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DISCUSSION

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Ensuring sustainable water security through sustainable land management: Research evidences for policy

Melku Dagnachew[1] | **Solomon Gebreyohanis Gebrehiwot**[1,2] | **Woldeamlak Bewket**[1,3] | **Tena Alamirew**[1,2] | **Katrina Charles**[4] | **Gete Zeleke**[1]

[1]Water and Land Resources Center, Addis Ababa University, Addis Ababa, Ethiopia

[2]Ethiopia Institute of Water Resources, Addis Ababa University, Addis Ababa, Ethiopia

[3]College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia

[4]School of Geography and the Environment, University of Oxford, Oxford, UK

Correspondence
Katrina Charles, School of Geography and the Environment, University of Oxford, Oxford, UK.
Email: katrina.charles@ouce.ox.ac.uk

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Abstract

Sustainable land management (SLM) practices is a key to reducing rates of land degradation and has proven to ensure water security by increasing soil moisture availability, decreasing surface runoff, decreasing soil erosion, increasing infiltration, and decreasing flood discharge. Land degradation is adversely affecting over 75% of the Earth's land surface and could exceed 90% by 2050. The rate of soil erosion will increase by 66% during the period 2015–2070. Over 85% of the land in Ethiopia is moderately to very severely degraded at an estimated cost of $4.6 billion annually. So far, only 18% of Ethiopia's cropland area is covered by SLM practices for the last 40 years of intensive interventions. Water security, in turn, is a powerful and multidimensional option that includes water availability, accessibility, use, and stability across time. In Ethiopia, though, the interconnections between SLM and water security are intimate and numerous, their linkage is very loose and yet to be understood. Ethiopia is among the 16 LDCs and is critically water-insecure, implying that abundant natural water availability does not necessarily ensure water security as it might be poor water quality, inaccessible, and unsafe. Hence, national and local level of SLM and water security linkages, impacts, and policy implications must come on board in the least developing countries like Ethiopia. Therefore, SLM-water security policy is crucial in successful SLM because governments/higher officials are capable of promoting well-informed water security decisions.

KEYWORDS

sustainable development goals, sustainable land management, water policy, water resource management, water security

1 | INTRODUCTION

Land degradation (LD) is one of the world's most pressing and pernicious environmental problems, happening at an alarming pace (Critchley et al., 2021; Nkonya et al., 2016) that can threaten future global water security (UNCCD & FAO, 2020). LD can be defined as *a degradation, impoverishment and long-term loss of ecosystem services* (AbdelRahman, 2023; Millennium Ecosystem Assessment-MEA, 2005); *depletion of both the quality and quantity of water resources* (Barbut & Alexander, 2016; Gebreselassie et al., 2016). Two thirds of Africa's productive land area are severely affected by LD (Ewunetu et al., 2021; Obalum et al., 2012; Perović et al., 2021). Land degradation takes many forms and affects water and land resources (Haregeweyn et al., 2023; Nkonya et al., 2016). It is mainly derived by numerous, complex, and interrelated (Critchley et al., 2021; Pani, 2020; von Braun et al., 2013) anthropogenic and/or natural proximate and underlying causes (Kirui & Mirzabaev, 2015; Lal & Stewart, 2013, 2019; Mirzabaev et al., 2015; Pingali et al., 2014). Ethiopia has been affected by a chronic and ongoing LD processes and forms (Hurni et al., 2010). The major proximate drivers are biophysical factors and unsustainable land management practices, while the underlying drivers are social, economic, and institutional factors that lead to unsustainable land management practices (Mirzabaev et al., 2015). Land degradation can diminish the natural capacity of the land to store and filter water leading to water scarcity, defined as *The lack of access to adequate quantities of water for human and environmental uses.*[1] LD also seriously affects water security indicators such as water availability, safety, quality, and quantity (Bossio et al., 2010). Human-induced land degradation and water scarcity are increasing the levels of risk for agricultural production and ecosystem services (FAO, 2022).

In Ethiopia, many researchers, land users, policy makers, and other research and development stakeholders have been trying to work on halting LD through SLM practices since the 1980s. With the ambition of reversing such LD and ensuring water security through SLM, the Water and Land Resource Centre (WLRC) established six learning watersheds in the Central and North-Western parts of Ethiopia in 2012. The intention was primarily to halt watershed degradation effectively through integrated SLM technologies. Sustainable land management (SLM) has been proven in reversing land degradation and ensuring water security by increasing soil moisture availability, decreasing surface runoff, decreasing soil erosion, an increased infiltration, and decreased flood discharge (Ebabu et al., 2019; Eekhout & de Vente, 2019; Mersha et al., 2022a). SLM[2] is fundamental to halt LD processes (Akinyemi et al., 2021; Ziadat et al., 2022) and thereby improving water security (Eekhout & de Vente, 2023; Huggel & Drenkhan, 2023; UNCCD & FAO, 2020). Nationally, in Ethiopia, SLM started as a national program since 2008 with the striving to reduce LD and improve land productivity in selected watersheds in targeted regions in Ethiopia (World Bank, 2020). In Ethiopia, Haregeweyn et al. (2015, 2023) reported that most of the interventions were not sufficiently implemented in the selected SLMP sites. Moreover, through the collaboration between WLRC, the University of Oxford, REACH's work has been investigating the role of SLM activities in securing water for livelihoods and household use. The outcomes of these findings are capable of shaping regional and national level agendas on SLM for water security, leading to improvements in rural and urban areas. Nowadays, SLM is widely distinguished as the key for improving water security (Critchley et al., 2021; Eekhout & de Vente, 2023; Fikadu et al., 2022; Huggel & Drenkhan, 2023; Naafs et al., 2020; UNCCD & FAO, 2020). However, positive impacts of the nexus-oriented watershed management interventions included 56% increase in food security, 63% increase in surface and groundwater resources, sediment accumulation behind bunds (up to 65 t ha^{-1} $year^{-1}$), and 80% reduction in soil loss (Tesfahunegn & Ayuk, 2021). However, only 18% of Ethiopia's cropland area is covered by SLM practices for the last 40 years of intensive interventions (Hurni et al., 2015). In Ethiopia, >50% of all cropland still needs to be conserved using SLM practices, as 77% of the cropland shows a slope >8% demanding a total of 44 billion Ethiopian Birr (2014) (Hurni et al., 2015). Therefore, identifying suitable SLM practices is crucial for the prevention, reduction, and restoration of LD processes (Abera et al., 2019; Ebabu et al., 2019; Mitri et al., 2019). The government of Ethiopia's and other NGOs' effort to implement SLM wholly relied on conserving soil and water resources; the effect of SLM with respect to water security has not yet been given much attention and has not been well addressed.

