongoing restoration efforts, (f) community awareness, participation and empowerment in restoration efforts, and (g) benefits and costs of FLR measures.

Participants were asked to list the social and ecological benefits of the FLR options and then to rank them using plus signs (+++ highest benefit, ++ and + least benefit), against the identified benefits. Each FDG took about two hours. Secondary data such as annual reports from government offices were consulted to collect data (e.g., agriculture and finance and economic offices); (a) household characteristics and demography; (b) livelihood activities; (c) income sources and (d) demand for forest products.

Quantitative Data Collection Methods

Datasets and Biophysical Characterization. Data for multiple biophysical characterizations of the catchment were collected from different sources (Table 1). The spatial distribution of average annual rainfall was established using an inverse distance weight interpolation algorithm in ArcGIS 10.8 (Girma et al. 2022a). Data on land productivity change was acquired using Trends.Earth, quantum GIS (QGIS 3.28) plugin (https://trends.earth/docs/en/).

Topographic features such as elevation, landform and slope were characterized using the freely available high resolution (12.5 m) digital elevation model (DEM) (Nair et al. 2018). Characterization of agroecological zones was based on elevation and mean annual rainfall. Tree cover dynamics between 2000 and 2010 were characterized using Global Forest Watch (https://www.globalforestwatch.org/). The Sentinel-2 multi-spectral at red and near infrared bands was used to derive a normalized difference vegetation index (Muhe and Argaw 2022).

TABLE 1. Description of biophysical datasets.

Dataset	Data source	Resolution	Website	Remark
Point rainfall data	Ethiopian Meteorology Institute			Thirty years (1987–2017)
SoilGrids	International Soil Reference Information Center	250 m	https://soilgrids.org/	To assess soil organic carbon loss/degradation
FAO harmonized digital soil map	FAO	250 m	https://www.fao.org/soils-portal	To describe the soil type of the study area
Tree cover	Global Forest Watch	30 m	https://www.globalforestwatch.org/	The recent global tree cover maps are still being processed and not yet validated or available
DEM	Alaskan Satellite Facility	12.5 m	https://search.asf.alaska.edu/#/	
Protected areas and National Forest Priority Areas	World Database Protected Areas	Shape file	https://www.protectedplanet.net	
Landsat-7	United States Geological Survey Earth Resources Observation and Science Center	30 m	http://glovis.usgs.gov/	Date of acquisition: 25/01/2002 and 05/01/2012
				Path/Raw: 168/54 and 168/55
Sentinel-2	Copernicus Open Access Hub	10 m	https://scihub.copernicus.eu/	Date of acquisition: 13/01/2022

Source: Author's creation.

Ground Truth Data. To assist with the land-use and land-cover classification and computation of accuracy measures, 300 ground truthing points were collected using a stratified random sampling technique. The GTPs collected from Google Earth (120) were used to train the classification algorithm (60 GTPs) and assess the accuracy of the classification (60 GTPs) of historical land-use and land-cover classes (i.e., for the years 2002 and 2012). The GTPs collected during field surveys (180) were used to train the classification algorithm (90 GTPs) and assess the accuracy of the classification (90 GTPs) of the 2022 land-use and land-cover class classification.

Field Sampling and Tree Parameters Measurement. We first conducted participatory reconnaissance surveys with community members and district-level experts to gather data on existing FLR measures and identify sample kebeles for vegetation surveys.[2] We used systematic sampling methods to establish sampling plots in each investigated land-use and land-cover type (Table 2). In each plot, vegetation variables, such as diameter at breast height (DBH) and height of individual trees, were measured using calipers or a diameter tape and graduated meter stick. Individual trees greater than or equal to 5 cm DBH were listed. People from local communities provided the local names of trees and shrubs and an estimation of the age of bamboo trees. The scientific names were identified using the guide on Flora of Ethiopia and Eritrea (Tadesse 2004).

[2] The lowest administrative units.

TABLE 2. Sampling strategies for vegetation surveys and collected variables.

Land use and land cover	Sampling	Vegetation variable	Remark
Home gardens	- Plot size 10 m×10 m (Bullock 1996) - 40 HHs (10 HHs from each woreda)	- Local name of tree species - Species richness - Height - DBH	Households were randomly selected. The plot was laid either to the side or back of the house, depending on the location of the garden. DBH was measured 1.3 m above the ground for all woody species ≥ 5 cm in diameter.
Scattered trees on farmlands	Plots of 100 m x 50 m were laid out at 400 m intervals along transects spaced 500 m apart (Hairiah et al. 2001).	- Local name of tree species - Species richness - Height - DBH	Non-targeted habitats (e.g., rivers, rocky hills) were excluded from the transect line.
Highland bamboo forest	12 (3 in each selected woredas) circular plots, each measuring 100 m² with a radius of 5.64 m were established in bamboo forests (Huy and Long 2019).	Age of culms Culm DBH Culm height Counting the culm for each age class	Culm DBH was measured at 1.3 m above the ground.
Exclosures, forest established through reforestation and tree buffers around lakes	- Plot size 10 m x10 m -10 plots for each FLR option	- Local name of tree species - Species richness - Height - DBH	The distance between plots was 50 m; distance between transects ranged from100 m to 500 m depending on the size of the exclosures/forest established through reforestation and tree buffer.

Source: Author's creation.
Note: DBH: diameter at breast height.

Physical Input, Output and Market Data for Cost–Benefit Analysis. Estimation of cost and benefit analysis requires biophysical and socioeconomic input and output data. In addition, detailed market analysis (observation) and secondary data (reports) were used to collect the physical quantities of inputs and activities used to implement the FLR options and the outputs and products that would be harvested from each FLR option (see section 3.5). The monetary value of each input and output related to each FLR measure was estimated using local market prices. Most FLR options include soil and water conservation structures such as soil or stone bunds, trenches and microbasins and forestry activities such as pit preparation, planting, weeding, thinning and harvesting. Their cost was determined using the person-per-day payment set by each woreda. The labor cost of guards hired to protect exclosures was estimated using the wage of unskilled labor in the woreda.

The harvested bundles of grass and fuelwood were calculated in cubic meters per hectare based on information obtained from the FGDs. We considered the equivalence of a bundle of grass for animal fodder and a bundle of fuelwood as 0.5 m^3 and 0.7 m^3, respectively. The amount of grass harvested from wetland areas and used for house construction was estimated in cubic meters based on the assumption that 3.375 m^3 equaled one donkey load. The harvested amount of tree products such as construction materials and round poles and logs for timber production were estimated based on primary information collected from the market.

Stratification of the Study Area and Identification of Restoration Options. Before selecting FLR options and conducting any further analyses, the study catchment was stratified based on biophysical (e.g., land-use, land-cover, topography, rainfall, elevation) and socioeconomic variables (e.g., population density, level of dependency on natural resources, demand for forest products). The stratification of the entire catchment was supported by insights gained through field observation, KIIs and FGDs and GIS and remote sensing techniques. We tried to limit the number of strata as much as possible as recommended by IUCN and WRI (2014).

Following the study catchment stratification, potential FLR options were identified by consulting documents on national and regional FLR priorities (MEFCC 2018; EFCCC 2019) and evaluating their contributions in terms of (a) generating income through provision of wood and nonwood products and contributions to crop and livestock production; (b) ensuring water security through increased water availability and reduction of sedimentation of waterbodies; (c) contributions to reducing greenhouse gas emissions through carbon sequestration; and (d) contributions to biodiversity conservation through restoration of degraded ecosystems. The potential FLR options were then presented to the local communities during FGDs and KIIs for further evaluation. Finally, identified and evaluated options were assigned to each stratum.

2.4. Data Analysis

Land-Use and Land-Cover Analysis

Image Pre-Processing and Land-Use and Land-Cover Classification. Image pre-processing was conducted before classification, (mainly layer stacking and enhancement). Layer stacking was carried out to convert multiple, usually single-band images into a single multi-band image layer (Islam et al. 2018). Image enhancement was performed using spatial enhancement tools such as the Convolution function to improve the quality of the raster image. Statistics and pyramid layers were computed using the Image Commands tool after removing the no data/null values. Masking and removing extraneous data were performed using the Subset and Chip tool. The hybrid classification (unsupervised classification and maximum likelihood classifier) approach was used to classify the land-use and land-cover classes (Wang et al. 2021).

Accuracy Assessment. Image classification performance was evaluated using accuracy assessment statistics such as overall accuracy (OA, Equation 1), user accuracy (UA, Equation 2), producer accuracy (PA, Equation 3), and kappa coefficient (Kappa, Equation 4) (Dey et al. 2021). Kappa values less than zero indicate no agreement, and 0–0.2 indicates slight, 0.2–0.41 poor, 0.41–0.60 moderate, 0.60–0.80 substantial, and 0.81–1.0 almost perfect agreement (Wang et al. 2021).

$$\mathrm{OA} = \left(\frac{\mathrm{A}}{\mathrm{N}}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (\mathrm{Eq.}\ 1)$$

$$\mathrm{UA} = \left(\frac{B}{D}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (\mathrm{Eq.}\ 2)$$

$$\mathrm{PA} = \left(\frac{C}{E}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (\mathrm{Eq.}\ 3)$$

$$\mathrm{Kappa} = \frac{\mathrm{N}\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} * x_{+i})}{\mathrm{N}^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . . \ldots\ldots\ldots (\mathrm{Eq.}\ 4)$$

where *A* is the total number of correctly classified pixels in the diagonals of the matrix, *N* is the total number of pixels (observations); *B* is the number of correctly classified pixels in each category, and *D* is the total number of pixels classified in that category (row total); *C* is the number of correct pixels in each category and *E* is the total number of pixels derived from the reference data (column total); x_{ii} is the number of pixels in row *i* and column *i;* x_{i+} and x_{+i} are the marginal totals of raw *i* and column *i* respectively; *r* is the number of rows in the matrix.

Land-Use and Land-Cover Dynamics. For each category, the change in area between two years was determined by subtracting the area of a specific category in the first year from the area of the same category in the second year. The annual rate of change per category was determined by dividing the change in area by the number of years between the two datasets (Girma et al. 2022b). The transitions from one land-cover category to another were measured using the transition matrix in ArcGIS (Zhang et al. 2017).

Assessment of Land Degradation

The severity of land degradation was assessed using Good Practice Guidance prepared for Sustainable Development Goal 15. Specifically, the analysis employed indicator 15.3.1 developed by the United Nations Convention to Combat Desertification (UNCCD) (Schillaci et al. 2022; Zhao et al. 2023). Based on the SDG 15.3.1 framework, the analysis considered three subindicators: (a) land productivity (LP), (b) land cover (LC), and (c) soil organic carbon (SOC). In this study, we used 2002 as a base year and 2022 as the target year.

The values for land productivity indicators (in kg ha^{-1} yr^{-1}) were computed from the mean annual normalized difference vegetation index trend. Trends.Earth computes a linear regression at the pixel level to identify areas experiencing changes in land productivity (Trends.Earth, 2022). Mann-Kendall nonparemetric significance test (at $p < 0.05$) was then applied to only consider pixels displaying significant changes. In the present study, the NDVI was derived from a Moderate Resolution Imaging Spectroradiometer sensor (MOD13Q1) with a 250 m resolution (Trends.Earth, 2022). Within a given ecosystem, the rate of change of land productivity overtime is affected by several factors. Water availability is one of those factors that can have a significant influence (Trends.Earth, 2022). Accordingly, the Water Use Efficiency (WUE) correlation method was used to correct for the effects of climate on land productivity. The NDVI trends from 2002 to 2022 were adjusted for the WUE index by using total actual annual evapotranspiration (Schillaci et al. 2022). This study used WUE instead of rainfall to correct for climate variability as Trends.Earth performs the correction process using predefined datasets. A linear regression and a non-parametric significance test were applied to adjust the trend of WUE over time (Schillaci et al. 2022).

The land-cover change subindicator was computed using custom data (see section 3.1.5) for the first year (2002) and the target year (2022). Both land-use and land-cover maps were reclassified to seven land-cover classes needed for reporting to the UNCCD (forests, grasslands, croplands, wetlands, artificial areas, bare land and waterbodies) (Trends. Earth, 2022). Land-cover transition analysis was performed to identify which pixels remained in the same land-cover class and which ones changed. A table of degradation typologies was then created to identify which transitions correspond to degradation, improvement or no change in terms of land condition. Finally, Trends.Earth combined information from the land-use and land-cover maps and the table of degradation typologies by land-cover transition to compute the land-cover subindicator.

The relative change in SOC between the baseline (2002) and the target year (2022) was estimated using a combined land-use, land-cover and SOC method in Trends.Earth. In the present study, SoilGrids 250 m carbon stocks for the top 30 cm of the soil profile were combined with the reclassified custom land-use and land-cover dataset. The area that experienced a loss in SOC of ≥10% during the reporting period (2002–2022) was considered potentially degraded and areas experiencing a gain of ≥10% as potentially improved (Trends.Earth, 2022).

Finally, the three subindicators were integrated into a final SDG 15.3.1 indicator map using the 'one-out all-out' rule (Schillaci et al. 2022; Trends.Earth 2022). An area was considered potentially degraded if it was identified as potentially degraded by any of the three subindicators. Otherwise, if at least one indicator showed a positive trend and none showed a negative trend (or neutral), it was considered as improved. Only when all indicators remained unchanged was the indicator considered stable for reporting purposes (Schillaci et al. 2022).

Estimation of Above-Ground Biomass and Carbon Content

Tree Estimation. Estimates of above-ground biomasses were based on field measurements of vegetation variables (i.e., DBH and height (H)) and using allometric Equation, Eq. 5 (Chave et al. 2014).

$$AGB(Kg) = 0.0673\ x\ (\rho \text{ x } \mathrm{DBH}^2 x\ H)^{0.976} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (\mathrm{Eq.}\ 5)$$

Where DBH is in cm, H is in m, and ρ (wood density) in g cm^{-3}.
Global and World Agroforestry Center databases on wood density were used to estimate the density of the identified woody species (Zanne et al. 2009).

Following the estimation of above-ground biomass, above-ground carbon was estimated using Equation 6 (Eggleston et al. 2006).

$$Carbon\ Content\ (tCha^{-1}) = 0.5 \times AGB\ (t) \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 6)}$$

Where $tCha^{-1}$ is tons of carbon per hectare, *AGB* is above-ground biomass.

Since the carbon stock is traded as CO_2 units (Hohne et al. 2003), the CO_2 equivalent (t CO_2 ha^{-1}) was estimated by multiplying the carbon stock (t C ha^{-1}) by the molar conversion factor of 3.67 (Olschewski and Benitez, 2005) as shown in Equation 7.

$$CO_2(tCO_2eq\ ha^{-1}) = Carbon\ content\ (tCha^{-1}) * 3.67 \ldots\ldots\ldots \text{(Eq. 7)}$$

Remote Sensing Estimation. Alternatively, AGB was estimated using a biomass function that considered NDVI as an independent variable using Equation 8 (Fantahun et al. 2022).

$$\log_{10} AGB = 0.812 + 1.762(NDVI) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 8)}$$

Where NDVI is the Normalized Difference Vegetation Index calculated as

$$\text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{(Eq. 9)}$$

Where NIR and R represent the Near Infrared and Red bands.

We used the values estimated with Equation 8 mainly for mapping the spatial distribution of above-ground biomass in the catchment. The values estimated using the allometric equation were used to determine the ecological benefits of restoration options.

Identification of Potential Areas for Forest and Landscape Restoration Measures

Various inclusion and exclusion criteria were used to identify or map suitable areas for each of the identified FLR options (MEFCC 2018). Setting these inclusion and exclusion criteria (Table 3) for each FLR option was supported by multiple datasets, including land-use and land cover, tree cover, slope, rainfall, agricultural systems, altitude, freshwater ecosystems, and protected areas (Table 3). We then used ArcGIS spatial analysis tools and techniques to identify suitable areas for each option. The following procedures were used (Shabir et al. 2019): (a) buffer analysis to identify suitable areas for forest and landscape restoration measures surrounding freshwater ecosystems (e.g., lakes, rivers), roads and wetlands, (b) overlay analysis to identify areas that meet multiple criteria simultaneously, (c) selection based on a specific attribute (i.e., inclusion or exclusion criterion) to identify suitable areas for a target option, and (d) Boolean logic (and, or) to combine multiple mappings of suitable areas.

TABLE 3. Inclusion and exclusion criteria to map suitable areas for each identified forest and landscape restoration option.

