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Restoring degraded landscapes and sustaining livelihoods: sustainability assessment (*cum*-review) of integrated landscape management in sub-Saharan Africa

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Introduction: Land degradation is a significant environmental challenge across sub-Saharan Africa. In recent decades, efforts have been undertaken, with varying successes, to rehabilitate degraded rural landscapes. However, there needs to be more evidence on the outcomes regarding enhanced productivity, environmental management, and socio-economic benefits.

Methods: This study uses a case study approach, using contrasting sites from Ethiopia and Mali to appraise restoration innovations implemented through various programs. Two distinct sites were chosen from each of the study cases, and an extensive literature search was conducted to document the evidence, focusing on the sustainability gains derived from integrated landscape management (ILM). For this, the sustainable intensification assessment framework (SIAF) was used, encompassing five domains, namely productivity, economic, environmental, social, and human condition, and featuring scales from plot to landscape, all facilitated by simplified yet robust indicators such as yield, soil loss, net income, land access, and food availability.

Results: Results highlighted a higher productivity gain (35% to 55%) and an improved socio-economic benefit (>20%). The ILM in the Ethiopian highlands enabled a significant improvement in wheat and barley yield ($p<0.01$). Introducing new crop varieties integrated with the *in-situ* and *ex-situ* practices enabled diversifying crops across the landscape and significantly reduced runoff and soil loss ($p<0.05$). By increasing the cultivable land by 44%, household income was increased by selling potatoes and agroforestry products. In Mali, ILM practices reduced soil loss to 4.97t/ha from 12.1t/ha. In addition to the improvements in the yield of sorghum and maize (33% and 63%, respectively), rehabilitating the once marginal and abandoned landscape in Mali enabled landless and female-headed households to work together, improving the social cohesion among the groups. The introduction of irrigation facilities enabled widowed women to increase household vegetable consumption by 55% and increase their income by 24%.

Discussion: The study showed positive evidence from ILM practices in the two contrasting landscapes. However, there is a need to address challenges related to the absence of timely data monitoring and documentation of successful practices. For this, the generation of evidence-based data and the use of advanced geo-spatial tools such as Remote Sensing and GPS-installed drones are recommended.

KEYWORDS

participatory research, degradation, sustainable intensification, sustainability indicators, restoration practices, landscape management, climate change, sub-Saharan Africa

1 Introduction

Land degradation is a significant threat to agriculture and food security in many parts of sub-Saharan Africa (SSA). Diminishing suitable agricultural land, soil erosion, and the continuous extraction of farm nutrients result in declining productivity and severe livelihood challenges to the agriculture-based communities of developing countries (Traore et al., 2017). By reducing soil fertility and agricultural yields, land degradation undermines livelihood security. As a result, communities already struggling to cope with the impacts of climate variability and change are trapped in a vicious cycle of conflicts, low farm incomes, poverty, and food insecurity (Amede et al., 2007; World Bank, 2019), making it difficult for SSA states to achieve sustainable development.

In SSA, land degradation is a complex challenge driven by many dynamic factors, including population growth and urbanization (AfDB, 2014), unsustainable agricultural practices, the conversion of pasture and forest lands to croplands, deforestation (Ussiri and Lal, 2019), and climate variability and change (IPCC, 2014, 2019). A history of food insecurity and poverty means that many governments have always focused on agriculture as a solution to both challenges. However, these well-intentioned efforts, through the expansion and intensification of agriculture, have inadvertently led to soil degradation and decreased agricultural productivity (Tully et al., 2015). Diminishing grazing and pasture lands restricts the traditional practice of livestock mobility and further drives the conversion of pastoral and livelihoods to sedentary farming, leading to severe land degradation and competition for scarce land and water resources; this has often led to conflict for pastoral communities and diseases moving more easily across livestock and people (Mackenzie and Jeggo, 2019). Deforestation for agriculture and fuelwood further exacerbates the problem, disrupting ecosystems and altering land cover (FAO, 2020). The prevailing land degradation problems are more complex when they happen across different land uses in fragile and ecologically sensitive landscapes that typify much of SSA; technological solutions alone do not provide lasting and sustainable solutions. This underscores the urgent need for sustainable and integrated land management practices that consider positive outcomes for people and the environment.

The problems need to be tackled through an integrated landscape solution that considers the balance of supply and demand, integration of production system and natural resource conservation, and socio-technical and socio-economic, local, and national objectives. Solutions must be driven from the description and analysis of the current context at farm and landscape scales and the co-design of strategic pathways for resilient, adaptive, and transformative interventions and action areas (Sanginga and Woomer, 2009). To ensure adaptation and sustainability of the solutions, planning and implementation of interventions have to be derived by community-led processes and partnerships with all interest groups (Bekunda et al., 2010). Despite being fragmented, sustainable landscape management practices are available in a few SSA landscapes with varying complexity, implementation status, and commitments by different actors at different levels. With support from the government and NGOs, smallholder farmers have improved traditional natural resources management practices (Dregne, 2002).

Landscape management and soil health recovery could successfully be achieved using existing, often traditional techniques and through affordable strategic management innovations at scale from individual fields to a more integrated system that combines technologies of soil, water, crops, livestock, and tree systems (German et al., 2007; Bado et al., 2022). For example, to restore degraded landscapes, implementing various soil and water conservation options in northern Ethiopia resulted in a significant decline in runoff and soil loss with a significant sediment yield reduction of 77% at the watershed level (Yaekob et al., 2020). Intending to manage torrential rains and flood water management, the once degraded landscape in the Afar region of Ethiopia (Amede et al., 2020) turned out to be a productive land for growing dryland crops (Getnet et al., 2020) and forages for livestock feed (Erkossa et al., 2020). The Ethiopian government restored several degraded areas through its watershed management program since the 1980s. Kibret et al. (2020) reported that restoration practices such as exclosure-based management are effective interventions to restore degraded lands and the associated ecosystem services. In Mali, landscape restoration practices focused on improvements in plant-available soil water, bridging dry spells, and shallow aquifer recharge by implementing soil and water conservation works (Traore and Birhanu, 2019). In other parts of West Africa, for example, Burkina Faso, the government planned to set up 120,000 ha of degraded lands treated using earthen benches (Hien, 2015). In Niger, landscape restoration techniques combine one or more agricultural technologies with land and water management practices. Half-moons, stone bunds, and benches were standard techniques at the farm level, while Farmer Managed Natural Regeneration (FMNR) has been widely considered a successful landscape restoration technique. Since the 1980s, 500,000 ha of degraded land has been covered by the FMNR technique in the Maradi region of Niger (Haglund et al., 2011; Sendzimir et al., 2011).