FLR option	Inclusions and exclusions		Datasets	Source
	Include	**Exclude**		
Exclcosures	Bare lands, degraded shrublands, areas with <30% of tree cover	Waterbodies, farmlands, altitude > 3,700 and <500 m asl	LULC, tree cover	Landsat; global tree cover
Afforestation/ reforestation	Areas with >60% slope and >250 mm rainfall, degraded shrublands	Waterbodies, farmlands, areas with altitude >3,500 m asl	Slope, LULC, rainfall	DEM, Landsat, EMI
Agroforestry practices	Croplands with slope ≤ 50%, areas with tree cover <30%, smallholder farms, areas with <250 mm annual rainfall	Waterbodies, areas with tree cover >30%, slope >50%, commercial large-scale farms, areas with <250 annual rainfall	LULC, tree cover, types of farmland, rainfall	Landsat, global tree cover, EMI
Expansion of highland and lowland bamboo	Areas covered with bamboo, potential areas	Areas with altitude > 3,200 and <500 m asl	Natural bamboo extent, altitude, bamboo potential areas	INBAR, DEM, National Potential and Priority maps for tree landscape restoration report 2018
Tree buffers surrounding freshwater ecosystems	Up to 50 m surrounding lakes, rivers and wetlands, areas with <30% tree cover	Forest and areas with > 30% cover located near lakes, rivers, and wetlands	Rivers, lakes and wetlands, LULC, tree cover	DEM, global tree cover
Tree buffers along roads and in towns	100 m from roads and 1 km from towns; areas with <30% tree cover around towns and along roads	Forestlands, areas with > 30% tree cover	Roads, towns, tree cover	ERA, CSA, global tree cover
Buffer plantations surrounding National Forest Priority Areas	Up to 1 km surrounding NFPA, areas with <3,500 m altitude and annual rainfall of >250 mm	Degraded and secondary forest areas, wildlife migratory corridors, church forests, areas with >3,500 m altitude, area with <250 mm annual rainfall	LULC, tree cover, protected areas, altitude, rainfall	DEM, global tree cover, Landsat, EMI

Source: Author's creation.
Note: LULC: land use land cover; DEM: digital elevation mode; EMI: Ethiopian Meteorology Institute; ERA: Ethiopian Road Authority; CSA: Central Statistics Agency: INBAR: International Bamboo and Rattan Organization.

Qualitative data analyses

Before conducting the qualitative data analyses, all notes collected by the researchers during FGDs and KIIs were consulted to produce a single note for analyses. The qualitative data collected through FGDs and KIIs were then processed through manual topic coding and building categories, which involved repeated readings of transcribed data. After repeated readings, themes were identified (e.g., benefits and costs of FLR options) and then key words and phrases representing each theme were categorized or summarized. Using deductive coding, each identified word or phrase was further coded (e.g., environmental benefit, environmental cost, economic benefits, economic cost, social benefit, social costs). Finally, each response was tagged with all themes and subthemes presented in the dataset and analyzed.

Cost–Benefit Analysis

The study used two economic evaluation criteria, cost–benefit ratio (CBR) and net present value (NPV) to assess the economic viability of identified FLR options. The cost–benefit ratio evaluates an investment's net return per dollar of expense and was computed using Equation 10. The economic net present value (NPV) of a project, defined as the present value of expected future returns minus the present value of expected future costs, with costs and revenues discounted at the appropriate social discount rate, was computed using Equation 11.

$$ECBR = \frac{\sum_{t=0}^{T} \frac{Bt}{(1+d)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+d)^t}} \ldots\ldots\ldots\ldots\ldots\ldots (\text{Eq. } 10)$$

$$\sum_{t=0}^{T} \frac{S_t}{(1+d)^t} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+d)^t} \ldots\ldots\ldots\ldots\ldots\ldots (\text{Eq. } 11)$$

Where *Bt* is benefits (cash-flows) in year t, *Ct* is costs (cash-flows) in year t, S_t is the net-benefit of a given restoration option at time *t*, *t* is the year in which the cash flow occurs, *d* is the discount rate, and *T* is the period (the last year of the intervention or rotation age). In this study, we used a discount rate of 12%, the same rate used by the Development Bank of Ethiopia for long-term loans for agricultural investment, and a 20-year project period for each option. Values of CBR >1 indicate the economic viability of an option; the higher the CBR, the greater the benefit in proportion to the costs. However, the CBR is insensitive to the magnitude of net benefits and, therefore, may favor projects with smaller benefits and costs over those with higher net benefits. As a result, it is mostly used to show the value of a single project rather than for comparison between projects.

In contrast, the NPV is a better criterion for selecting from different alternatives. Values of NPV>0 suggest the economic viability of an option. If there are multiple investments (interventions), the project alternative that can generate greater ENPV is the most desirable. Therefore, the identified options were ranked based on their net present values.

The identified FLR options support carbon sequestration and help to adapt to climate change. The amount of carbon stock was considered an indirect benefit and was included in the economic analysis. Accordingly, the monetary value of the amount of carbon accumulated due to implementing an option was estimated by multiplying the CO_2 equivalent with the voluntary market price. In this study, a market price of 22 € per ton of CO_2 (equivalent to 23.18 USD) was used.[3] This price was based on the recent experience of one of REDD+ site in Ethiopia, the Humbo restoration site, because data on the mean annual increment of carbon stock for restoration options was not available. We distributed the carbon stock accumulated in each FLR option over the project period (20 years) by taking the mean carbon stock estimated using am allometric equation calculated on the basis of the age of each FLR option in the sampled woreda.

Dependency Ratio Analysis

An active labor force contributes to effective planning and implementation of FLR interventions. Accordingly, we analyzed the active labor force in the catchment area using a dependency ratio, a ratio showing the burden of economically inactive people over economically active people using three criteria: youth dependency ratio, old-age dependency ratio and total dependency ratio. The total dependency ratio (DR_t) combines the two dependency ratios (Equation 12). The youth (Equation 13) and old-age (Equation 14) dependency ratio considers the burden on economically active people due to people younger than 15 years and retired people, respectively.

[3] Average exchange rate in 2022, 1€ = 1.0538 USD.

$$DR_t = \left(\frac{People < 15 \ + \ People \geq 65 \ years}{People \ between \ 15 \ and \ 64}\right) * 100 \ldots \ldots \ldots \ldots \ldots \ldots \ (\text{Eq. } 12)$$

$$DR_y = \left(\frac{People < 15 \ years}{People \ between \ 15 \ and \ 64}\right) * 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ (\text{Eq. } 13)$$

$$DR_o = \left(\frac{People \geq 65 \ years}{People \ between \ 15 \ and \ 64}\right) * 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ (\text{Eq. } 14)$$

Validation of Results

The validation of the study findings was determined in a workshop. Thirty-six participants were invited, with a turnout of 34 participants representing the Ministry of Agriculture, Ministry of Water and Energy, the regional agricultural bureau, and district and kebele level agricultural offices. The validation workshop was intended to (a) improve the output of the assessment; (b) reduce the number of areas open to criticism; and (c) confirm whether the proposed interventions were feasible in the prevailing regional and catchment circumstances. The objectives and methods, key findings, conclusions and recommendations were presented during the validation workshop. The workshop focused on assessing whether the overarching conclusions and recommendations of the assessment make technical, political and institutional sense. The participants were encouraged to raise any concerns about confusing, contradictory or unclear results and to identify any other work that might be relevant to the assessment and support (or not) the analyses and outcomes of the study.

During the workshop, participants were divided into groups, and the discussion was facilitated using guiding issues but was not limited to only providing opinions to improve the study results. The discussion issues were; (a) stratification of the study area (how fit and acceptable in terms of the approach followed and the stratum used), (b) potential and prioritization of the FLR options (how fit the suggested potential FLR options and the prioritization), (c) area suitability for the FLR options (evaluating the recommended FLR options for the specific area within the catchment) and (d) success and failure factors and financing options (evaluate the success and failure factors presented, and the financial mechanisms). Maps and tables were provided to each group to remind them what had been presented. Finally, each group presented their comments and recommendations for the whole group, focusing on the guiding discussion points and related issues.

3. Results and Discussion

3.1. Applicability of ROAM for Catchment Level Studies

We used ROAM, primarily designed for national and sub-national level studies, to identify and map FLR opportunities in the western catchment of Lake Ziway. We found that the ROAM approach is flexible and facilitates the collection and analysis of data relevant to identifying and mapping FLR options at the catchment scale. The contextualization of the ROAM approach allowed us to gather detailed data and suggest context-specific interventions. A customized application of ROAM contributed to better measurement of the costs and benefits of each intervention and enabled the estimation of ecological benefits such as carbon sequestration. Diagnoses of the presence of key success factors and identification of strategies to address major policy, legal and institutional bottlenecks and analysis of the finance and resourcing options for restoration in the assessment area were done effectively at the catchment level using the customized ROAM.

Applying ROAM to catchment assessment is an important contribution to the woreda and kebele experts and helps them make intervention recommendations. This approach also helped us gather firsthand and context-specific information and consider community priorities and interests. This, in turn, supports better operationalization of opportunities for implementing forest and landscape restoration options. We argue that the ROAM approach could provide increased benefits in identifying and implementing forest and landscape restoration measures if it is included as an approach for operationalizing identified opportunities.

3.2. Biophysical Profile

Climate and Agroecology

Rainfall and temperature in the western catchment of Lake Ziway showed strong spatial variations with altitude. The average annual rainfall varied between 620 and 989 mm (Figure 3a). Based on the Ethiopian traditional classification of agroecological zones, which uses altitude and annual rainfall as criteria, most of the catchment area (73%) is characterized as dry *weyna dega* (i.e., receiving an average annual rainfall of less than 900 mm and having an altitude ranging from 1,500 and 2,300 meters above sea level) (Figure 3b).

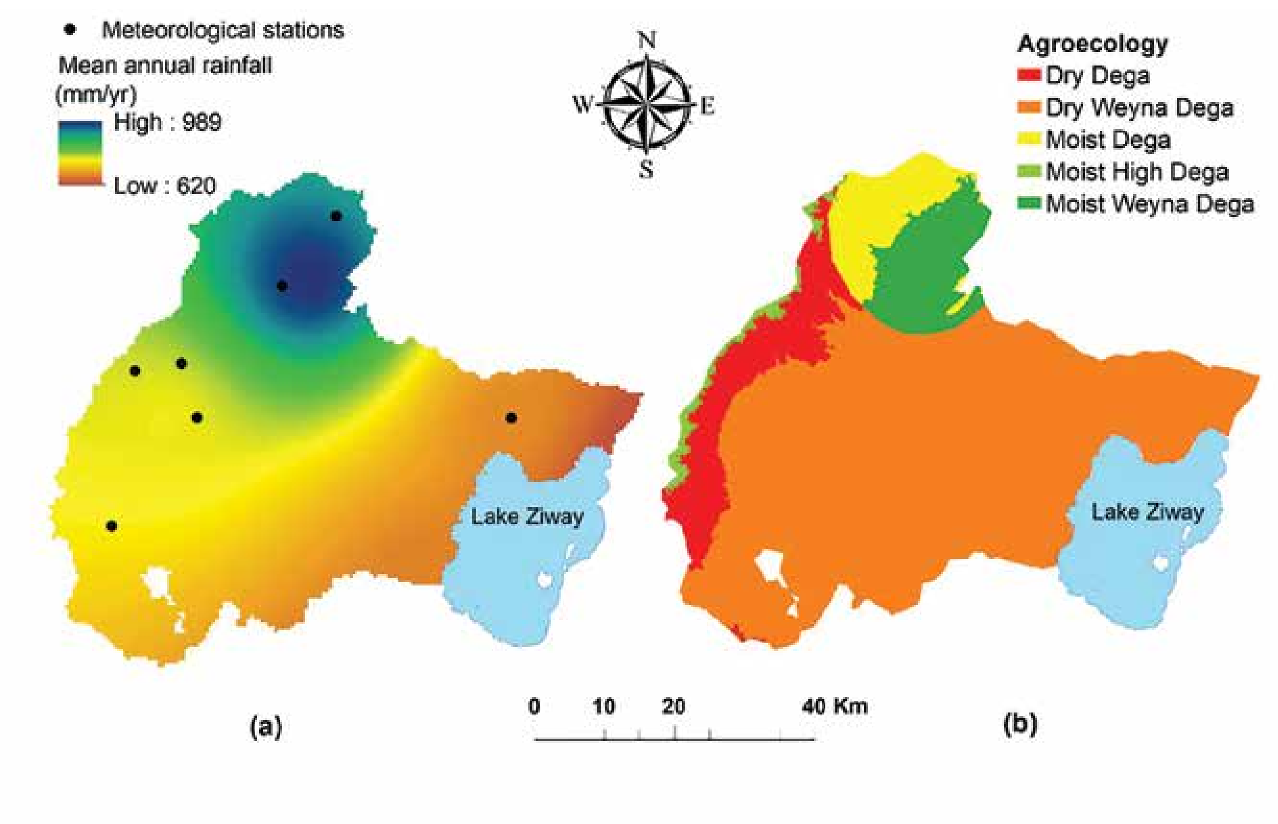


FIGURE 3. Spatial distribution of mean annual rainfall (a) and major agroecological zones (b) in the western catchment.
Source: Author's creation.
Notes: Dega refers to coldish, less than temperate zones with altitudes ranging between 2,300 and 3,200 m. Weyna dega is warm and wet and lies between 1,500 and 2,300 m.

Based on the annual rainfall distribution (Figure 4), the climate of the study catchment can be divided into three seasons: (a) *kirem,t* or long rainy season, also called *meher*) which extends from June to September; (b) *bega,* or dry season, which lasts from October to February; and (c) *belg,* or short rainy season, which covers March to May. The rainfall during the main rainy season contributes to agricultural production and fills reservoirs during the spring rains. (Asfaw et al. 2018). Annual rainfall shows large inter-annual variation. The highest annual rainfall was recorded in 1995 and the lowest in 2017.

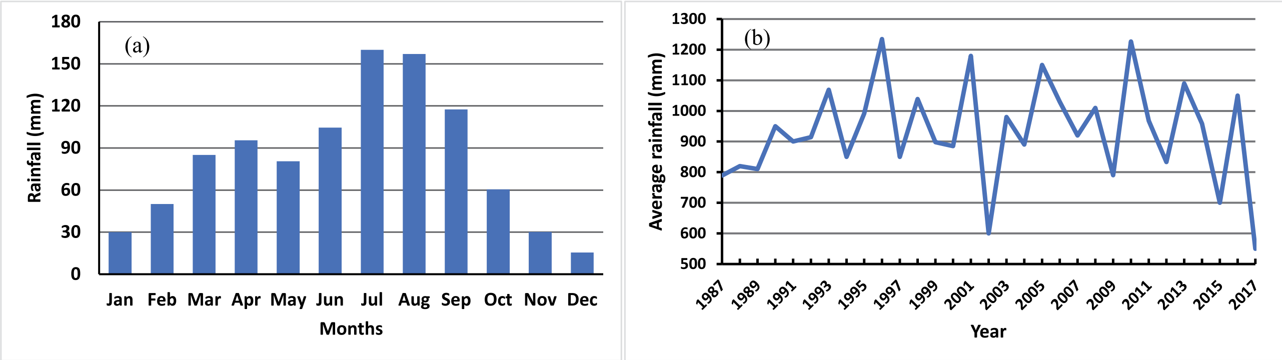


FIGURE 4. Rainfall distribution in Lake Ziway western catchment for the years 1987 to 2017: (a) mean monthly rainfall and (b) mean annual rainfall.
Source: Author's creation.

Figure 5 shows the spatial distribution of mean annual minimum (T_{min}) and maximum (T_{max}) temperatures. The mean annual minimum temperature ranged from 12° C to 16° C (Figure 5a), while the mean annual maximum temperature varied between 25° C and 27° C (Figure 5b). Both the minimum and maximum temperatures gradually increase toward the valley floor.