Other restoration techniques that are common in West Africa include the Zaï technology (Liniger et al., 2011), contour bunding combined with fast-growing tree species (Birhanu et al., 2022), and semi-circular bunds (Ray and Simpson, 2014). Zaï became popular in the early 1980s in the West African Sahel (Roose et al., 1999). Contour bunding technology was introduced in southern Mali in 1980 as a Soil and Water Conservation (SWC) practice to control erosion and improve soil fertility in many farm fields (Gigou et al., 2006). It provided multiple benefits of increasing crop yield (Traore and

Birhanu, 2019) and reducing soil water erosion by over 40% (Birhanu et al., 2022). Semi-circular bunds (SCB) are earthen embankments practiced in semi-arid areas for rangeland improvement (Ray and Simpson, 2014). They can increase crop yields by 112% (Hien, 2015). The bio-reclamation of degraded land (BDL) system is an integrated system aimed at increasing the food production and income of poor farmers (mainly women) by utilizing degraded lands to produce rainfed fruit trees and vegetables. The BDL is very popular in Niger (Bado et al., 2016).

Against this background, managing degraded landscapes in many SSA countries faces several barriers. Often, there are limited efforts to integrate natural resource management practices with agricultural intensification and livelihood options, and only some of the proven technologies and practices at the farm level can be implemented at scale successfully. In Ethiopia, for example, despite significant progress by the government to restore degraded landscapes, rural growth and poverty reduction have been critically hampered by land degradation in the past decade. A report by the World Bank (2019) highlighted that approximately 27 million hectares (ha) of highland areas are significantly eroded, and approximately 80% of Ethiopia's land surface is prone to moderate or severe soil degradation. In Mali, the aggravated land degradation is exacerbated by climatic changes and inaction due to several factors that complicate efforts to increase food production and security. The absence of timely data monitoring, documentation of successful practices, and identification of appropriate scaling options still needs to be addressed. Decision-makers require tangible evidence to believe in the success of technologies and practices for broader scaling. For this, it is imperative to record successful stories where integrated solutions have been co-validated with relevant stakeholders. The limited available documentation highlighted the challenges related to degraded landscapes in SSA and the efforts made by government and development programs. The major weakness is the lack of analytical study and associated documentation to scale proven practices. Therefore, this paper aims to present practical cases of landscape management practices from restoration innovations established under different research for development (R4D) programs and investigate the gains using the sustainable intensification assessment framework (SIAF) sustainability indicators. Case studies from Ethiopia and Mali were considered to provide valuable insights into the lessons learned, data management system, and potential challenges under contrasting scenarios and direct future landscape management approaches.

2 Materials and methods

The methodology employed for this study uses a mixed approach. It begins with a purposeful and selective decision to identify and investigate landscape management practices from restoration innovation sites established under different programs over the past decades across SSA. An extensive literature search based on the sustainability gains was conducted for the identified innovation sites to document the evidence, focusing on the sustainability gains derived from landscape management practices. Using data obtained on sustainability domains, namely, productivity, economic, environmental, social, and human condition, the sustainable intensification assessment framework was utilized to assess the effectiveness and multifaceted impacts of integrated landscape management practices across diverse contexts. Additionally, the experimental data collected at the watershed level enabled comparisons of the benefits of ILM practices over non-interventions. The details of the mixed approach are described below.

2.1 Study area identification and description

This study uses a case study approach, using contrasting sites from Ethiopia and Mali to appraise restoration innovations implemented through various programs. Two distinct sites were chosen from each study case based on available datasets and documentation. In Ethiopia, the Yewol watershed in the South Wollo Zone and the Chifra and Yallo sites in the Afar regional state were considered. In Mali, the study encompassed the Bougouni and Koutiala districts in southern Sikasso (Figure 1). Though each case study is quite distinct, for example, in terms of average household farm sizes (Table 1), persistent problems of land degradation, soil erosion, limited smallholders' access to sufficient resources to invest in agricultural intensification solutions, and lack of farm to landscape scale natural resource management are common in both cases. In Ethiopia, the study areas are in the highland sloppy catchment (>30%) with an elevation that ranges from 1,090 m to 3,170 m. Mali's relatively flatland characterizes the study site (with slopes less than 5%) and elevation ranging from 350 m to 400 m. Agriculture dominates the land use system in both countries, with mixed-crop livestock as the primary farming system (Table 1). Before the intervention practices, the study areas represented degraded, drought-prone, and poor soil fertility conditions.

2.2 Literature search

Major scientific websites such as ResearchGate, Google Scholar, and ScienceDirect were used to search literature on the sustainability gains of landscape management practices. The literature search did not impose a time limit but considered two case studies from Ethiopia and Mali, representing East Africa and West Africa, respectively, under contrasting conditions. Literature outside the two countries was considered on a limited case to show comparable advantages of implemented practices. Keywords used were 'degraded landscape,' 'agricultural productivity,' 'sustainable development,' 'integrated practices,' 'sustainable landscape management,' 'farmers perception,' 'Ethiopia,' and 'Mali.' Criteria for further screening of the search results were done based on criteria such as (i) the presence of innovation sites for validating and co-learning landscape management practices, (ii) community or end users' participation in the landscape management process, (iii) the existence of practices at different scale (field/plot, farm, and landscape), (iv) land use and land cover changes, and finally (iv) outputs that signify agricultural water and land sustainability options. Most of the articles (over 96%) used in the literature were published in the last 10 years, a period that signifies the establishment of the selected innovation sites in both countries.

2.3 Restoration innovation sites in northern Ethiopia and Mali

In the rainfed highland of northern Ethiopia, a good example of an innovation site is the Yewol mountain landscape's rehabilitation initiated in 2013. Landscape intervention practices were implemented jointly through public works of the Productive Safety Net Program (PSNP), where rural communities played an active role in the implementation process (Child et al., 2021). Activities were co-designed and driven by the needs of communities and local partners, and through local government support, approximately 7,500 hectares of degraded landscape were restored. In the co-designing process, integrated solutions of locally adaptive practices such as soil and water conservation, fertility management, improved crop and fodder varieties, contour ditches, and agroforestry practices were implemented through investing in public works. Another example of an innovation site is in the dry lowlands of Afar Regional State, where two learning sites were established in 2015 to benefit more than 200 agro-pastoral households. The region is a drought-prone area with low rainfall and high temperatures. The lowlands suffer from recurrent droughts and flash floods emerging from adjacent highlands. Flood-spreading weirs, an engineering structure aimed to divert and spread flash floods and create recession farming, were identified as innovative solutions to promote agro-pastoral intensification through food and fodder varieties in a purely pastoral farming system.