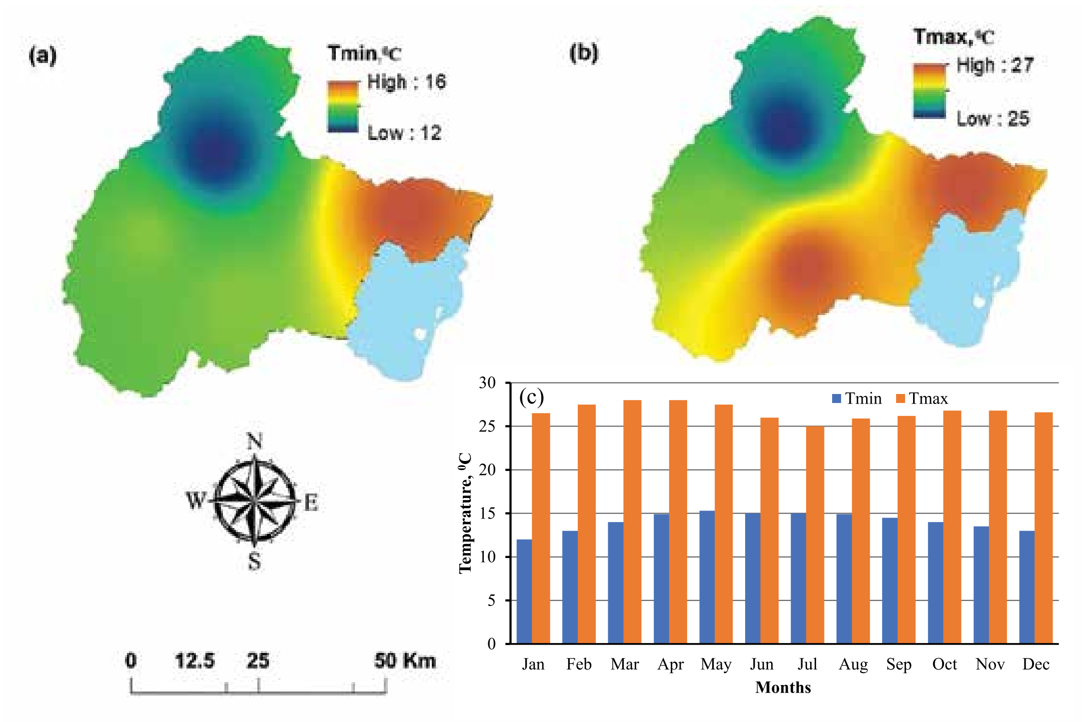


FIGURE 5. Mean annual minimum (a) and maximum (b) temperatures and mean monthly temperature (c) 1995–2017.
Source: Author's creation.

Soil Type

The results indicate that the soils of the study catchment can be divided into ten soil groups (Figure 6a). More than fifty percent of the catchment is covered by three soil groups: Eutric Cambisols (23%), Luvic Phaeozems (20%) and Eutric Vertisols (17%). Most of the central catchment is dominated by Eutric Cambisols. This soil is mainly characterized by weak to moderately developed soils. The upper catchment is dominated by Chromic Luvisols, mainly characterized by a subsurface accumulation of high-activity clays and high base saturation. Most of the lower catchment is characterized by young soils formed from volcanic deposits called Virtic Andosols (FAO et al. 2012).

Topography and Landform

The rift system of fault lines primarily determines the topography of the study area. The altitude ranges from 1,607 to 3,612 meters asl (Figure 6b). The greatest variability in terms of elevation and the longest and steepest slopes are found in the western escarpments of the catchment. For example, the elevation drops from 3,612 m to 1,847 m in the upper 20 km of the catchment. In contrast, the elevation drops from 1,693 m to 1,633 m in the lower 20 km. The slope of the upper reaches of the catchment is very steep (>45% slope) and mountainous, while the valley floor is characterized by a flat plain (<5% slope) (Figure 6c). Most (80%) of the central and lower parts of the catchment exhibit gentle to moderately steep slopes (Table 4) and are dominated by plain landforms (42%) (Figure 6d).

TABLE 4. Slope classes of the study area.

Class	Slope range (%)	Description	Area	
			km²	%
1	0–5	Very gentle or flat slope	473.4	16
2	5–15	Gentle slope	1,384.3	46
3	15–30	Moderately steep slope	7,45.0	25
4	30–45	Steep slope	2,16.0	7
5	>45	Very steep slope (Escarpments)	1,84.8	6
Total			3,003.5	100

Source: Author's creation.

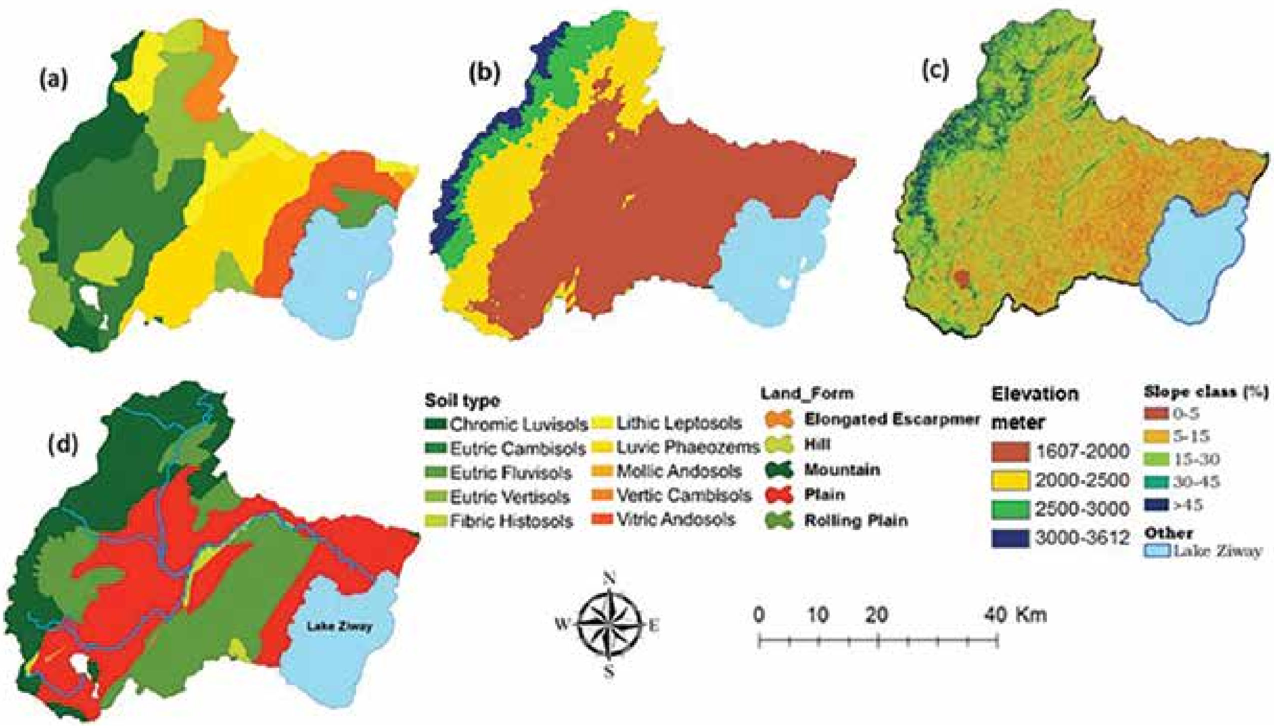


FIGURE 6. Major soil types (a), altitude (b), slope (b) and landform (d) of western Lake Ziway.
Source: Author's creation.

Tree Canopy Cover

The spatial extent of tree cover (>5 m high) gradually increases toward the western escarpment (Figure 7). Most of the central and lowlands are dominated by scrub canopy cover (0–10%). From 2000 to 2010, the cover of open forests and very dense forests dropped by 35% and 26%, respectively, while the cover of scrub and moderately dense forests increased by 7.7% and 6%, respectively (Table 5). The analysis revealed that tree cover significantly decreased due to extensive deforestation and the expansion of farmland.

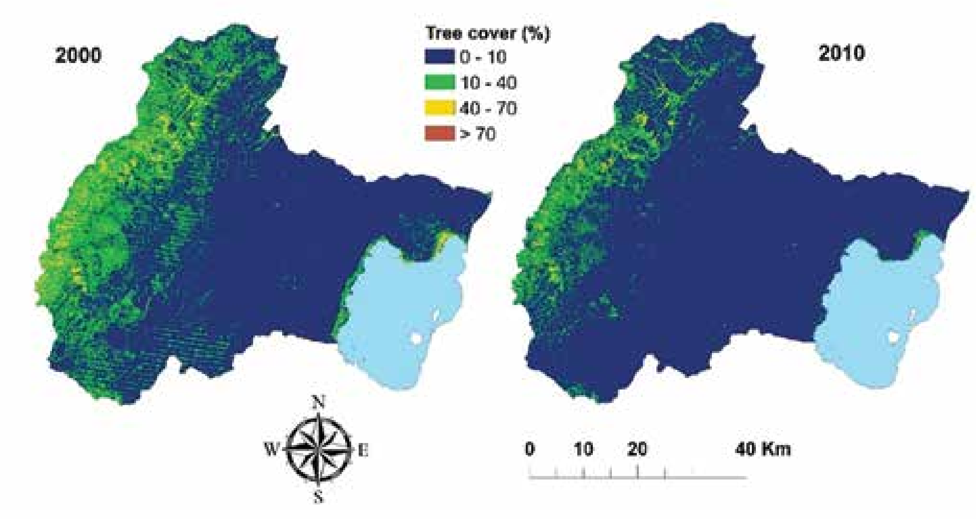


FIGURE 7: Tree canopy density.
Source: Author's creation.

TABLE 5. Tree canopy cover for 2000 and 2010.

Canopy density* (%)	Class	2000		2010	
		Area (ha)	%	Area (ha)	%
0–10	Scrub	243,585	81.1	262,433.5	87.4
10–40	Open forest	53,400.1	17.8	344,72.3	11.4
40–70	Moderately dense forest	2,972.4	1.0	31,54.2	1.1
>70	Very dense forest	392.8	0.1	290.4	0.1
Total		300,350.5	100	300,350.5	100

Source: Author's creation.
* The 2022 tree cover analysis was not included as the recent global tree cover data used for the analysis as it has not yet been validated.

Land Use and Land Cover

Eight major land-use and land-cover (LULC) classes were identified in this study. These are waterbodies, grasslands, forestlands, farmlands, bare land, settlement/built-up areas, shrublands and wetlands. The overall classification accuracy and kappa analysis were greater than 83 and 80%, respectively (Table 6), suggesting that classified maps can be used for further analyses.

Figure 8 shows the LULC for 2002, 2012 and 2022. Forestlands are mainly found in the western escarpments, while farmlands dominate the central and low-lying areas. Bare land dominates in the central plain. Among the LULC classes, agriculture is the dominant land-cover class in all investigated years (Table 7). The study area experienced significant landscape alterations and various LULC changes have been observed over the last 20 years (2002–2022). The trends of LULC changes from 2002 to 2022 showed decreases in forestlands (81%), shrublands (64%) and grasslands (78%)

decreased and increases in croplands (35%), settlement areas (158%) and bare land (169%). These changes have been mainly attributed to deforestation and the expansion of farmlands (Yemiru et al. 2010; Belete et al. 2015). The expansion of farmlands occurred mainly at the expense of forest, shrublands and grasslands. For example, 36,551 ha (65%) of forestlands, 23,405 ha (79%) of shrublands and 66,763 ha (84%) of grasslands were converted to farmlands over a period of 20 years (Table 8). This is mainly attributed to increased demand for farmlands due to population increase. The slight increase in wetlands might be associated with the recession of the lake or errors in the accuracy of LULC classification.

TABLE 6. Accuracy of classified maps.

LULC Class	2002		2012		2022	
	PA* (%)	UA* (%)	PA (%)	UA (%)	PA (%)	UA (%)
Forestlands	88.89	80.1	88.2	75.0	89.5	85.0
Waterbodies	90.48	95.0	90.0	90.0	85.7	90.4
Farmlands	82.61	95.0	72.0	89.9	81.8	90.0
Wetlands	94.12	80.0	84.2	80. 4	88.9	80.1
Shrublands	77.27	85.4	81.0	85.0	81.8	90.0
Grasslands	94.74	90.0	94.4	85.0	94.4	85.0
Settlement	86.36	95.0	85.7	90.0	95.0	94.9
Bare land	83.33	75.2	79.0	75.0	90.0	90.2
OA* (%)	86.88		83.75		88.13	
Kappa coefficient	0.85		0.81		0.86	

Source: Author's creation.
Notes: According to the cited literature in the above paragraph, Kappa values less than zero refer to no agreement, 0–0.2 to slight agreement, 0.2–0.41 to poor agreement, 0.41–0.60 to moderate agreement, 0.60–0.80 to substantial agreement and 0.81–1.0 to perfect agreement.
* PA refers to producer accuracy, UA to user accuracy and OA to overall accuracy.

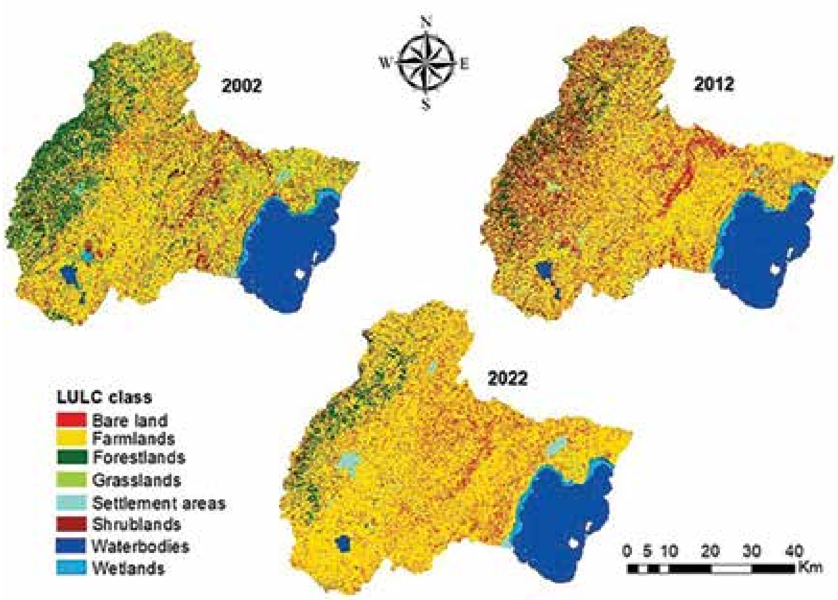


FIGURE 8: Land use and land cover for 2002, 2012 and 2022.

Source: Author's creation.

TABLE 7. Land-use and land-cover dynamics between 2002 and 2022.

No	LULC class	2002		2012		2022	
		ha	%	ha	%	ha	%
1	Bare land	12,472.0	4.2	223,60.5	7.4	33,585.3	11.2
2	Farmlands	161,086.1	53.6	197,683.1	65.8	21,6965.0	72.2
3	Forestlands	55,993.3	18.6	175,72.5	5.9	10,604.2	3.5
4	Grasslands	31,591.0	10.5	12,275.8	4.1	64,10.2	2.1
5	Settlement areas	1,239.7	0.4	6,451.7	2.1	12,570.0	4.2
6	Shrublands	29,618.6	9.9	36,592.6	12.2	10,555.3	3.5
7	Waterbodies	4,022.1	1.3	2,021.2	0.7	1,823.1	0.6
8	Wetlands	4,325.9	1.4	5,391.3	1.8	78,35.7	2.6
	Total	300,348.6	100	300,348.6	100	300,348.6	100

Source: Author's creation.
Notes: LULC: Land use and land class.

TABLE 8. Pattern of land-use and land-cover change (from–to analyses).

2002–2022	Forest	Water	Cultivable	Wetland	Shrub	Grassland	Settlement	Barren land	Loss 2022
Forest		**80.72**	**36,551.01**	**37,56.88**	**4,393.65**	**2,279.41**	**1,773.6**	**1,789.26**	**50,624.53**
Water	1,125.17		1,071.29	75.77	400.34	44.4	54.64	18.09	2789.7
Farmland	1,999.2	1,56.93		2,013.92	3,296.23	2,011.11	2,860.51	11,001.22	23,339.12
Wetland	1,78.02	270.64	2,006.22	-	703.59	521.11	13.72	14.46	3707.76
Shrub	1,524.88	55.33	23,404.81	835.14		791.89	557.77	1,428.1	28,597.92
Grassland	448.08	19.66	26,817.92	548	736.64		587.93	1,689.15	30,847.38
Settlement	22.15	2.36	357.36	9.19	34.44	6.69		28.86	461.05
Barren land	50.66	9.44	11,172.01	37.37	91.4	62.62	291.03		11,714.53
Gain-2022	5,348.16	595.08	101,380.6	7,276.27	9,656.29	5,717.23	6139.2	15,969.14	
Net changes	-4,5276.4	-2,194.62	78,041.5	3,568.51	-18,941.6	-25,130.2	5,678.15	4,254.61	

Source: Author's creation.