In Mali, under the Africa Research In Sustainable Intensification for the Next Generation (Africa RISING), innovation sites were

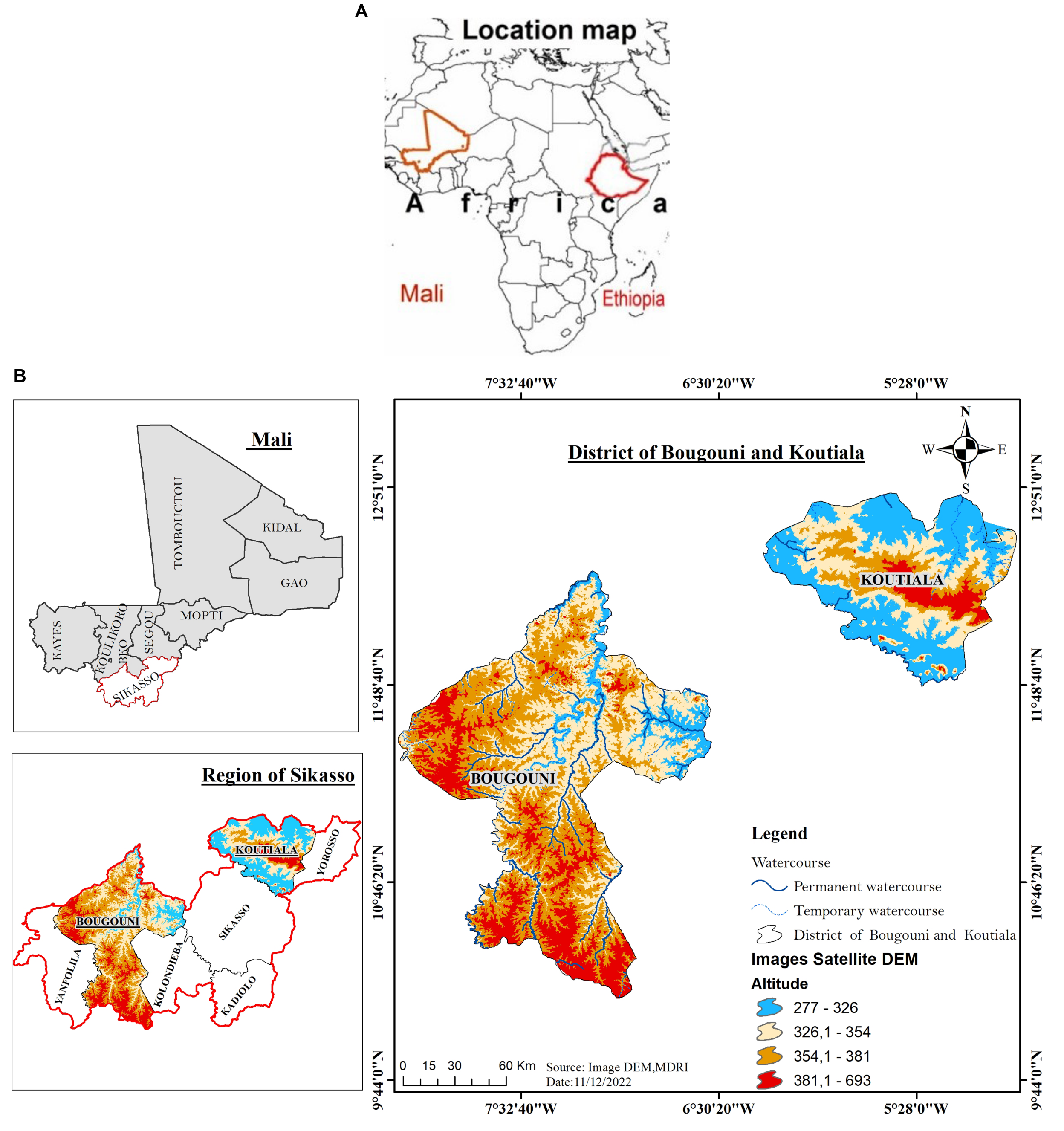

FIGURE 1 (Continued)