Land Degradation Status

Most (74%) of the study area was characterized as 'stable productivity'. An insignificant (0.12%) proportion of the study catchment showed improvements in productivity over a period of 20 years (Table 9). Similarly, an insignificant proportion (0.1%) was characterized as 'stressed', while 10% and 16% was categorized as 'under early signs of decline and declining land productivity' (Table 9). The stress or pressure on land productivity varied with land use and land cover. For example, of the total stressed area, 38% was in croplands. Similarly, the largest share of early signs of decline (54%) and declined (65%) categories were from croplands (Figure 9). These results were consistent with the FGD participants' opinions. They said that the trend in crop productivity had declined over the last decades. Declining rainfall and soil fertility were mentioned as the main drivers. This resulted in increased demand for farm inputs (e.g., fertilizer, pesticides) and increased production costs. The land degradation status based on this subindicator showed an increased decline toward the southeast, but the land degradation status in the northeast only showed early signs of land productivity decline (Figure 10a).

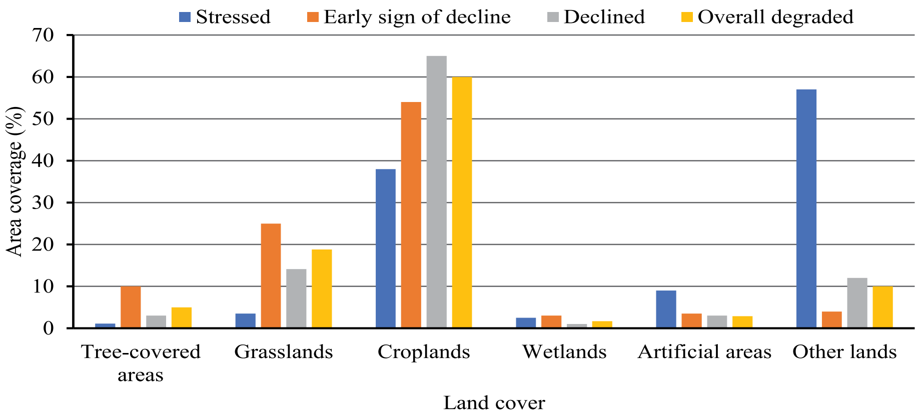


FIGURE 9: Area coverage of the status of lands analyzed using the land productivity indicator across the different land-use and land-cover types.
Source: Author's creation.

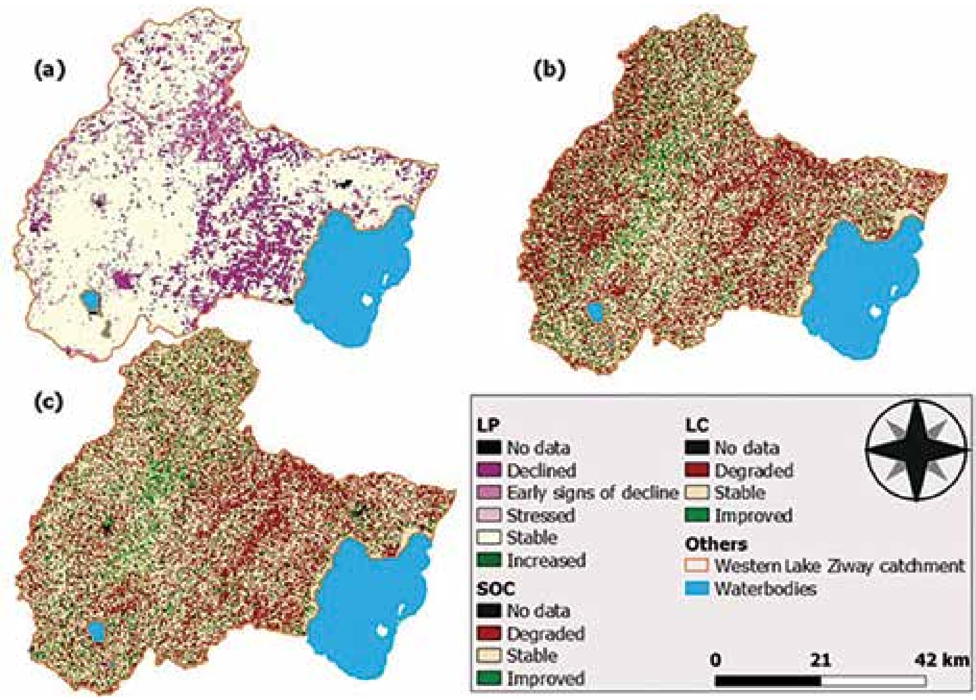


Figure 10. Land degradation subindicators: (a) land productivity (LP), (b) land cover (LC) and (c) soil organic carbon (SOC).
Source: Author's creation.

The analysis of land degradation status based on land cover showed that 16% and 49% of the catchment displayed 'improvement' and 'stable' conditions, respectively (Figure 10b). Figure 10b indicates that the stable condition was dominant in the central buffer zone of the catchment. Thirty-five percent of the catchment showed degraded status (Table 9). Figure 10c shows the spatial distribution of SOC over 20 years. The results indicate that 16% of the study area showed improvement in SOC, mainly in the central plain, 54% of the catchment area shows stable condition and 30% shows degraded status (Table 9). The loss or degradation could be attributed to the significant conversion of forestlands (3,6551 ha), grasslands (2,6817.9 ha) and shrublands (23,404.8 ha) to croplands (Table 8) and the extractive nature of farming practices. Negasa et al. (2017) and Okolo et al. (2019) found that the highlands are losing SOC due to forest conversion to other land uses and agricultural intensification.

Combining all three indicators, 51% of the study catchment is degraded, 13% improved and 34% unchanged over 20 years (Table 9). The improvement in some parts of the catchment might be attributed to watershed management practices. The high-risk degraded land was mainly in areas dominated by croplands and bare land of the central and low-lying areas (Figure 11). These areas are characterized by lower tree cover, unsustainable land management practices and accelerated carbon decomposition and erosion. Studies identified that human and livestock populations in regions of limited resources, unsustainable farming techniques, insecure land tenure systems, poverty and climate change are the major drivers of LULC and land degradation (Meshesha et al. 2012; Desta and Fetene, 2020; Mesfin et al. 2020; Mekuria et al. 2021). As a result of the expansion of land degradation over time, agricultural productivity has decreased and worsened food security and poverty in the CRV (Meshesha et al. 2012).

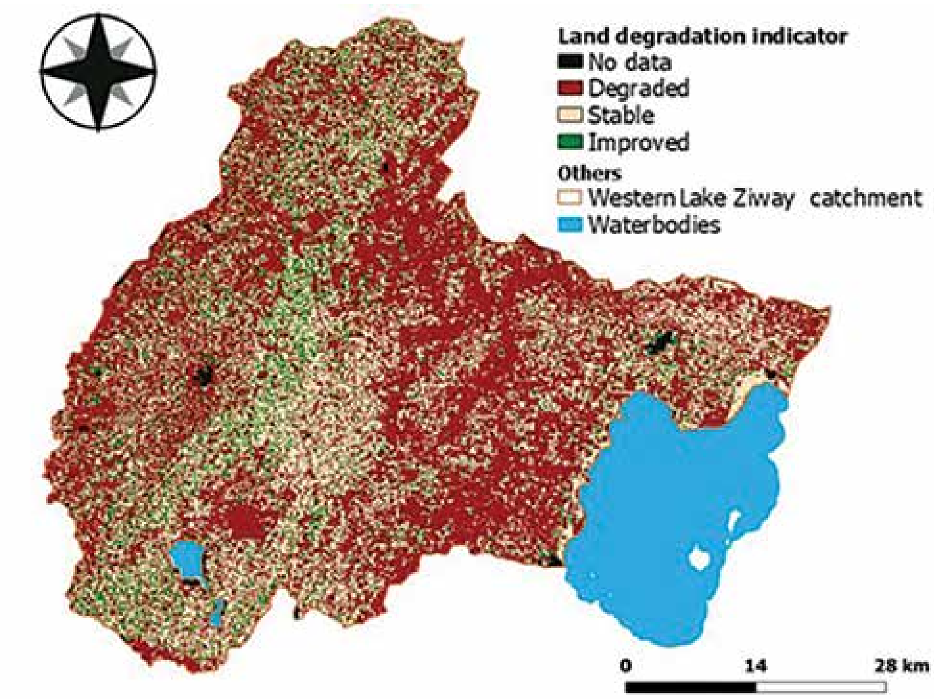


FIGURE 11. Land degradation indicator map for western Lake Ziway catchment.
Source: Author's creation.

TABLE 9. Summary of land degradation indicators based on SDG 15.3.1.

LP indicator	Area (sq km)	Percent of land area
Land area with improved productivity	3.5	0.1%
Land area with stable productivity	2,209.6	73.9%
Land area with degraded productivity	764.9	25.6%
Land area with no data for productivity	11.5	0.4%
Total land area	2,989.6	100%
LC indicator		
Land area with improved land cover	479.5	16%
Land area with stable land cover	1,459.7	48.8%
Land area with degraded land cover	1,034.1	34.6%
Land area with no data for land cover	16.3	0.5%
Total land area	2,989.6	100%
SOC indicator		
Land area with improved SOC	475	15.9%
Land area with stable SOC	1,602.2	53.6%
Land area with degraded SOC	890.7	29.8%
Land area with no data for SOC	21.7	0.7%
Total land area	2,989.6	100%
Combined indicators		
Land area improved	3,91.4	13.1%
Land area stable	1,020.3	34.1%
Land area degraded	1,532.0	51.3%
Land area with no data	45.9	1.5%
Total land area	2,989.6	100%

Source: Author's creation.
Notes: land productivity (LP), land cover (LC) and soil organic carbon (SOC).

The key informants also said the spatial extent and severity of soil erosion is increasing, and land degradation has become a serious issue. They said high sediment loads and floods toward the catchment outlet characterize the western catchment. The respondents mainly attributed the severity of soil erosion to anthropogenic drivers such as deforestation, intensive cultivation, overgrazing and sand mining. However, they also said other causes like topographic features (e.g., steep slopes, undulating landscapes), LULC, climate change, and shortage of farmland contributed to soil erosion. FGD participants said that in the 1980s, there was dense vegetation cover on the Lake Ziway shoreline (forest dominated by *Aeschynomene elaphoxylon*, locally known as *bofofe*) and that agroforestry practices in the upper and central part of the catchment were widespread. However, forest or tree cover decreased over time due to the expansion of cultivated land, which is consistent with the tree cover analysis and the long-term analyses of LULC changes (see sections 3.2.4, and 3.2.5).

Key informants and FGC participants identified the socioeconomic and environmental consequences of land degradation. Land degradation reduced the capacity of soil to support plant growth which undermined vegetation cover. The productivity of agricultural land is diminished owing to soil degradation (e.g., decline in soil fertility), resulting in increased labor and input costs as well as economic losses. Increased sand mining also resulted in riverain forest degradation along the Meki River. Key informants and FGD participants also said there was flooding in 2020 that displaced rural communities, increased sediment deposition on the lower slopes and affected the water quantity and quality of freshwater ecosystems.

Key informants said that integrated watershed development activities were implemented by various organizations to address land degradation problems. The integrated watershed development activities include diverse soil and water conservation measures like soil and stone bunds, terraces on steep slopes, waterways and cut-off drains, trenches, microbasins, gabion and brushwood check dams; tree landscape restoration activities including exclosures, agroforestry and plantation of perennial trees and fruit trees, and on-farm soil fertility management practices (e.g., use of manure and compost).

3.3. Socioeconomic Profile

According to the data obtained from the woreda finance and economic development offices, the study area has a total population of 2,239,704, of which 49.9% (1,117,038) are men and 50.1% (1,122,666) are women. The average family size is estimated at five. Of the 18 woredas in the catchment, Lanfero (7.4%), Siltie (9.3%) and Adami Tullu Jido Kombolch (9.5%) have the highest population (Figure 12) and Debub Sodo (2.2%) and Misirak Siltie (3.3%) have the lowest. On average, 52% (1,159,521) of the people in the catchment are 15 and 64 years of age, indicating that labor will not be a constraint when planning and implementing FLR measures. The fact that 45.3% of the population are children indicates high potential for future labor.

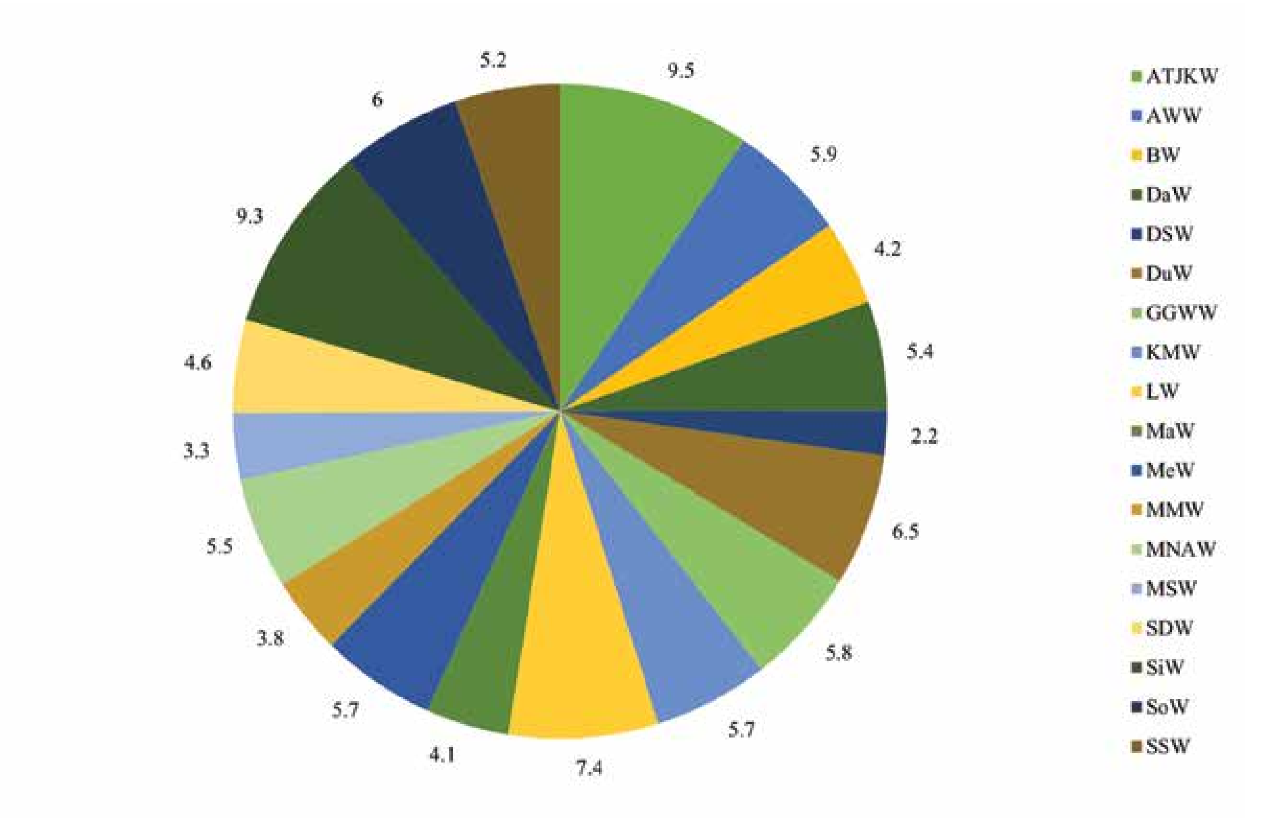


FIGURE 12. Population distribution in the western catchment of Lake Ziway.
Source: Author's creation.
Notes: Values indicate the proportion of the total population in percent.
Abbreviations (each is a woreda): ATJKW: Adama Tulu Jido Kombolcha; AWW: Alicho Woriro; BoW: Bora; DaW: Dalocha; DSW: Debub Sodo; DuW: Dugda; GGWW: Gedebano Gutazer Welene; KMW: Kersana Malima; LaW: Lanfero; MaW: Mareko; MeW: Meskan; MMW: Misrak Meskan; MSW: Misrak Siltie; MNAW: Muhur Na Aklil; SSW: Seden Sodo; SiW: Siltie; SoW: Sodo; SDW: Sodo Daci.

The total dependency ratio (i.e., the ratio of inactive to active population) varied between 88.3 and 111.4%, with a mean value of 93%.[4] This indicates that, on average, out of 100 people, 93 are economically dependent on active labor forces. Of 93 economically dependent individuals, 87 represent the youth dependency ratio, while 6 represent aged dependency.

Mixed crop-livestock farming, which is mainly rainfed (96.2%), is the major livelihood activity of the people in the catchment. Figure 13 shows the spatial distribution of major farming systems such as commercial farming (17%), enset cereals mixed farming system (24%), highland cereal-livestock mixed farming system (6%) and lowland cereals-livestock mixed farming system (40%). Looking at the spatial distribution of cultivated crops, enset, wheat, tomatoes, onions, beans and barley dominate in the highland areas, and wheat, teff and maize are cultivated mainly in the mid-lands.[5] Fruit and vegetables are produced close to the lake in the lower part of the catchment. People get their income mainly from crop production and agroforestry (66.9%) and 19.8% of the income derived from forestry, 8.8% from animal production and 4.6% from non-farm activities. Fishing is also common in Adama Tulu Jido Kombolcha Woreda adjoining Lake Ziway.

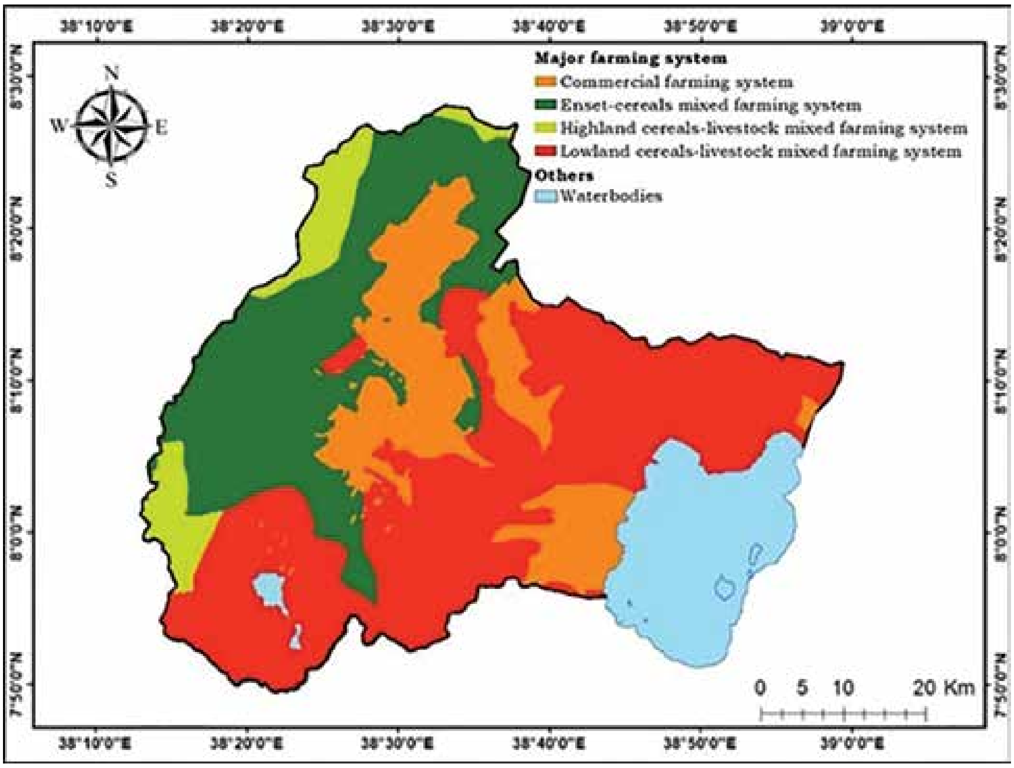


FIGURE 13. Major farming systems.
Source: Author's creation.

[4] Of the 18 woredas, the proportion of the inactive population (52.7%) was higher than active population (47.3%), resulting in a value larger than 100%. This means, (52.7/47.3) × 100 = 111.4%.

[5] Enset (E. ventricosum) is Ethiopia's most important root crop, a traditional staple in the densely populated south and southwestern parts of the country.

3.4. Zoning

The catchment was divided into five main zones based on selected biophysical and socioeconomic features. The Gurage highland, the first stratum was further subdivided into three strata (Figure 14). The key biophysical and socioeconomic features of each stratum are summarized in Table 10. The upstream area of the catchment, mainly in the Guraghe highland, is dominated by steep slopes and receives relatively high amounts of rainfall. The central plain is mainly used for agriculture, mainly maize production. The rolling plain is typically degraded but with intensive farming bounded by the main south-north road crossing the catchment. The lower part of the catchment below the main road is mainly used for irrigated agriculture producing fruits and vegetables. The outlet of the catchment along the boundary of the lake is also a distinct area categorized as the fifth strata representing wetland ecosystem.

TABLE 10. Stratification of the study area.

Strata	Name	Dominant features
1	Gurage highland Substratum 1	Moist high *dega*, mountainous landform, high rainfall, very steep slopes, high erosion vulnerability, gully erosion, low temperatures, deforestation, dominated by farmland.
	Substratum 2	Dry *dega*, mountainous landform, gully erosion, dominated by very steep slopes and forests.
	Substratum 3	Dry *weyna dega*, rolling plain, gully erosion, steep slope terrain, dominated by forests.
2	Central plain	Dry *weyna dega*, moderately steep slope terrain, intensively cultivated smallholder rainfed farming, bare eroded soil, high population density.
3	Rolling plain	Dry *weyna dega*, gentle slopes degraded farmland, intensively cultivated, smallholder mixed farming.
4	Valley floor	Dry *weyna dega*; flat terrain, considerable irrigated agriculture, vegetables and fruit trees, sedimentation, roadside erosion, flooding.
5	Buffer zone of the freshwater ecosystem	Dry *weyna dega*, wetland, flat terrain, aquatic animals and plants (*Bofofe, Aware*), wetland dominated, few cultivated areas, pumping stations, high water contamination, sheet and rill erosion, high human and livestock pressure, water hyacinth, water-dependent investments.

Source: Author's creation.
Notes: In Ethiopia, this variation in climate is traditionally divided into three main climatic zones: *dega*, *weyna dega* and *kolla*. Dega refers to coldish, less than temperate zones with altitudes between 2,300 and 3,200 m. *Weyna dega* represent moderate temperature, wet and lies between 1500 and 2300 m.

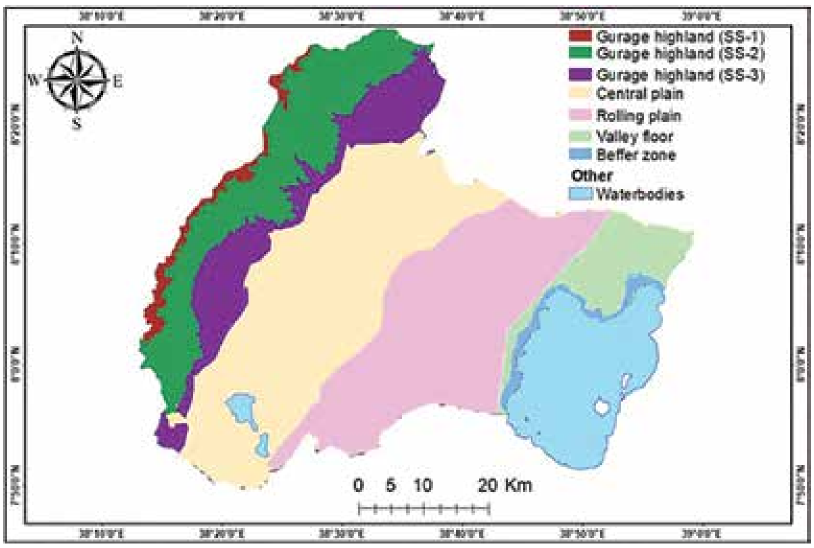


FIGURE 14. Spatial distribution of the five major strata of the catchment.
Source: Author's creation.
Note: SS stands for substratum.

3.5. Restoration Potential

Experience in Forest and Landscape Restoration

The results of the KIIs indicate that people in the catchment have been using forest and landscape restoration practices. Commonly used practices include biologically regenerated and assisted exclosures (e.g., 260 and 95 ha of exclosures in Adami Tulu Jido Kombolcha and Sodo Woredas), afforestation/reforestation, agroforestry, home gardens (Figure 15) and multiple soil and water conservation measures (e.g., stone bunds, microbasins, trenches and check dams). Agroforestry practices, particularly scattered trees on farmlands, are the dominant FLR intervention. Farmers keep native trees (e.g., *Acacia spp*, *Cordia africana*, *Croton* etc.) on their farms for shade, soil fertility enhancement and wood products (Figure 15). In addition to native trees, they also integrate multipurpose exotic tree species such as fruit trees around homesteads. Participants of the validation workshop suggested that production of rosemary (*Salvia rosmarinus*) around homesteads is becoming a common practice in the Gurage highlands, increasing the economic benefits obtained from home garden agroforestry practices.

Key informants and FDG participants said exclosures supported the rehabilitation of degraded communal lands. They further said that rehabilitated areas are becoming a source of income, particularly from the sale of grasses (e.g., annual income amounting 100,000 to 700,000 Ethiopian birr per kebele in Sodo Woreda). Restoration of degraded lands by establishing exclosures has increased availability of construction materials for health posts and schools. Other benefits mentioned by key informants were improvement of micro-climate and soil and biodiversity conservation (e.g., mentioned in Adele Mirt Meteja Kebele in Sodo Woreda) and increased access to water due to increased dry season stream flows (Adazer Kebele). Key informants and FGD participants in Duggda and Adami Tulu Jido Kombolcha Woradas said the importance of retaining *Aeschynomene elaphoxylon* (indigenous woody species locally known as *bofofe*) (Figure 15) to protect the lake from sedimentation and conversion of the lake shore to agriculture (Figure 15). The plant is also used for making handcrafts and locally made boats.

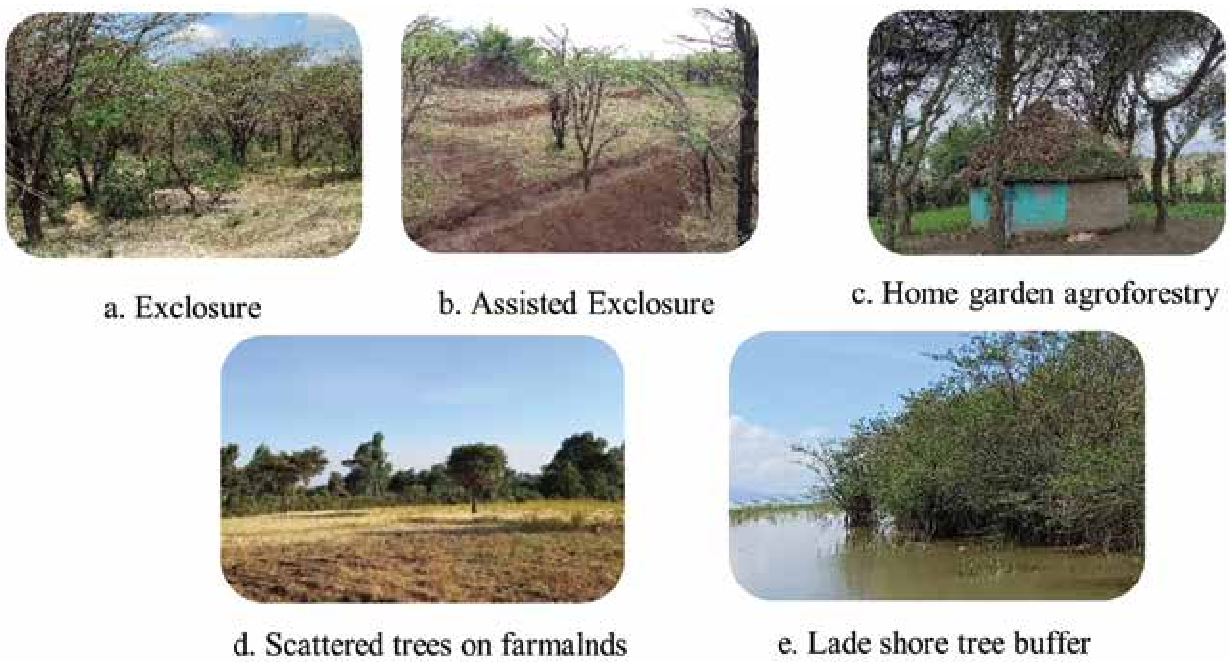


Figure 15. Multiple forest and landscape restoration measures: (a) exclosure established through natural regeneration; (b) assisted exclosures, (c) home garden agroforestry, (d) scattered trees on farmlands and (e) lake shore tree buffer.
Source: Authors creation.
Pix: Rediet Girma and Getahu Yakob

Identification of Forest and Landscape Restoration Measures

An essential step in ROAM is identifying context-specific FLR measures based on the experience of experts and local communities and the literature. FLR options that could be implemented are identified in Table 11).

TABLE 11. Forest and landscape restoration options identified for the catchment.

FLR option	Description
Exclosure establishment	Excluding degraded land from grazing, cutting trees, shrubs and cultivation to let vegetation regenerate, reduce soil erosion, increase rainwater infiltration, and increase biomass production.
Afforestation/Reforestation	Establish forests, such as natural high forests and woodlands, through reforestation, tree planting on land that recently had tree cover, or afforestation, tree planting on land that has long been deforested (Edenhofer, 2015). These interventions will reestablish forest ecosystem services.
Agroforestry	(a) Scattered trees on farmlands: plant/retain scattered trees on farmlands to increase the number of trees on existing croplands in high and mid-altitude areas. (b) Home gardens and woodlots: Expand private and small-scale production of wood (e.g., timber used in construction) and non-timber forest products (e.g., fruits, medicinal plants) for domestic and commercial use on communal and private land (MEFCC, 2018).
Expansion of highland and lowland bamboo	Restock existing natural bamboo forests and establish new ones in highland and lowland areas with suitable species.
Tree buffers around rivers, lakes, and wetlands	Develop and restock buffer zones around water bodies.
Tree buffers along roads and around town	Create rehabilitation programs to restore areas that were deforested due to the construction of roads, towns, and other infrastructure.
Buffer Plantations around National Protected Forest Areas	Increase tree plantations within 1,000 m of national parks and protected and priority areas.

Prioritization of Identified Forest and Landscape Restoration Measures

The results of the KIIs and the FGDs indicate that exclosures were considered the top priority for rehabilitation of degraded lands because of the multiple environmental and socioeconomic benefits, particularly in areas with high coverage of bare land such as Dugada, Sodo and Adami Tulu Jido Kombolcha Woredas (Table 12). Scattered trees on farmland (the dominant FLR measure in all surveyed woredas) and home gardens are preferred interventions across the entire catchment. Expansion of highland and lowland bamboo trees in Dugda, Sodo and Meskan was suggested as another option to restore bare lands. Retaining *Aeschynomene elaphoxylon* trees as a buffer zone to protect Lake Ziway from sedimentation and conversion of lakeshore to agriculture was the top priority for conservation and sustainable use of wetlands and freshwater ecosystems in Adami Tulu Jido Kombolcha and Dugda woredas (Table 12). Key informants also suggested that keeping trees along the lake buffer zone contributed to reduced deforestation, over grazing, unstainable agricultural practices and wetland degradation. The prioritization exercises indicated that there were similarities in most cases in relation to local community preferences for FLR options. However, there are some differences among woredas and considering these differences when planning and putting FLR measures into practice is crucial for sustainability.

TABLE 12. Prioritization of identified forest and landscape restoration options.