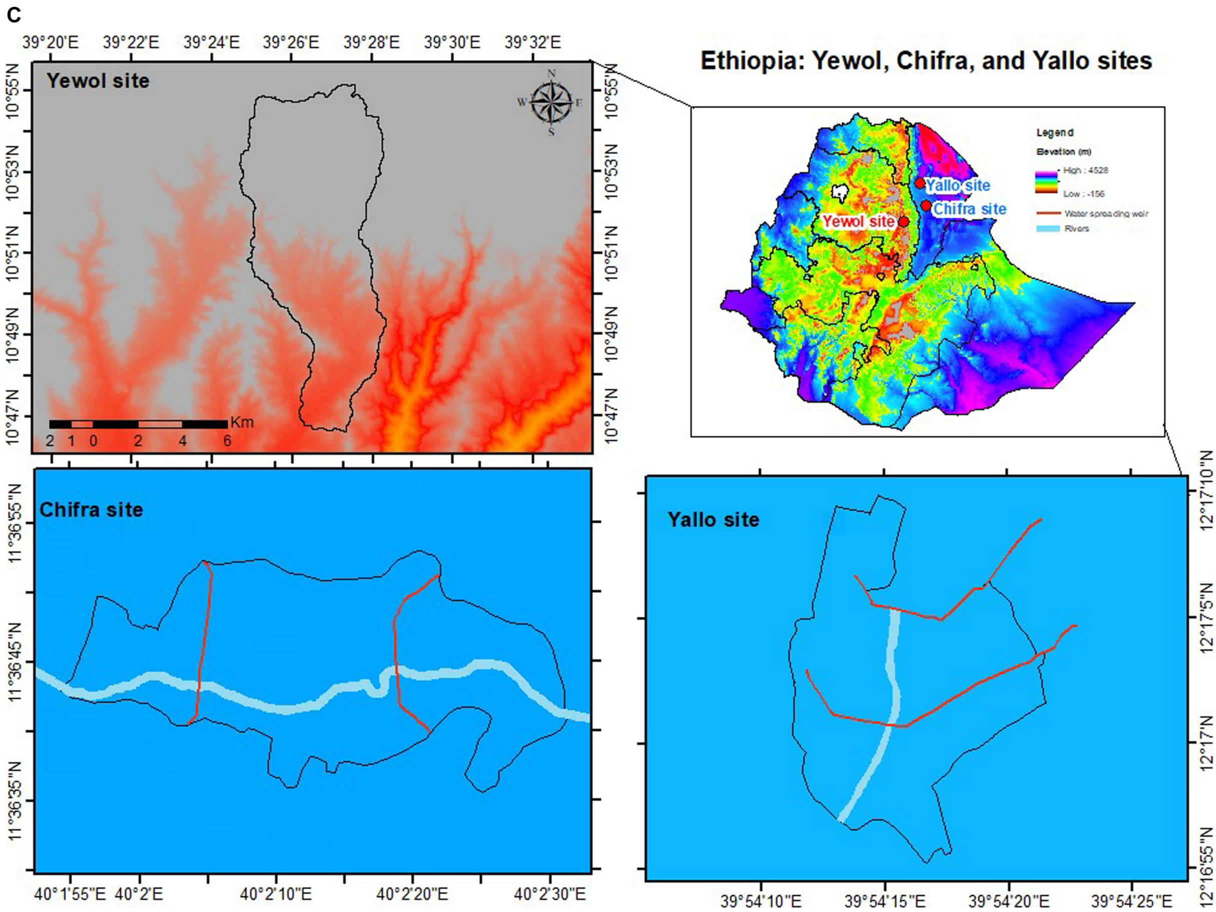

FIGURE 1
(A) Location map of Ethiopia and Mali, **(B)** Study sites in Mali (Bougouni and Koutiala districts of Sikasso region), **(C)** Study sites in Ethiopia (highlands of Wollo and lowlands of Afar region). Source: Birhanu et al. (2023).

established in the districts of Bougouni and Koutiala of the Sikasso region. The Africa RISING program commenced in early 2011 to showcase different technologies and practices through the inclusive engagement of government extension agents, NGOs, and R4D partners (Africa RISING, 2018). Reducing soil loss, enhancing water utilization, and integrating soil fertility management were a few of the expected outputs from the innovation sites (ICRISAT, 2022).

2.4 Assessment of landscape management practices using sustainability indicators

Evidence-based data monitoring and landscape management assessment help to demonstrate how socio-economic and environmental benefits are improving beyond productivity gains. We selected the Sustainable Intensification Assessment Framework (SIAF) with its comprehensive approach encompassing five domains, namely productivity, economic, environmental, social, and human condition, and featuring scales ranging from plot-level to landscape-level, all facilitated by simplified yet robust indicators (Musumba et al., 2017). This framework was chosen for its ability to provide a holistic and nuanced understanding of sustainable intensification, allowing us to assess the effective and multifaceted impacts of integrated landscape management practices across diverse contexts. Selected indicators and metrics for each domain were considered essential and present assessment methods to show broader implications and interactions of sustainability at multiple scales. Sustainability indicator outputs were adopted from previous works (Snapp et al., 2010; Zurek et al., 2015; Frelat et al., 2016). Table 2 presents the adopted approach for this study. Results were compared against the outputs obtained for each indicator in the traditional or non-intervention practice.

3 Results

Table 3 presents the multiple benefits of landscape management practices based on sustainability indicators for case studies. In Ethiopia, annual crop cover and application of green manure were integrated into *in-situ* and *ex-situ* management practices such as contour ridge tillage, hillside terraces, agroforestry, improved crop and fodder varieties, and water-spreading weirs. In Mali, implementing contour bunding and contour ridge tillage resulted in significant benefits over non-treated farms. For each case study, details of the analytical result based on the sustainability assessment and comparisons against non-intervention practices are presented below.

TABLE 1 Major biophysical and physiographic characteristics of the study sites in Ethiopia and Mali.

Country	Innovation site/ major challenge	Geographic coordinate			MAR* (mm)	Avg. Temp (°C)	Slope (%)	Major LULC	Major soil	Average household farm size (ha)	Average household number	Farming system	Reference
		Lon	Lat	AvEL** (m)									
Ethiopia	Yewol • Unreliable rainfall and intensive drainage system • Erosion and over-grazed land • Dissected and steep topography • Subsistence farming • Food scarcity	39.4	10.8	3,170	773	16.46	70% of the land mass is greater than 30%	Agriculture/ Crop cultivation	Cambisols/ Regosols/ Lithosols	0.45	5	Mixed crop-livestock	Amede et al. (2023) Alem et al. (2022)
	Afar • Recurrent drought • Torrential floods • Low rainfall and high temperature • Seasonal migration to search for water and pasture • Severe competition for biomass (livestock, soil fertility, and cooking)	40	11.61	1,090	300	27.8	Steep slope (>30%) in the upstream and medium to low slopes (<10%) in downstream areas	Degraded dry rangeland	Deep alluvial soils and gravel-dominated soils in degraded rangelands	2	ND	Pastoral and agro-pastoral	Getnet et al. (2020) Gumma et al. (2021)
Mali	Bougouni • Extended dry spell • Loss of ecosystem • Degraded arable land • Soils with heavy erosion risk, low water storage capacity, and poor drainage	11.42	−7.64	350	1,060	27.5	1.5–2%	Natural vegetation (59%), Agriculture (20%)	Regosols (62%), and Lixisols (37%)	8	14	Mixed crop-livestock	Sanogo et al. (2023); Birhanu et al. (2022); Birhanu et al. (2023); Dembele et al. (2021)
	Koutiala • Water scarcity • Unpredictable and unreliable rainfall • Degraded catchment and stream channels • Highly eroded topsoil • Arid and hot	12.67	−5.71	365	862	28.5	1.5–2%	Savanna rangeland (48%), Agriculture (35%)	Entisols (35%) and Lixisols (37%)	5	16	Mixed crop-livestock	

*Mean Annual Rainfall, **Average Elevation.

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TABLE 2 Description of sustainable intensification assessment framework, indicators, and data collection methods.

Sustainability domain	Analyzed system	Indicator	Metrics and scale	Data collection method	Critical input	Essential characteristics
Productivity	Major cropping system	Crop yield	Yield in Kg/ha/season (plot/farm level) Crop diversity (farm level)	Yield measurement	Land/Crop type	Increasing output per unit of input in a given period
		Crop biomass	Biomass production in Kg/ha/season (plot/farm level)	Biomass measurement		
Environment	Farm/Landscape	• Soil loss • Erosion • Groundwater recharge • Vegetation cover • Water productivity • Soil moisture	• Soil loss in tons/ha/year (field/plot) • Erosion in tons/ha/yr. (landscape) • Sediment load in % (landscape) • Improvement in groundwater level, water productivity, moisture, vegetation cover (farm and landscape)	Direct measurement/survey/model output	Soil/water	• Improved natural resource base supporting agriculture • Improved environmental services • Reduced pollution coming from agriculture
Economic	Household	Profitability	• Net income: total net income for all farm activities (household) • Marginal rate of return • Increments in irrigable and cultivable land	Survey	Land/Labor/Capital	• Profitability of practices • Returns to factors of production
Social	Household/Community	Gender Equity	Land access by gender, access to information, income by gender (household)	Survey/Focus group discussion (FGD)	Land/Livestock	Equitable relationships across gender and social groups
		Collective action	Participation in a collective action group (Landscape)	Survey FGD	Social groups	• Level of collective action • Ability to resolve conflicts related to agriculture and natural resource management
Human well-being	Household	Food Security	• Food availability in a year (household) • Access to nutritious food (household)	Survey	• Food type • Household size	• Meeting dietary needs for a productive and healthy life • Improved nutritional status through consumption or sale value

TABLE 3 Results of sustainable intensification assessment framework in the degraded landscapes of Ethiopia and Mali under different cropping systems and management conditions.