Land use	Woreda	Area (ha)	Local communities preference or ranking			
			First	Second	Third	Fourth
Bare land	Dugda	8,352	Exclosure	AFR	Lowland bamboo	
	ATJ K	3,114	Reforestation	Exclosure	Afforestation	Lowland bamboo
	Sodo	5,156	Exclosure	AFR	Highland and lowland bamboo	
	Meskan	752	AFR	Exclosure	Highland and low land bamboo	
Farmlands	Dugda	43,250	Trees on farmlands	Boundary planting	Agroforestry home gardens	Woodlots
	ATJ K	13,256	Trees on farmlands and alley cropping	Agroforestry home gardens	Boundary planting	Woodlots
	Sodo	36,626	Agroforestry home gardens	Trees on farmlands	Woodlots	
	Meskan	22,451	Trees on farmlands	Agroforesty homegardens	Woodlots	
Forestlands	Dugda	320	Participatory forest management	Restocking natural forest		
	ATJ K	79	Participatory forest management	Restocking natural forest		
	Sodo	3,139	Participatory forest management	Restocking natural forest		
	Meskan	5,661	Participatory forest management	Restocking natural forest		
Grasslands	Dugda	925	Silvopastoral	Exclosure		
	ATJ K	103	Exclosure	Silvopastoral*		
	Sodo	840	Exclosure	Silvopastoral		
	Meskan	521	Exclosure	Silvopastoral	Afforestation	
Settlement	Dugda	1,691	Trees along roads and towns			
	ATJ K	662	Trees along roads and towns			
	Sodo	781	Trees along roads and towns			
	Meskan	2,330	Trees along roads and towns			
Shurblands	Dugda	487	Exclosure	Participatory forest management	Lowland bamboo	
	ATJ K	103	Participatory forest management	Exclosure	Lowland bamboo	
	Sodo	1,832	Exclosure	Highland and lowland bamboo		
	Meskan	2,730	Exclosure	Afforestation	Expansion of bamboo	
Wetlands	Dugda	1,610	Exclosure	*Bobofe* tree buffer via exclosure	Ornamental trees	Lowland bamboo
	ATJ K	811	*Bobofe* tree buffer via exclosure	Ornamental trees	Exclosure	Lowland bamboo

Source: Author's creation.
Notes: ATJK refers to Adami Tullu Jido Kombolcha.
*Silvopastoral is an agroforestry system that integrates fodder trees and shrubs into grasslands.

Potential Areas for Identified and Prioritized Forest and Landscape Restoration Options

Based on inclusion and exclusion criteria (Table 3), potential areas for each FLR option were identified (Table 13). The spatial analysis confirmed that a given area could be suitable for multiple FLR options, suggesting that further consultation with communities and local-level practitioners is needed during actual planning and implementation of options. The results indicated that 40% of the study catchment is potentially suitable for agroforestry practices. The area identified for afforestation/reforestation was the least suitable, followed by tree buffers along wetlands and freshwater ecosystems, roads and buffers for National Forest Priority Areas. The estimated potential areas identified for each FLR option in each woreda is presented in Table 14. The spatial distribution of the different FLR options is presented in Figure 16.

Table 13. Estimated area of proposed forest and landscape restoration options.

No	Forest and landscape restoration options	Potential area	
		ha	Percent
1	Exclosure	73,010.9	24.5
2	Afforestation/Reforestation	18,197.5	6.1
3	Agroforestry on croplands	148,184.2	49.6
4	Highland and lowland bamboo	68,295.6	22.8
5	Tree buffers around rivers, lakes, and wetlands	2,511.4	0.8
6	Tree buffers along roads and around towns	56,664.1	19.0
7	Buffers for National Forest Priority Area	3,605.0	1.2

Source: Author's creation.

Table 14. Potential areas in each woreda for proposed forest and landscape restoration options.

Woreda	Afforest-ation Reforest-ation		Agro-forestry		Ex-closure		Expan-sion of bamboo		Tree buffer								Buffer around NFPA	
					Around wetland			Along rivers		Around lakes	Along roads							
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Adami Tulu Jido Kombolcha	1,655	9	10,585	7	3,176	4	2,798	4	103	22					3,640	6		
Bora	233	1	1,062	1	322	0.4	204	0.3	47	10					359	1		
Dugda	5,308	29	32,731	22	9,255	13	8,310	12	312	67	328	17			14,674	26		
Kersana Malima	170	1	1,508	1	2,123	3	1,610	2			23	1			357	1		
Seden Sodo	216	1	1,360	1	2,271	3	1,762	3							202	0		
Sodo Daci	18	0.1	871	1	539	1	661	1			15	1			502	1		
Debub Sodo	1,355	7	12,749	9	8,578	12	7,075	10			318	17			4,304	8	16	0.4
Eastern Meskan	518	3	5,684	4	1,684	2	1,743	3			106	6			4,643	8		
Gedebano Gutazer Welene															7	0.01	86	2
Mareko	1,784	10	16,853	11	4,468	6	5,186	8			166	9			8,503	15		
Meskan	263	1	10,130	7	8,717	12	8,387	12			176	9			6,224	11	2,626	73
Muhur Na Aklil			153	0.1	62	0.1											465	13
Sodo	4,229	23	23,950	16	15,569	21	14,279	21			379	20			6,001	11		
Alicho Woriro	93	1	1,123	1	1,485	2	1,139	2			0.3	0.01			186	0.3	412	11
Dalocha	53	0.3	1,151	1	531	1	343	1			8	0.4						
Eastern Siltie	603	3	5,341	4	1,723	2	1,958	3			82	4	83	48	2,919	5		
Lanfero	618	3	5,645	4	2,126	3	2,472	4			49	3	84	49	1,530	3		
Siltie	1,081	6	17,287	12	10,384	14	10,369	15			227	12	6	4	2,615	5		
Total	18,198	100	148,184	100	73,011	100	6,8296	100	462	100	1,876	100	173	100	56,664	100	3,605	100

= Non-potential wordas

Source: Author's creation.

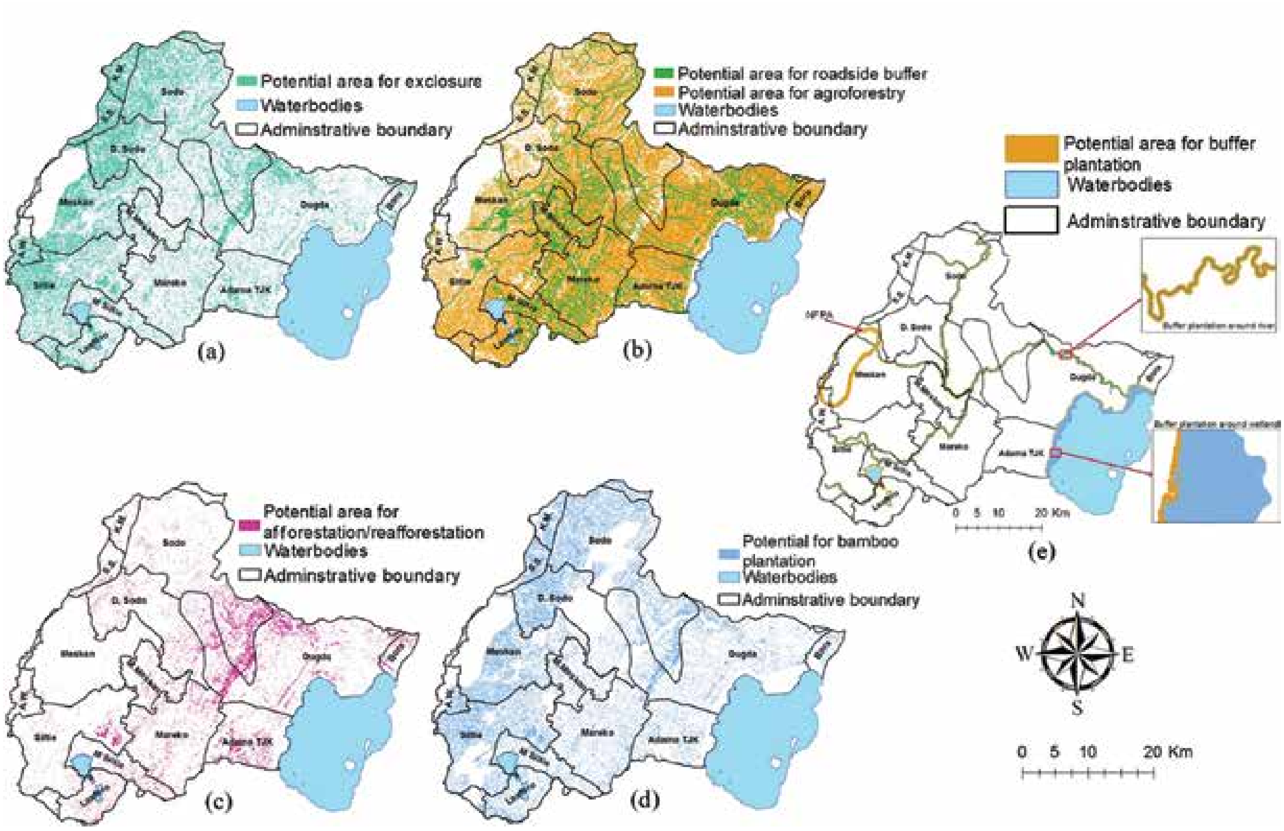


Figure 16. Potential areas for (a) exclosure, (b) agroforestry and buffers along roadsides, (c) afforestation/reforestation, (d) bamboo plantation and (e) buffer plantation around NFPA, river, wetlands and lake.
Source: Author's creation.

3.6. Ecological Benefits of Restoration Options

The above-ground biomass and carbon stock estimated using the allometric equation varied with FLR options. The mean above-ground biomass varied between 9 and 402 tha^{-1} (Table 15). The highest above-ground biomass was recorded in agroforestry home gardens, while the lowest value was recorded in trees scattered on farmlands (Table 15). The differences are mainly attributed to differences in tree density, height and DBH. Research showed that above-ground biomass is correlated with tree diameter (Clark et al. 2001; Chave et al. 2005; Pragasan, 2015) and height (Wang et al. 2021b). Encroachments were seen in most of the surveyed exclosures in the catchment. For example, at Meskan, farmers have been illegally expanding khat (*Chat edullis)* production in the exclosures. This could lead to the removal of big trees, which negatively affects above-ground biomass and carbon. The highest estimated mean CO_2 equivalent sequestered in the above-ground biomass was 737 tCO_2 eq ha^{-1} (Table 15), while the lowest value was 14 tCO_2 eq ha^{-1} (Table 15). The results indicated that FLR options have huge potential to sequester carbon and adapt to climate change (Stinson et al. 2011).

TABLE 15. Above-ground biomass and carbon stock estimates using field data under different landscape restoration interventions.

FLR	Woreda	Age (year)	AGB (tha⁻¹)	Stock (t c ha⁻¹)	t CO_2 eq. ha⁻¹
Buffer around lakes	Adami Tulu Jido Kombolcha	Unknown	162	81	297
	Dugda	Unknown	97	39	145
	Meskan	NA	NA	NA	NA
	Sodo	NA	NA	NA	NA
	Overall Mean		120±41	60±21	107±76
Exclosure	Adami Tulu Jido Kombolcha	19	9	4.5	17
	Dugda	18	58	29	106
	Meskan***	12	30	15	55
	Sodo	12	9	4.7	17
	Overall		27±11	13±6	49±21
Home garden Agroforestry	Adami Tulu Jido Kombolcha	20-45	305	152	559
	Dugda	25-45	414	207	759
	Meskan	30-40	416	208	762
	Sodo	30	474	237	868
	Overall		402±35	201±18	737±64
Trees on farmlands	Adami Tulu Jido Kombolcha	35-40	8	0.2	0.6
	Dugda	40-45	2.4	6	23
	Meskan	40-45	12	6	22
	Sodo	40-45	12	0.14	0.5
	Overall		9±2	4.5±1	14±4
Plantation	Adami Tulu Jido Kombolcha	NA	NA	NA	NA
	Dugda	NA	NA	NA	NA
	Meskan (Eucalyptus)**	13	59	30	108
	Sodo (Cuppressus)	38	117	58	214
	Overall		88±42	44±14	161±53
Bamboo	Adami Tulu Jido Kombolcha	NA	NA	NA	NA
	Dugda	NA	NA	NA	NA
	Meskan (Highland)	2-5	38	19	70
	Sodo (Lowland)	5	26	13	47
	Overall		32±6	16±3	59±12

Source: Author's creation.
Notes: AGB: above-ground biomass
*** High encroachment in the exclosure, such as for khat production, was observed during field surveys.
** Eucalyptus coppice was observed during field surveys.

Above-ground biomass was also estimated using biomass functions derived from NDVI. The spatial distribution of NDVI and above-ground biomass are presented in Figure 17. The results indicate that most (85%) of the catchment area displayed sparse vegetation cover (with NDVI values of 0.2– 0.4). The NDVI values gradually increase toward the highland (0.6 and above). Lower NDVI values (≤0) indicates the presence of bare land and water bodies. The estimated above-ground biomass followed similar patterns (Figure 17 b). The estimates varied between 0.1 and 237 tha^{-1} with a mean value of 87.2 tha^{-1}, which is lower than the value estimated using the allometric equation (113 tha^{-1}). Most (93%) of the catchment areas had above-ground biomass below 50 tha^{-1}, while areas with biomass between 50–100 tha^{-1} are comparatively smaller (6%). Areas with above-ground biomass below 50 tha^{-1} are the sparsely vegetated central and low-lying areas. Areas with higher biomass values occur toward the western highlands (Figure 17).

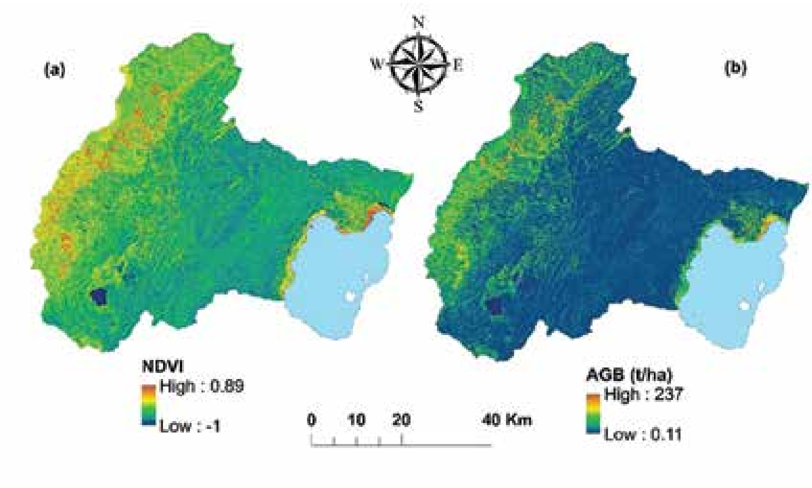


FIGURE 17. The spatial distribution of NDVI values (a) and above-ground biomass (b).
Source: Author's creation.
Notes: NDVI: Normalized Difference Vegetation Index; AGB: Above-ground biomass.

For economic analyses, we used the estimates from field data, as field measurements offer more accurate and site-specific data than GIS and remote sensing techniques. Remote sensing approaches provide large-scale coverage and continuous monitoring capabilities but rely on indirect estimates. Several factors can affect the accuracy of the remote sensing above-ground biomass estimations, such as atmospheric conditions, complex biophysical environments, spatial resolution and the algorithms used to develop the estimation models, among others (Ermias et al. 2021). Both methods are valuable and often used in conjunction, with field measurements providing ground truth data for validating and calibrating remote sensing estimates, ultimately improving our understanding of above-ground biomass and carbon sequestration dynamics at different scales.

3.7. Economic Viability of Identified Forest and Landscape Restoration Options

Physical Input, Output and Monetary Values

The physical inputs, outputs, and monetary values varied among the management options (Table 16). The study considered the investment costs for agroforestry practices (i.e., home gardens and scattered trees on farmlands) as zero, provided these practices are part of smallholders' agricultural practices. However, we considered the per hectare labor cost to harvest products in the analyses for both options (Table 16). We found the values were higher by USD 3.37 for scattered trees on farmlands compared to home garden agroforestry. These differences could be attributed to the differences in accessing trees. Managing trees planted around homesteads (i.e., home garden agroforestry) is relatively easy compared to managing trees scattered across farmland. This results in a difference in the cost of management. The cost of labor per seedling for weeding and cultivating trees scattered on farmlands was higher by

USD 0.05 compared to the costs associated with home garden agroforestry. The cost incurred for activities related to the management of trees (e.g., preparing planting pits, planting seedlings, weeding) in exclosures did not vary among other FLR options (i.e., among exclosures, afforestation/reforestation, and expansion of highland and lowland bamboo, which is USD 0.31). Some of the FLR options (e.g., tree buffers in wetlands (USD 0.50) and buffer plantations around national priority areas (USD 0.89) have relatively higher costs for tree management. This can be attributed to labor shifting from crop cultivation (opportunity cost) and a higher wage rate in and around towns. As afforestation/reforestation and buffer zones around National Forest Priority Areas are predominantly established through planting, they have additional costs for thinning, pruning and land preparation.

TABLE 16. Physical inputs, activities and market price (mean) per forest and landscape restoration option.

Inputs and activities	Exclosure		Afforestation/reforestation		Agroforestry (Home garden and scattered trees)	
	Quantity (ha^{-1})	Market price	Quantity (ha^{-1})	Market price	Quantity (ha^{-1})	Market price
Investment cost[6] (planning and Infrastructure) (ha)	1	13.48 (USD ha^{-1})	1	13.48 (USD ha^{-1})		
Seedlings of d/t trees (number)	2,500	0.26 (USD Pit^{-1})	2875	0.30 (USD Pit^{-1})	513	0.39 (USD Sed^{-1})
Planting pit preparation (number)	2,500	0.19 (USD Sed^{-1})	2875	0.19 (USD Sed^{-1})	1,068	0.24 (USD Sed^{-1})
Seedling plantation (number)	2,500	0.06 (USD Sed^{-1})	2875	0.06 (USD Sed^{-1})	1,068	0.24 (USD Sed^{-1})
Weeding and cultivation (no)	2,500	0.06 (USD Sed^{-1})	2875	0.06 (USD Sed^{-1})	65	0.24 (USD Sed^{-1})[7]
Labor for harvesting products (PD)	8	3.13 (USD PD^{-1})	20	3.13 (USD PD^{-1})	10	3.13 (USD PD^{-1})[8]
Monitoring and fire protection (ha)	1	111.66 (USD ha^{-1})	1	111.66 (USD ha^{-1})	1	111.66 (USD ha^{-1})
Fence, with angle iron and mesh wire (m)	400	10.92 (USD m^{-1})	400	10.92 (USD m^{-1})		
Fence maintenance (m)	400	0.84 (USD m^{-1})	400	0.84 (USD m^{-1})		
Guard (PD cost is per month)	3	36.1 (USD PD^{-1} Mo^{-1})	4	36.1 (USD PD^{-1} Mo^{-1})		
Soil and water conservation (soil/stone bund) (km)	0.6	577.56 (USD km^{-1})				
Soil and water conservation (microbasin or eye-brow basin) (number)	3,010	0.68 (USD km^{-1})				
Maintenance of Soil and water conservation works (ha)	0.5	96.26 (USD ha^{-1})				
Pruning (PD)			20	13.13 (USD PD^{-1})		
Thinning (PD)			20	13.13 (USD PD^{-1})		
Seedling of d/t species (fruit trees) (number)					556	1.69 (USD Sed^{-1})
Labor for tree management (PD)					556	1.06 (USD PD^{-1})
Fencing (fruit trees) (number)					65	1.06 (USD Sed^{-1})
Labor for area preparation (PD)			50	2.89 (USD PD^{-1})		

[6] Represents the cost of planning and infrastructure related to land preparation.

[7] If the agroforestry is scattered, 65 seedlings ha^{-a} can be managed (weeding) at a cost (market price) of 0.13 USD Sed^{-1}

[8] If the agroforestry is scattered, 13 PD ha^{-1} would be needed to harvest products at a market price of 6.5 (USD PD^{-1})

(Table 16 Continued)

Identified Inputs and Activities	Expansion of Bamboo		TBB on Wetland		Buffer Plantation around NFPA	
	Quantity (ha^{-1})	Market Price	Quantity (ha^{-1})	Market Price	Quantity (ha^{-1})	Market Price
Investment cost (planning and Infrastructure) (ha)	1	13.48 (USD ha^{-1})	1	13.48 (USD ha^{-1})	1	13.48 (USD ha^{-1})
Seedling of d/t trees (number)	4,000	0.48 (USD Sed^{-1})	1,750	0.34 (USD Sed^{-1})	5000	0.19 (USD Sed^{-1})
Planting pit preparation (number)	4,000	0.19 (USD Pit^{-1})	1,750	0.19 (USD Sed^{-1})	5000	0.06 (USD Sed^{-1})
Seedling plantation (number)	4,000	0.06 (USD Sed^{-1})	1,750	0.12 (USD Sed^{-1})	5000	0.06 (USD Sed^{-1})
Weeding and cultivation (number)	4,000	0.06 (USD Sed^{-1})	1,750	0.48 (USD Sed^{-1})	5000	0.77 (USD Sed^{-1})
Labor for harvesting products (PD)	14	3.37 (USD PD^{-1})	11	5.78 (USD PD^{-1})	18	2.89 (USD PD^{-1})
Monitoring and fire protection (ha)	1	111.66 (USD ha^{-1})	1	111.66 (USD ha^{-1})	1	111.66 (USD ha^{-1})
Fence, with iron angle and mesh wire (m)					400	10.38 (USD m^{-1})
Fence maintenance (m)					400	0.67 (USD m^{-1})
Guard (PD- cost is per month)	4	28.88 (USD PD^{-1} Mo^{-1})	4	57.76 (USD PD^{-1})	2	28.88 (USD PD^{-1} Mo^{-1})
Soil and water conservation (soil or stone bund) (km)						
Soil and water conservation (micro basin or eye-brow basin) (number)						
Maintenance of Soil and water conservation works (ha)						
Pruning (PD)					15	2.89 (USD PD^{-1})
Thinning (PD)					15	2.89 (USD PD^{-1})
Seedlings of d/t species (Fruit trees) (number)						
Labor for tree management (PD)						
Fencing (fruit trees) (number)						
Labor for area preparation (PD)					50	2.89 (USD PD^{-1})

Source: Filed survey, Focus Group Discussions and Key Informant Interviews, 2022–2023
Notes: Average exchange rate in 2022, 1 USD = 51.9425 Birr).
Abbreviations: d/t: different; PD: Person Day; NFPA: National Forest Priority Areas, Sed: Seedlings

The physical outputs and market prices for the identified FLR options are summarized in Table 17. The identified options provide both timber and non-timber forest products. These include fruits, livestock feed, fuelwood, charcoal, wood for construction, timber and wood for making farm implements. Among the benefits non-timber forest products are grasses harvested from exclosures and tree buffers around wetlands mainly used for making roofs. The results suggest that the volume of leaves harvested from trees scattered on farmland was lower by a value of 48 m^3 ha^{-1} compared to the volume of leaves harvested from trees found in home garden agroforestry. In addition, the selling price was less by USD 0.67 than for leaves harvested from trees in home gardens. This could be attributed to differences in the palatability of plant materials.

We assumed that differing amounts of products such as wood for fuelwood and charcoal production, grasses for livestock feed and honey are produced from different management options. For example, trees scattered on farmlands might produce less wood for fuelwood and charcoal production compared to home garden agroforestry. Similarly, assisted exclosures might produce more grass, fuelwood and honey than naturally regenerated exclosures (Table 17). This strengthens the importance of soil and water conservation (SWC) practices and enrichment plantations to generate more benefits from exclosures. Table 17 summarizes the total amount of carbon dioxide sequestrated in each FLR option over the project period of 20 years. According to the estimated carbon dioxide sequestration of each FLR option, the highest and smallest amounts of carbon were sequestrated in home garden agroforestry and exclosures (Table 15).[9] However, significant differences in the amount were detected within agroforestry practices.

[9] The Co_2 equivalent for each FLR option for 20 years is calculated using the mean carbon dioxide equivalent (tHa^{-1}) of the amount determined with the allometric equation (subsection 3.4.5). Accordingly, the mean and the total (for 20 years) sequestrated tCo_2 eq for each FLR option is summarized in Supplementary Material 14 and Supplementary Material 16.

TABLE 17. Physical products, outputs and market price (mean) per forest and landscape restoration option.

Products/outputs	Exclosure		A/R		Agroforestry (Home garden and scattered trees)	
	Quantity (ha^{-1})	Market price	Quantity (ha^{-1})	Market price	Quantity (ha^{-1})	Market price
Animal fodder/house construction (m^3) (Grass or leaf)	32.5[10]	140 (ETB/m^3)	25	150 (ETB/m^3)	60[11]	60 (ETB/m^3)
Fuelwood (m^3)	56.7[12]	300 (ETB/m^3)	86.3	245 (ETB/m^3)	105[13]	300 (ETB/m^3)
Honey (kg)	125[14]	425 (ETB/kg)	200	350 (ETB/kg)		
Round pole (tree/bamboo)	450	115 (ETB Unit^{-1})	725	120 (ETB Unit^{-1})		
Logs for timber production			350	340 (ETB Unit^{-1})	88	680 (ETB Unit^{-1})
Wood for charcoal production			613	125 (ETB Unit^{-1})	500[15]	140 (ETB Unit^{-1})
Fruit (kg)					463	40 ETB/kg
Construction wood (split poles)					50	100 ETB Unit^{-1})
House utensils (broom and cane/stick)						
Carbon sequestration for 20 years (tCO_2 equivalent ha^{-1})	686.70	23.18 USD	1,352.4	23.18 USD	4,670.40[16]	23.18 USD

[10] Indicates the amount of grass produced from an exclosure assisted with SWC and enrichment plantation. However, the exclosures assisted with only SWC practices pro duce about 28.3 m^3 of grass, while biologically regenerated exclosures produce up to 20.6 m^3 of grass.

[11] Indicates the amount of grass produced from home garden agroforestry. However, the FLR measure, scattered trees on farmlands, can produce up to 12 m^{-3} ha^{-1} with a market value of 0.48 (USD m^{-3}).

[12] Indicates the amount of grass produced from exclosures assisted with SWC and enrichment plantation. However, if the exclosure is implemented without any SWC or en richment plantation, the amount of fuelwood harvested would be 35.9 m^{-3}; if it is assisted only with SWC practices, it would be 47.5 m^3.

[13] Indicates the amount of fuelwood produced from home garden agroforestry. However, if the agroforestry is scattered, 15 m^{-3} ha^{-1} of fuelwood would be harvested and sold at a market price of 2.50 (USD m^{-3}).

[14] Indicates the amount of honey produced from an exclosure assisted with SWC and enrichment plantation. However, if the exclosure is implemented without any SWC or enrichment plantation or assisted with only SWC practices, the amount of honey harvested would be 75 kg.

[15] Indicates the amount of charcoal produced from home garden agroforestry. However, if the agroforestry is scattered, 5 tree ha^{-1} would be harvested for charcoal production and sold at a market price of 3.18 (USD Unit^{-1}).

[16] Indicates the amount of carbon sequestrated by home garden agroforestry. However, if the agroforestry is scattered, per hectare, 71.4 tCo_2 equivalent would be seques trated within 20 years and sold at a market price of 23.18 USD per tCo_2 equivalent.

Continued (Table 17)

Identified products/outputs	Expansion of bamboo		TBB on wetland		Buffer plantation around NFPA	
	Quantity (Ha^{-1})	Market price	Quantity (ha^{-1})	Market price	Quantity (ha^{-1})	Market Price
Animal fodder or house construction (grass/leaf) (m^3)	100	50 (ETB/m^3)	80.2[17]	410 (ETB/m^3)		
Fuelwood (m^3)			22	63 (ETB/m^3)	200	500 (ETB/m^3)
Honey (kg)						
Round poles (tree/bamboo)	890	13 (ETB $Unit^{-1}$)				
Logs for timber production					200	1,000 (ETB $Unit^{-1}$)
Wood for charcoal production						
Fruit (kg)						
Construction wood (split poles)					300	700 ETB $Unit^{-1}$)
Household utensils (brooms and cane/sticks)	1,800	90 (ETB $Unit^{-1}$)				
Carbon sequestration for 20 years (tCO_2 equivalent ha^{-1})	1,932	23.18 USD				

Source: Filed survey, Focus Group Discussions and Key Informant Interviews, 2022–2023.
Notes: Average exchange rate in 2022, 1 USD = 51.9425 birr.
Abbreviations: ETB: Ethiopian birr; NFPA: National Forest Priority Area

[17] The grass harvested as a product from a tree buffer as part of a wetland FLR option is sold as dried grass and used during house construction.

Economic Viability of Identified Forest and Landscape Restoration Options

The results of the economic analyses indicate that the discounted total benefit and costs per hectare associated with the restoration options, excluding the environmental benefits and costs, ranged from USD 212.47 to 16,156.95 and USD 120.55 to 10,201.27, respectively. The cost-benefit ratio ranged from 0.97 to 1.83 (Table 18), suggesting all FLR options, except the expansion of bamboo, are economically viable. Thus, most management options have the potential to be sustainably implemented. FLR options such as afforestation/reforestation and agroforestry practices appear to be the most attractive investments (Table 18). However, the analysis using the two basic criteria, net present value (NPV) and cost-benefit ratio, indicates the expansion of both highland and lowland bamboo is not attractive and showed a loss of about 126 USD per hectare. This is attributed to the low market price of bamboo poles in the local market, suggesting that value addition and working in a value chain is crucial.

Table 18 also captured the environmental benefits of each FLR option over the 20-year project period. The highest economic value was obtained from homestead agroforestry (USD 27,032.5), followed by the expansion of bamboo (USD 12,785.73). It is worth noting that including environmental benefits makes all management options economically viable, provided there are enabling environments to implement carbon financing.

TABLE 18. Discounted costs and benefits of identified forest and landscape restoration options (USD, 1 ha model).

Indicators	FLR Options						
	Exclosure	A/R	Agroforestry		Expansion of bamboo	Tree buffer on wetlands	Buffer plantation around NFPA
			Scattered	homestead			
Total Benefit (TB)	28,572.52	48,015.35	594.57	17,369.21	13,498.20	12,789.78	31,573.37
Total Cost (TC)	15,650.64	14,293.44	519.85	4,416.39	8,789.05	9,310.78	12,598.74
Net value (TB minus TC)	12,921.88	33,721.92	74.71	12,952.81	4,709.15	3,479.01	18,974.64
Total Benefit (Discounted)	10,269.73	16,156.95	212.47	4,828.06	4,753.20	4,768.46	8,656.01
Total Cost (Discounted)	10,201.27	8,821.68	120.55	2,742.87	4,879.44	4,373.20	8,090.64
NPV (Discounted)	68.46	**7,335.27**	91.92	2,085.19	**(126.24)**	395.26	565.37
Cost-Benefit-Ratio	1.01	1.83	1.76	1.76	**0.97**	1.09	1.07
Carbon Stock Benefit (CSB)	15,917.71	31,348.63	1,655.05	108,259.9	44,783.76		
Discounted CSB	3,974.65	7,827.76	413.27	27,032.5	12,785.73		

Source: Author's creation.
Notes: A/R: Afforestation/reforestation; FLR: Forest and landscape restoration; NFPA: National Forest Priority Area; TC: Total cost.

Social and Biodiversity Benefits of Identified Forest and Landscape Restoration Options

The results of the KIIs and the FGDs suggest that the identified FLR options could contribute to rehabilitating degraded lands and convert 'bad' lands into productive lands. One participant in a FGD elaborated on the environmental benefits of exclosure as, "bringing life back from grave" (FGD, Dugda Woreda). Some of the benefits mentioned by FGD and KII participants are summarized in Table 19. The respondents also ranked the options (Table 20). The results indicate that both afforestation/reforestation and exclosures were evaluated as the best options to improve both environmental and socioeconomic benefits, followed by agroforestry practices. The local communities rated buffer plantations around National Forest Priority Areas as the least preferred option in relation to both environmental and socioeconomic benefits (Table 20). Given the overall benefits of the FLR options (cost-benefit, carbon sequestration benefits, ecological and social benefit), the afforestation/reforestation and agroforestry are the best FLR options. This finding is consistent with the results of the economic analyses in that both afforestation/reforestation and agroforestry practices were economically viable with additional environmental benefits.

TABLE 19. Socioeconomic and environmental benefits of identified forest and landscape restoration options.

Forest and landscape restoration options	Environmental and ecological benefits	Socioeconomic benefits
Exclosure establishment	Regenerated grass and shrubs Recovery of degraded land Enhancement and reappearance of water resources (springs) Reappearance of disappeared wild animals Conservation of biodiversity Enhancement of microclimatic conditions	Increased crop and livestock productivity Increased grass (fodder) production Improved honey production
Afforestation/ Reforestation	Improved soil fertility Recovery of degraded land	Increased income through selling logs and poles Improved crop productivity
Agroforestry	Attractive and green landscape Improved air quality Enhancement of microclimatic conditions	Serves as shade for livestock Serves as a gathering place for farmers Enhances diversification of income Diversification of healthy and nutritious food
Tree Buffer around rivers, lakes and wetlands	Attractive and green landscape Improved air quality Enhancement of microclimatic condition	Enhance diversification of income Reduce unemployment by creating job opportunities for youth
Tree Buffers along roads and around towns	Attractive and green landscape Improved air quality Enhancement of microclimatic conditions	Reduce unemployment by creating job opportunities for youth
Expansion of highland and lowland bamboo	Enhancement of soil fertility Improved air quality Enhancement of microclimatic conditions	Diversification of income Reduce unemployment by creating job opportunities for youth
Buffer plantations around National Forest Priority Areas	Enhancement of soil fertility Improved air quality Enhancement of microclimatic conditions	Reduce unemployment by creating job opportunities for youth

Source: Author's own creation based on data from Focus Group Discussions and Key Informant Interviews at sampled woredas 2022–2023.