Study site/ primary cropping system/ intervention practice	Productivity	Environment	Economy	Social	Human well-being	Reference
Yewol (Ethiopia) Wheat • Hillside terracing • Implementation of contour farming • Annual crop cover and green manuring	• Yield improvement: Wheat by 142% ($p < 0.01$) (from 0.7 t/ha), barley by 100% ($p < 0.01$) (from 0.8 t/ha), and Faba bean by 66% ($p < 0.05$) (from 0.9 t/ha) • Crops diversity increased from 3 to 8 at the landscape level	• Runoff and soil loss were reduced on an average by 27 and 37% ($p < 0.05$), respectively (at plot level) • Sediment yield reduced by 75% ($p < 0.01$ at watershed level) • Increased recharge of groundwater • Vegetation cover increased from 13 to 29% ($p < 0.1$), and degraded rangelands reduced from 87% to just 28% ($p < 0.05$)	• An income of $140 per season from the sale of potatoes, $115 from agroforestry products • A five-fold increase in irrigable land (200 ha to 970 ha) • Increased cultivated land by 44% ($p < 0.05$)	• Improved land quality (soil moisture and nutrients) enabled a gradual change of degraded hillslopes to restored and productive mountain slopes. Hence, land allocation from communal use covered by grasses and shrubs to individual occupation. • A producers' cooperative was formed to support 69 unemployed youth in producing potatoes using emerging mountain springs. • Nearly 56% of women and 30% of men farmers send their children to school. • Additional livelihood assets acquired by women (11%) and men (9%) • Lessons learned are being applied to degraded land in at least 20 additional watersheds	Food security status improved by 31%, and reliance on food aid reduced by 39% compared to non-targeted communities in adjacent watersheds.	Yaekob et al. (2020); Alem et al. (2022); Gumma et al. (2021); Kane-Potaka (2015); ICRISAT (2018)
Afar (Ethiopia) Maize Participatory flood-based farming using water-spreading weirs	• Grain Yield increased by 3.5–5.8 tons/ha ($p < 0.05$) (from 1 ton/ha) • Biomass increased from 13.4–20.0 tons/ ha ($p < 0.05$) (from 7.0 tons/ha) • Fodder biomass stored for the dry months increased by more than 80% ($p < 0.01$).	• Coverage of cultivated and vegetation land increased from nil to 44 and 13 to 29%, respectively ($p < 0.05$). • Bare lands decreased from 87 to 28% of the area ($p < 0.05$).		• The gradual shift from predominantly communal pastoral land covered by grasses and shrubs to a fenced agro-pastoral farming system. • Community leaders negotiated with neighboring communities to protect crops from livestock. • Better skills were developed in new farming systems and agronomic practices. • Community groups produced sufficient grass biomass harvest and shared with neighboring communities		Amede et al. (2023); Gumma et al. (2021)
Koutiala (Mali) Sorghum Contour bunding Ridge tillage Solar-based irrigation system	• Grain Yield increased by 33% from 1,371 Kg/ha ($p < 0.05$) • Biomass increased by 42% from 3,402 Kg/ha ($p < 0.05$)	• Increase in Water Productivity (WP) from 2.4 to 3.2 Kg/mm ($p < 0.1$) • Increase in soil moisture at different soil horizon depths: 21% at 10 cm and 20 cm, 19% at 30 cm, 15% at 40 cm, and 13% at 60 cm and 100 cm ($p < 0.1$) • Average Runoff Coefficient reduced to 19.25% from 35.62% ($p < 0.05$) • Mean soil loss (farm level) reduced to 4.97 t/ha from 12.1 h/ha ($p < 0.01$)	• Increment in the net benefit by 24% (from $US201 to $US249) per year • The average marginal rate of return of improved practices was 5.13 • SBISs enabled household incomes to increase by over 40% ($p < 0.05$).	• After rehabilitating the once marginal and abandoned farmlands, landless female-headed households and widowed women came together to grow sorghum. • The introduction of SBISs enabled an increase in household vegetable consumption by 55%.		Birhanu et al. (2022); Traore and Birhanu (2019)

(Continued)

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TABLE 3 (Continued)

Study site/ primary cropping system/ intervention practice	Productivity	Environment	Economy	Social	Human well-being	Reference
Bougounu (Mali) Maize Contour bunding Ridge tillage Solar-based irrigation system	• GY increased from 63 to 87% from 1330Kg/ha in non-treated farms ($p < 0.05$) • On average, biomass increased between 64 to 71% in different test sites ($p < 0.05$).	• WP increased from 2.31 to 3.76 • In treated fields, 162 mm of rainfall per year was saved as soil moisture • Increase soil water infiltration in the sub-surface by 10% • Reduction of erosion loss by 73% • On average, 13 tons/ha of soil was lost in non-treated fields, and soil loss was reduced by 63% in farms treated with landscape management practices such as CBT ($p < 0.05$).	• Value Cost Ratio (VCR) due to CBT was 2.2 • Most farmers (78%) perceived higher income from selling crops grown on treated fields.	• Maize farming yielded the highest income at the household level after the introduction of contour bunds in farm fields. • Men have a high level of land ownership and hence control income on productions from farms with management practices. However, women in female-headed households indicated a high level of decision-making power concerning income.		Dembele et al. (2021); Birhanu et al. (2022)

3.1 Sustainability assessment for Yewol and Afar innovation sites in Ethiopia

Before intervention practices, yields of major staple crops such as wheat and barley in the Yewol watershed were stagnant at 0.7 tons/ha and 0.8 tons/ha, respectively. Crop yields increased significantly after introducing *in-situ* and *ex-situ* management practices such as hillside terraces, Fanya juu, and contour ridge tillage. Farmers could diversify cropping systems by adding other crops such as faba bean and potato into their farming practices. Compared with untreated plots, implementing management practices reduced soil loss in treatment plots (Table 3). In places where crop covers and green manuring were integrated, plot-level soil loss was reduced below 10 tons/ha (Desta et al., 2021). At the farm level, the introduction of new crop varieties (such as faba beans and potato) integrated with the *in-situ* and *ex-situ* management practices enabled a reduction of runoff and soil loss by 27 and 37%, respectively. Faba beans are nitrogen fixing and enhance soil fertility and if incorporated regularly into diets, enhance household nutrition. They are also relatively resilient to varied rainfall. By increasing the cultivable land by 44%, household income was raised by selling potatoes and agroforestry products (Yaekob et al., 2020). As shown in Table 3, farmers were able to obtain an income of $140 per season from the sale of potatoes and $115 from agroforestry products. This is an opportunity for Yewol watershed communities to benefit from the implementation of ILM practices. At the watershed level, significant improvements in sediment load reduction (by 75%) and groundwater recharge were observed (Gumma et al., 2021). The vegetation covering the entire landscape increased from 13 to 29%. A five-fold increase in irrigable land from 200 ha to 970 ha (Kane-Potaka, 2015) enabled improvements in the food security status of the Yewol community (additional benefits are presented in Table 3 and in ICRISAT, 2018).

In the dry lowlands of the Afar regional state, participatory flood-based farming using water spreading weirs (WSW) helped convert degraded dry rangelands to be productive and support diversified crop and fodder production. As highlighted in Table 3, the major staple crop (maize) grain yield increased by 3.5 to 5.8 tons/ha. Before the intervention, farmers were getting biomass yields of less than 7 tons/ha, with the use of WSW biomass of maize increased by over twofold (13.4 to 20 tons/ha). Additionally, the 80% increase in fodder biomass provided feed for calves and milking cows, reducing calf mortality from 35–40% to 5–8% in the dry season (Getnet et al., 2020). This is an important livelihood benefit to the livestock community of Chifra and Yallo communities in the Afar regional state. At the landscape level, increments in cultivable land (from nil to 44%), vegetation cover (from 13 to 29%), and reductions of degraded rangelands from 87% to just 28% were the environmental benefits gained by introducing flood recession farming (Gumma et al., 2021). Improved land quality (soil moisture and nutrients) benefitted the community by enabling the introduction of new dryland crops and fodder varieties into the flood-based farming system (Amede et al., 2023). The primary forage types utilized by farmers include desho grass (*Pennisetum glaucifolium*), vetch (*Vicia sativa*), and Napier (*Pennisetum purpureum*; Adie and Blummel, 2019). Additionally, pigeon pea and sesbania species were introduced to increase the amount and quality of available forage. Apart from utilizing them for feed, farmers utilized improved forage species for soil and water conservation (desho grass), fencing, and as a windbreak (sesbania and

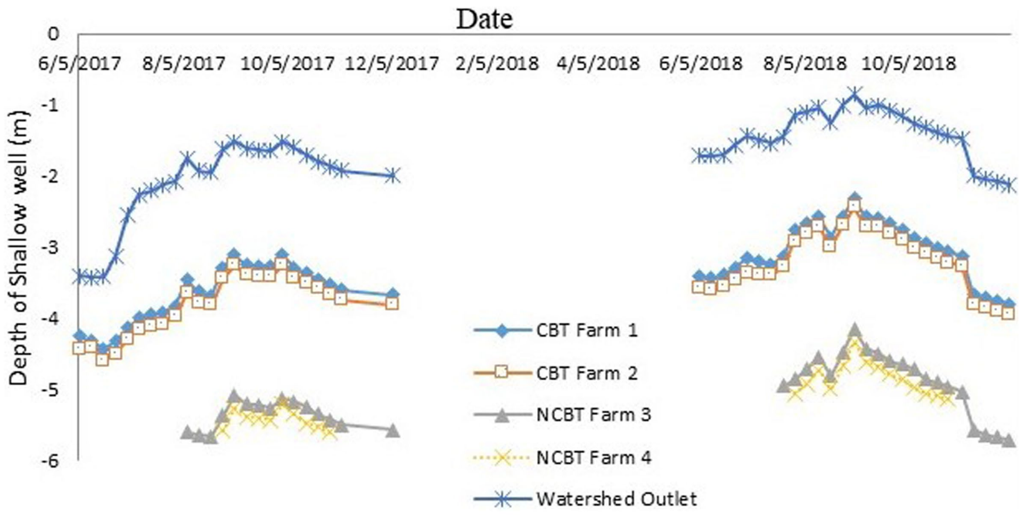

FIGURE 2
Variation in groundwater level at farm and watershed for agriculture fields treated with and without contour bunding technology. Source: Authors' data.

leucaena; Mijena, 2022). With fodder trees and shrubs, soil fertility was improved, and landscape level erosion was controlled. Additional benefits include the provision of firewood and timber. Challenges are related to the shortage of land, lack of capital to purchase improved forage seed, and poor extension services, among others (Zereu and Lijalem, 2016; Melese et al., 2019). A gradual change in land allocation from communal use covered by grasses and shrubs to a fenced agro-pastoral farming system enabled community leaders to negotiate with communities to protect crops from livestock (ICRISAT, 2021). Further, with water-spreading weirs, crop and fodder production could be scaled to over 1.27 million hectares in different seasons (Gumma et al., 2021). Such innovations co-validated at the learning sites are one entry option to support the government policy to expand dryland irrigated agriculture, for example, to the dry lowlands of the Somali and Oromia states (OICR, 2018).