TABLE 20. Ranking of socioeconomic and environmental benefits of forest and landscape restoration options.

Benefits	FLR options						
	Exclosure	A/R	Agro-forestry	Expansion of bamboo	Tree buffers around wetlands	Tree buffers around towns	Buffer plantations around NFPA
Soil protection	++	+++	++	+++	+	+	+
Crop production	++	+++	++	+	+	+	+
Livestock production	++	+	++	+	+	+	+
Conservation of Biodiversity	+++	+	+	+	+	+	+
Water resource	+++	++	+	+	++	++	+
Social and cultural importance	+	+++	+++	++	+	+++	+

Source: Focus Group Discussions and Key Informant Interviews at sampled woredas 2022–2023.
Notes: +++ very high; ++ high; + low

3.8. Success and Failure Factors

Motivating Factors

The key motivating factors influencing the participation of actors include benefits, awareness and legal issues (IUCN and WRI 2014). The benefits generated from FLR options could inspire or motivate stakeholders to support restoration interventions. The results of the qualitative study suggest that the FLR measures could make an important contribution to the livelihoods of the people in the western catchment of Lake Ziway because they can provide food, non-timber forest products (e.g., honey, livestock feed, medicinal plants), fuelwood and charcoal, construction material, timber and farm implements. For example, the use of bamboo and *Aeschynomene elaphoxylon* for house construction and household furniture is common (Figure 18).

The identified FLR measures play an important role in securing water through increased water availability and reduction of sedimentation of waterbodies. FLR measures such as exclosures, for example, improve soil organic carbon and soil moisture conservation and facilitate groundwater recharge. The restoration options are also important for sequestering carbon and improving biodiversity. For example, focus group participants in Sodo Woreda reported how exclosures improved habitats for wildlife. However, it was also reported that exclosures harbor vertebrate pests such as wild boars that can damage crops.

FIGURE 18. Wood and nonwood products; a. bamboo mats, b. fuelwood; c. roofing material, d. handcraft materials made from lake shore plants from the existing FLR options in the catchment.
Source: Author's creation.
Pix: Rediet Girma and Getahu Yakob

In addition to benefits, the level of awareness that actors have of different initiatives influences their motivation. The results suggest that the idea of FLR as an approach is not clearly understood by key informants or FGD participants. A more comprehensive approach to awareness creation would help address the low sense of ownership in communities in the restoration processes and the misunderstandings that can arise about land use and forestry extension. Most FLR activities are focused on conservation (e.g., mass mobilization of watershed management) with little clear connection to livelihood issues.

Enabling Conditions

The diverse ecological conditions of the western catchment of Lake Ziway provide an opportunity to scale up FLR measures. The various indigenous trees (e.g., *Acacia* spp, *Croton spp*, *Cordia africana*) kept on farms and communal lands suggests the potential for FLR options. The presence of degraded communal lands could help to start wide-scale restoration options. The presence of permanent water sources, such as the Meki River that crosses various kebeles in Sodo Woreda could be an opportunity to establish new tree nurseries. There are various projects hosted in agricultural offices that provide technical and financial support to the implement FLR measures. For example, in Sodo and Meskan Woredas, the Climate Action through Landscape Management program supports integrated watershed development activities in selected catchments. The program supports biological soil and water conservation measures, reforestation/afforestation and promotion of agroforestry on croplands and home gardens. Some NGOs such as the Pro-development Network, World Vision, Wetlands International and Farm Africa support the implementation of FLR in most surveyed woredas. Most provide seedlings of improved fruit trees (such as *Persea americana*, *Mangifera indica*) and coffee to be planted around the homesteads. Some are involved in promoting soil and water conservation measures, small-scale irrigation and establishing tree nurseries. The validation workshop participants indicated that the existing beliefs, values, ethics and taboos of indigenous knowledge in Dugda and Adami Tullu Jido Kombolacha woreda could contribute to sustainable management and promotion of FLR options. For instance, the active participation of Aba Gedas, elders and religious leaders at every stage is highly beneficial in terms of implementing FLR interventions effectively.[18]

[18] Aba Gedas are highly respected cultural leaders in the Oromia region and Gedeo Zone in Ethiopia.

Policies supporting FLR measures could provide suitable conditions for implementing restoration options by providing clear and secure rights to, and tenure of, land and natural resources (IUCN and WRI, 2014). In Ethiopia, there are several policies supporting FLR measures, for example, the Ethiopia National Forest Sector Development Program (2016–2025). The aim of this program is to increase national forest cover to 20% by 2020 and 25% by 2025 through sustainable management of timber and non-timber forest products. As part of the Growth and Transformation Plan II (GTP II 2015–2020), the country included the Climate Resilient Green Economy Strategy. This strategy aims to achieve the country's development goal to reach middle-income status by 2025. As part of the 2011 Bonn Challenge and the 2014 New York Climate Summit goal, the Ethiopian government has also pledged to restore 22 million hectares of degraded lands and forest by 2030. Afforestation/reforestation, assisted natural regeneration and conservation and management of remaining forests are some of the strategies indicated in the document. Several soil and water conservation (SWC) and sustainable land management practices have been implemented across the country through sustainable land management programs (SLM) and the Climate Action through Landscape Management programs. In Ethiopia, SLM projects treated more than 860,000 hectares of degraded landscapes in 1,820 micro-watersheds between 2008 and 2018 (SLM 2020). Recently, the Green Legacy Initiative has been launched with a target of planting 20 billion seedlings in four years.

The presence of mandated institutes and offices and ongoing initiatives both at woreda and kebele level could contribute to scaling FLR measures. For example, the recent Green Legacy Initiative improved the trend of tree planting activities on communal and farmland and at schools, farmer training centers and religion institutions). The Office of Agriculture is the responsible institution for the implementation and coordination of most of FLR interventions. Forest development and rural administrations are also getting involved in some intervention such as afforestation/reforestation programs.

Constraints

Key informants and FGD participants reported low levels of implementation of existing proclamations and laws and this is affecting the implementation of FLR options. The informants stressed the importance of land-use policy to promote FLR interventions. For example, the existing tree buffer zone is increasingly being converted to agricultural land. Farmers do not have secure rights to the benefits that would accrue from restoration of communal resources such as exclosures and community plantations. Political instability (e.g in Meskan and Dugda) have been affecting restoration activities negatively. Informants reported weak and ineffective coordination among responsible institutions engaged in the implementation of FLR interventions (Bureau of Agriculture, Office of Forest Development, Office of Rural Land Administration and multiple NGOs). The presence or absence of planting material could also be affecting actors' motivation. According to key informants and FGD participants, farmers' access to planting materials, such as tree seeds and seedlings is limited. In all surveyed areas, the absence or inadequate number of tree nurseries was reported. For example, in Sodo Woreda, out of 36 kebeles, there are only four tree nurseries mandated to produce tree seedlings permanently (two government funded and two supported by NGOs). There are also few community-managed nurseries in the woreda (e.g., at Ejersa and Gemise kebeles). Due to the absence of nurseries for production of fruit tees, most surveyed woredas (except Meskan) have been importing seedlings (e.g., banana, mango, avocado and pome) form other areas.[19]

Human and financial capacities are the keys to putting FLR measures into practice. For example, the successful implementation of FLR measures requires effective leadership and transfer of knowledge (Slobodian et al. 2020). According to key informants, political commitment and leadership is not consistent across government agencies. Informants suggested that leadership at the grassroots level should be strengthened. Efforts to increase tree cover and translate Ethiopia's ambitious climate and sustainable development targets into action need further commitment. . Limited funding is reported to be a major bottleneck for FLR interventions. Incentive frameworks that actively promote forest and landscape restoration (for instance, for tree-grower farmers) are lacking. Duplication of effort among institutions was also reported by participants in the validation workshop.

[19] Pome is a type of fruit produced by flowering plants in the subtribe Malinae of the family Rosaceae.

3.9. Sources of Financing

Discussion with local communities and observations revealed a lack of financing for implementing FLR measures. However, the discussions with key informants and a literature search indicated potential financing mechanisms that could be tapped with relatively little effort by experts and political leaders. The study tried to link these potential financing options with the benefits of the identified FLR measures. The various financing mechanisms other than the regular budget are presented in Table 21. Potential financing mechanisms include revolving funds, payment for ecosystem services schemes, biodiversity and climate financing, compensation payments, establishing forest trust funds, urban and rural productive safety net programs, private and co-investment, agricultural credit and citizen contributions. The validation workshop participants suggested that income generating activities from Farmers Training Centers needs to be allocated for support FLR interventions.

TABLE 21. Financing mechanism for Identified forest and landscape restoration options.

FLR option	Financing mechanisms	Means of implementation
Exclosure	Implementing revolving funds	Providing revolving capital for farmers to use for livelihood activities. These include activities such as beekeeping and livestock fattening.
	Implementing biodiversity finance (payment for ecosystem services) (OECD 2010)	Providing capital (making payments) based on the level and intensity of rehabilitated tree species and reappeared wild animals for farmers who manage an FLR option.
	Ecotourism (Meselu et.al. 2022)	Hunting wild animals in developed exclosures with the benefit of generating income and controlling the size of herds and their impact. At the same time, the changed environment due to improved vegetation attracts both domestic and international visitors.
Afforestation/ Reforestation	Establishing forest trust funds	Providing soft loans (low-interest loans) for possible forest-based businesses in the forest value chain for farmers and private investors.
	Implementing climate financing	Enhancing farmers' awareness and transferring ownership of degraded land to conserve it through participatory forest management.
	Productive safety net program (rural)	Engaging people in need in community works of this kind as a regular funding process to enable households to receive payments over multiple years.
	Contract arrangements with private investors	Providing technical, technological and financial support to investors to plant preferred tree species using contract arrangements (building on the experience in Sodo).
Agroforestry	Private investment	Managing privately and jointly with communities for commercial purposes.
	Agricultural credit	Providing land for private investors to enhance the forest combined with apiculture or livestock fattening in adjacent forests on a large scale.
TBB around waterbodies	Implementing revolving fund	Providing capital which would be revolved within a specific period for farmers to use for livelihood activities (e.g., beekeeping and livestock fattening).
TBB along roads and around towns	Establishing a Green Climate Fund (government fund)	This is a way of financing FLR options with government budgets through a percentage of the total budget to mainstream the activities.
	Productive safety net program (urban)	Engaging the food-insecure households in the works of tree buffer plantations along roadsides and around towns.
	Crowd-funding (citizens contributions)	Raising funds through contributions from the public through donations or lending so that the FLR option will be implemented in an area.
Expansion of high and lowland bamboo	Private investment	Managing jointly with a community for commercial purpose.
Buffer plantations around NFPAs	Co-investments (multilateral investment institutions)	An investment between government and private investors. The government supplies land for free and the investor plants trees at their cost. Benefits are shared equally.

Source: Focus Group Discussions and Key Informant Interviews at sampled woredas, 2022–2023; Abebaw, 2019; OECD, 2010; Besacier et al., 2021; Meselu et al. 2022.
Notes: FLR: Forest and Landscape Restoration; NFPA: National Forest Priority Area; PSNP: Productive Safety Net program; TB: tree buffer.

3.10. Validation Workshop Feedback

The feedback from the validation workshop participants was constructive and helped improve the findings and recommendations. The summarized recommendations from the participants are presented in Table 22.

TABLE 22. Summary of feedback from the validation workshop.

Groups	Stratification of the study area	Potential and prioritization of FLR options	Suitability of FLR to the area	Success and failure factors and financing
Group 1	Accepted the study report.	Accepted the study report but suggested exclosures in bare lands should be assisted.	Accepted the report but suggested afforestation be given emphasis in Zebider mountain	Suggested financial sources: (a) community contribution for seedlings in nurseries; (b) using Farmer Training Centers for income generating activities; (c) financial penalties for individual failures to respect bylaws.
Group 2	Accepted the study report.	Suggested spice (rosemary) as an additional priority.	Suggested that afforestation and reforestation be recommended in the Guraghe highlands.	Accepted the report.
Group 3	The group accepted all stratifications.	Suggested that less capability for growing bamboo in the woreda is due to lack of experience.	Accepted the study report.	Awareness creation through training for Aba Geda, Tuluma, elders and religious leaders would be good. A failure factor is the absence of a clear land-use policy for buffer land.
Group 4	Accepted the study report.	Accepted the study report.	Accepted the study report	Success factors: Watershed development, Green Legacy Initiative, policy condition, and participatory approaches. Failure factors include a lack of integration and no incentives for tree growers.
Group 5	Questions raised: Why new land use, soil features not included in the map? Also suggested rivers and wetland buffer zones be shown.	Accepted the study report but suggested considering urban forestry and shade trees in settlement areas and appropriate species for appropriate sites.	Questions raised: Why are all the FLR options not shown on one map? Why not detailed assessments and recommendations for kebeles or smaller areas? Why no accuracy assessment in the Remote Sensing analysis?	Suggested duplication of effort, and lack of job creation as a failure factor and local institutions (idir, equb, church) and civil society as source of finance.

Source: Author's creation.

Note: Group 1: Sodo Zone and Woreda participants; Group 2: Meskan Zone and Woreda participants; Group 3: Dugda Woreda participants; Group 4: Adami Tulu Jiddo Kombolcha Woreda participants; Group 5: participants from federal ministries and NGOs

The suggestions and questions were considered during the discussion, and answers and clarifications were offered. All the concerns, comments and suggestions were analyzed and the following core points form the basis for the recommendations included in this final document.

i. The participants considered the report appropriate and useful for their respective areas. They would like to get the final report to put into use and as a resource for various ongoing watershed activities.
ii. The participants suggested implementing participatory forest management practices in existing natural forests for improved economic benefits and conservation. Therefore, we considered participatory forest management as one option in natural forest areas.
iii. Including rosemary to improve the agroforestry home gardens specifically in the Guraghe highlands is recommended.
iv. Additional success and failure factors incorporated suggestions from validation workshop participants and the subsections were strengthened.

4. Conclusion and Recommendations

This study was conducted in the western catchment of Lake Ziway, Central Rift Valley, Ethiopia. The aim was to identify FLR options, map potential areas, assess the costs and benefits of interventions and investigate the success and failure factors for implementing options. The study was based on the assumption that generating and documenting this information supports effective planning, design and implementation of FLR measures in the catchment.

The study employed both qualitative and quantitative methods to collect and analyze data. The western catchment of Lake Ziway has experienced severe forest and landscape degradation due to anthropogenic and climate factors, resulting in multiple environmental and socioeconomic consequences. This study identified seven context-specific FLR measures which vary in cost, trajectory and specific economic and social outcomes. Most of the identified FLR options were found to be economically viable with additional environmental and social benefits such as carbon sequestration. Exclosures were considered the preferred option to restore degraded landscapes, while agroforestry practices (home gardens and scattered trees on farmland) were preferred options to enhance the productivity of land and diversify livelihoods. The results suggest that integrated implementation of multiple FLR measures would maximize the environmental and socioeconomic outcomes.

The availability of adequate active labor, the diverse benefits of measures, the existence of supporting policies and strategies and multiple potential financing mechanisms are needed to create an enabling environment for successful implementation of the FLR options. We found that the adaptation of ROAM to the catchment scale supported the generation of site-specific data, consideration of local communities' interests and priorities and provision of context-specific suggestions regarding potential FLR options. The absence of guidelines for the implementation of legal issues, weak coordination among responsible institutions and inadequate finance and incentives were identified as major constraints to scaling up FLR measures. We offer the following recommendations for future actions.

- Prepare a site-specific management plan, coordinate efforts and incentivize active engagement of stakeholders to effectively implement FLR measures. A development plan should be prepared with development partners based on the recommended FLR options.
- FLR options suggested for the catchment should target both men and women equally, as both have equal proportions in the population structure of the studied catchment.
- FLR measures should be assisted by soil, water and conservation practices and enrichment plantations to generate maximum, sustainable economic benefits.

- Maximize the enforcement of existing policies and improve integration among stakeholders to maximize the economic and ecological benefits of FLR measures.
- Adopt adaptive management and regular monitoring with clear indicators for economic and ecological benefits to ensure the sustainability of interventions and benefits.
- Mobilize adequate financing and sustainable funding mechanisms to sustain FLR interventions.

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