3.2 Sustainability assessment for Bougouni and Koutiala innovation sites in southern Mali

In southern Mali, contour bunding technology (CBT) is the most widely adopted management practice from farm to landscape. Improvements in crop productivity, erosion control, and increased household incomes are a few of the reported benefits (Table 3). Regarding crop productivity, the introduction of contour ridge tillage in farmers' fields increased yield of sorghum and maize by 33, and 63%, respectively. Compared to non-treated fields, the biomass of sorghum and maize increased by 42 and 64% in the Koutiala and Bougouni innovation sites, respectively. The overall advantage of CBT technology was reflected at the household level by providing improved incomes. For example, the net benefit generated by sorghum production with contour bunding was about 24% higher than that generated without contour bunds (Birhanu et al., 2019). Improvements in water productivity and soil moisture at different soil layers, reductions in landscape runoff coefficients, and soil loss rates are some of the benefits of ILM practices (detailed data is presented in Table 3). The majority of communities living in the watershed (>78%) witnessed higher income by selling sorghum and maize crops planted on farms treated with contour ridges. Integrated landscape management practices combining trees and crops have helped manage agricultural resources and benefit from ecosystem services (Dembele et al., 2021). The most common tree species used for erosion control and dry-season livestock feed include *Leucaena leucocephala and Gliricidia Sepium.* Additionally, several tree species, such as *Vitellaria paradoxa*, *Parkia biglobosa*, *Adansonia digitata*, and *Tamarindus indica,* are left in farmers' fields to grow with crops to serve as a shed and improve soil fertility. In addition to the farm level and household benefits, CBT was evaluated at the watershed scale, with measurements performed on water table levels in 2017 and 2018. As shown in Figure 2, toward the end of the rainy season in October 2017, recorded water levels below the ground surface at the watershed outlet, CBT plots, and non-CBT plots were 1.52 m, 3.11 m, and 5.08 m, respectively. Improvements were observed after a year in 2018, where the respective recordings were 0.86 m, 2.44 m, and 4.33 m. CBT implementation and recharging of the subsurface soil moisture have implications for facilitating better water uptake for crops grown near CBT ridges, especially during the growing season in Mali, where dry spells are common. A recent study from the innovation sites by Sanogo et al. (2023) highlighted that the highest rates of erosion (7.8 to 17.53 t/ha/year) were recorded from landscapes without CBT and hence resulted in significant deficiency ($p < 0.05$) of soil nutrients in most untreated agricultural fields.

The analytical study using sustainability indicators enabled us to understand gender roles and decision-making power at the household level. In male-headed households, men have a high level of land ownership and hence control income on productions made from farms with ILM practices. However, women in female-headed households indicated high decision-making power concerning income. In most households (60%), household heads and adult males are primarily responsible for implementing ILM practices. Communities living in the innovation areas were beneficial in providing feedback regarding other management practices implemented at the landscape level. Socio-economic data from 112 farm households in the nine innovation sites in Bougouni and Koutiala enabled us to understand that water productivity was consistently higher in farms treated with ILM practices (Table 3). For example, solar based irrigation systems enabled local communities to increase household vegetable consumption by 55% and household incomes by 40% (Birhanu et al., 2023). Other studies conducted in the innovation sites at the plot level further enabled the understanding and usefulness of farm-based intervention practices, such as vegetable sack gardens to increase household income and nutrition (Badolo et al., 2022; Govoeyi et al., 2022; Tignegre et al., 2022).

4 Discussion

Land degradation has seriously threatened food security in most SSA landscapes. Successful remediation through improved natural resource management enables improvements in livelihood diversification in targeted, degraded watersheds. When proper interventions are implemented at different scales, the landscape can support enough crops and livestock to feed the local population (Musumba et al., 2017). Effective stakeholder collaboration, experimentation, and social learning combining scientific and local knowledge enabled communities in the innovation sites of Ethiopia and Mali to benefit from improved management practices and restore once degraded and unproductive landscapes. Improvements were obtained in crop productivity, food security status, erosion control, management of grazing lands, and improvements in surface and groundwater status (Birhanu and Tabo, 2016; Gumma et al., 2016; Umutoni et al., 2016). The success of specific ILM implementation lies in the proper identification and definition of the roles of stakeholders, their level of collaboration, and the required facilitations at different levels. Other possible factors are understanding the benefits of co-learning and identifying possible challenges to scale appropriate and proven ILM practices. Details are presented below.

4.1 The role of stakeholder collaboration and facilitation

Though the idea of having a standard operation unit, such as innovation sites, was common in the studied cases, the collective effort in rehabilitating degraded landscapes and co-validation of management at different scales were guided by specific contexts in the study cases. In Ethiopia, for example, integrated watershed management was considered a key area of intervention by the government to address developmental challenges related to land degradation. According to the World Bank report, four strategic operations were necessary to achieve these: (i) soil restoration, (ii) management of rainwater, (iii) land use and vegetation management, and (iv) diversifying livelihood options (World Bank, 2019). Thus, these different operations are implemented in a watershed approach through the community's multi-stakeholder collaboration and collective actions. The government's ambition was to deliver intervention practices in 5,000 community watersheds that cover 2.5 million hectares of land (9.3% of 27 million ha degraded area) until 2023.

In terms of collaboration the Yewol watershed community contributed 60 labor days per year at a household level, and, through the lead of the PSNP public work and technical support provided by different local organizations, the entire watershed (7,500 hectares) was terraced, and 2000 households have been benefitting with more food, higher incomes, and a revitalized environment.

In Mali, the implementation of landscape management practices was promoted by the Institut d'Economie Rurale (IER) and Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD; Birhanu et al., 2019). CBT was a landscape management practice introduced to improve agricultural productivity and erosion control. The CBT technology gained quick acceptance and was adopted by the Malian cotton company Compagnie Malienne de Development des Textiles (CMDT) to increase cotton productivity in southern Mali (Birhanu et al., 2022). The rollout of ILM practices considered watersheds a landscape comprising several micro-watersheds (Gumma et al., 2021; Amede et al., 2023; Sanogo et al., 2023). Practices such as terracing and earthen bunds are usually constructed in the upstream areas. The middle and lower parts of the landscape are for crops (e.g., sorghum and faba beans) and several soil fertility measures (intercropping and cereal legume rotations). Training activities are facilitated through extension agents and lead farmers at the watershed level (Birhanu et al., 2022; Amede et al., 2023). In most cases, married women are essential contributors to the agricultural labor force (Grosz-Ngaté, 2000; Doka et al., 2014). In contrast, for Malian households, decision-making on ILM practices (such as contour bunds) and economic benefits are controlled by the head of the household, who is usually an adult man (Birhanu et al., 2022). Documentation on gender dynamics is limited. The ILM practices were mainly conducted in several cases to capture excessive rainfall and maximize infiltration into the soil. A recent study by Abera et al. (2023) indicated that gender and social inclusion are rarely considered in landscape restoration studies in Ethiopia. Most studies and interventions are heavily focused on the biophysical and environmental aspects of restoration. Despite the importance of gender and social inclusion in supporting positive decision-making and outcomes (Leisher et al., 2016), scientific evidence on gender power dynamics and the role of social capital is lacking (Wossen et al., 2015; Abera et al., 2023). In some instances, the ILM approach is embedded in existing local coordination mechanisms, but the participation of women groups is limited. The study by Umutoni et al. (2016) in southern Mali highlighted that decentralized management of natural resources is dominated by a small group of individuals, often community leaders and elites. Women are marginalized and are not encouraged to participate in decision-making actively.

4.2 The advantage of co-learning

The co-learning from innovation sites enabled an understanding of the stability of crops under climate change conditions. In Mali, for example, by establishing innovation sites for technology co-validation and showcasing, it was possible to generate high-quality data for decision-making. Akinseye et al. (2023) utilized data collected from innovation sites in Mali from 2014 to 2021 to predict sorghum yield under changing climate scenarios. Accordingly, they reported that the yield of early maturing sorghum varieties will decline by 2.5 to 4% during 2010–2039, and a further decline by up to 5.7% would be expected in the mid-century scenario (2040–2069). In this case, helpful policy guidance was provided to adopt medium-maturing varieties that exhibit a high-yielding potential with a mean simulated yield of up to 12.2% in the near future. Other studies conducted at different scales highlighted how co-validation of technologies and participatory research at the innovation sites brought significant improvements in the management of soil, water, and integrated crop-livestock systems (Birhanu et al., 2019; Traore and Birhanu, 2019; Birhanu et al., 2022; Guindo et al., 2022). In Ethiopia, the experience obtained in the Yewol watershed paved the way to scale out integrated landscape management practices and community-led experiences to over 20 other adjacent watersheds.

4.3 Key highlights of sustainability assessment of landscape management practices

Evidence-based data monitoring and sustainability assessment helped demonstrate how landscape management practices improved the socio-economic and environmental benefits beyond productivity gains. Different sets of data collected in the domains of productivity, environment, social, economic, and human well-being enable the quantification of the gains in sustainability indicators to promote restoration practices and to comply with international climate change treaties such as the Paris Agreement in reducing GHG emissions. From 2020 to 2030, for example, the government of Mali has determined a mitigation scenario of reducing GHG emissions to mitigate national carbon emissions and build community resilience. By diversifying livelihood options, increasing soil fertility, reducing soil loss, and addressing rural energy security needs using renewable energy sources, the ambitious plan of reducing GHG emissions by 29% from agriculture, 31% from energy, and 21% from forest and land use change could be achieved.

4.4 Challenges to scaling landscape management practices

Several technical options exist to improve the sustainability of landscape management and reverse degradation. In most cases however, institutional, socio-cultural, economic, and policy barriers hinder adoption at a scale (Thomas et al., 2018). In the case study sites of Ethiopia and Mali, for example, the absence of quicker gains from restoration efforts discourages local communities from being fully committed. Additionally, NGOs and the private sector are less engaged because of initial investment risks. Other challenges are related to uncoordinated and sector-oriented development actions such as land tenure insecurity, inadequate data availability, limited technical support, and weak research-extension linkage (Haregeweyn et al., 2015; Fleskens, 2019).

In most African countries, policies promoting ILM exist; the challenge lies in pilot project-based projects with inadequate strategies for upscaling by the respective governments (Chirwa et al., 2015). Sometimes, the situation is global as well. In Sweden, for example, ILM practices are hindered by institutional and regulatory barriers and the timely availability of sufficient funds (Dawson et al., 2017). In Ecuador, the barriers to large-scale adoption of ILM (for example, Agroforestry) are rooted in the misalignment between small-scale farmers and beneficiaries at large (Buck et al., 2020). Mismatch of political cycles and the absence of proper restoration objectives were identified as scaling challenges in the ILM practices in Ecuador (Wiegant et al., 2020). In Ethiopia and Mali, successful restoration practices are documented from specific localities by specific studies with little luck in collecting long-term research data that supports designing and targeting sustainable action plans in the face of current and future climate challenges (Abera et al., 2023; Birhanu et al., 2023).

Competing interest in natural resource use and the absence of guiding bylaws in natural resource use management is another challenge worth mentioning (for example, Umutoni and Ayantunde, 2018). Promoting and broader scaling of ILM requires collective effort and commitment that includes government extension systems, NGOs, communities, and others interested in investing in management practices and combating long-term impacts (Dawson et al., 2017; Plieninger et al., 2020). For a successful scaling strategy, efforts are required to protect existing ecosystems and rehabilitate degraded areas. Additionally, investments in soil health, good agronomic practices, timely funding requirements, and monitoring practices are crucial (Mansuy et al., 2020; Peng et al., 2022; Abera et al., 2023). Often, there needs to be more balanced investments in the different sustainability options.

In most cases, extension service agents need upskilling and capacity strengthening for example through the farmer field schools (Fleskens, 2019), to enable them to utilize digital technologies to facilitate data monitoring and guidance of implementation practices. The study has been limited to two restoration innovation sites in Ethiopia and Mali. We recommend the inclusion of sustainability and livelihood gains from other SSA regions for more inclusive decision guidance in integrated landscape management practices.

5 Conclusion and recommendation

The study showed positive evidence from implementing integrated landscape management practices in the two contrasting landscapes of Ethiopia and Mali. Rural communities in the two areas have experienced tangible benefits from sustained productivity and household income increases. Regarding the environment, ILM practices in both study cases enabled better vegetation cover and reduced degraded rangelands. The success of restoration efforts hinges on the collective actions of diverse stakeholders. This is exemplified in the cases of Ethiopia and Mali, where government institutions, community mobilization and contribution, and research and development institutes have played a pivotal role in validating and demonstrating effective practices, albeit within a limited scope. To achieve lasting impacts at a regional or national level, efforts to scale up these practices must align with long-term government strategies and goals. The enhancement of rural livelihoods can be further achieved by integrating good agronomic practices (GAP) and leveraging a combination of technologies and landscape options at farm and landscape levels. The importance of generating evidence-based data and conducting regular visits to innovation sites cannot be overstated, as it enables decision-makers to appreciate the significant advantages of communities residing within restored ecosystems compared to control sites. Beyond traditional field-based monitoring, adopting advanced tools such as Remote Sensing and GPS-installed drones for recording and monitoring landscape-based implementation practices is increasingly crucial. These efforts are compelling incentives for attracting government and donor agencies to commit to longer-term funding and support at a scale. It is alarming that soil erosion, a leading cause of land degradation in many sub-Saharan African landscapes, is projected to increase by 40 to 70% annually. This underscores the critical priority of integrated landscape management as an adaptation strategy to the impacts of climate change. Practices that mitigate runoff and enhance groundwater recharge will become increasingly essential to enhance livelihoods and meet the rising demands for food and energy driven by a growing population, particularly under changing climatic conditions.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

BB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. GD: Formal analysis, Investigation, Methodology, Writing – review & editing. OC: Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Writing – review & editing. ST: Conceptualization, Methodology, Writing – review & editing. TM: Conceptualization, Funding acquisition, Methodology, Project administration, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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