In Ethiopia, very few studies have been conducted to quantify the impact of SLM on water security. For instance, Schmidt and Zemadim (2015) reported that SLM investments showed improvements in infiltration, decreases in surface runoff, and decreases in erosion in the Mizewa watershed, which could contribute to water security. Various findings also depicted that SLM can contribute to various sustainable development goals, such as food security (Branca et al., 2013; Ewunetu et al., 2023; Yimer, 2015) and water security (Bob et al., 2021; Calow et al., 2013; Kato et al., 2019; Mersha et al., 2022a, 2022b). However, very limited evidences have been reported on the impact of SLM practices for water security at watershed and basin levels in Ethiopia. Moreover, the impacts of SLM practices on water security have not yet well investigated and documented. Hence, it is highly imperative to have empirical evidences that clearly show the impact of SLM for ensuring water security from local to national level. Hence, there is an urgent need for evidence-based SLM impacts on water security, using more reliable data and robust SLM practices. Hence, adequately strong policy action for SLM is lacking, and a coherent and evidence-based policy framework for action is missing. Therefore, the objective of this paper is to review and analyze the linkage between SLM practices and water security at national level to deduce policy inputs.

2 | METHODS AND APPROACHES

This section describes the methods used for identifying literature, including selection criteria, types of literature included, and processes for collecting literature. The approach of the literature review was to collect sufficient information to capture the general dynamics of SLM interventions in relation to water security in improving human well-being. The review was guided by aspects of the "Target Review" (TR) guidelines. A "targeted review" is a type of narrative review that includes a synthesis of both qualitative and quantitative research on SLM and water security. This differs from the website systematic review in that we are able to include key articles identified by experts as well as those identified from a search of electronic databases of published literature. Secondary data were collected through review of relevant materials including articles, theses, conference presentations, and other documents available on the internet. The documents were identified through a combination of searches, using keywords and terms associated with SLM and water security. These included LD, land management, SLM, water security, and sustainable development goals without publication date restrictions. No date was imposed on the search as priority was given to the relevance of the materials in terms of their substantial contribution to the ongoing discourse on SLM and water security, irrespective of the age of the material. However, recent literatures were made to capture in order to reflect the currency and increasing relevance of the topic. In this regard, three types of literature were used: (i) International Academic Literature, which includes articles in journals that are published by a publishing company or organization and have undergone peer-review; (ii) academic literature published in various locations of Ethiopia including hard copies of academic literature published that are kept in university libraries, public libraries, and the libraries; (iii) gray literature: purposefully selected relevant and high-quality gray literature documents to include in the review. The publications were to focus on the contribution of SLM for water security to ensure either and/or both of environmental, economic, and social sustainability of the community. Importantly, the publications that focused on multidisciplinary studies on SLM and water security were given priority.

3 | SLM FOR WATER SECURITY-WITH THE CONTEXT OF ETHIOPIA

Actions to halt land degradation can be broadly classified as prevention, mitigation, and restoration interventions (Zucca et al., 2012). According to Sanz et al. (2017), the United Nations (UN) 1992 Rio Earth Summit defined SLM as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions." WOCAT defined SLM as: "The use of land resources including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and ensuring their environmental functions" (Liniger et al., 2013).

There are numerous SLM practices (Technologies: consists of measures, such as agronomic, vegetative, physical, and management measures, and Approaches: ways and means used to implement SLM Technologies, including technical and material support, stakeholder engagement) (Rudiger et al., 2023), which can help to address water security. According to Haregeweyn et al. (2023), 1900 SLM practices have been reported in 129 countries globally, implementing as many as 169 SLM technologies. Africa and Asia showed the greatest number of SLM practices, with a total of 699 and 700, respectively, jointly accounting for 70% of total global SLM coverage. The East African region accounted for about 45% of implemented SLM practices. In most rainfed regions, SLM practices can be tailored to improve water management and security (Bossio et al., 2010). In Ethiopia, SLM has been promoted for the last few decades since the 1980s (Bob et al., 2021; Desta et al., 2005) to address LD due to soil erosion, nutrient imbalances and other factors adversely affecting land productivity. Despite the increasing need for addressing LD, investments in SLM remain limited, especially in low-income countries (Issahaku & Abdulai, 2020; Kansanga et al., 2021). For example, in addition to farmers' effort, Ethiopia needs a total of nearly 44 billion birr to invest SLM technologies on sloppy cultivated land for the next 30 years (Hurni et al., 2015). In Ethiopia, sustainable management of land resources, particularly soil and water, is of paramount importance for ensuring water security.

Water security has emerged as a leading framework in water resource management and governance (UNESCO & UNESCO i-WSSM, 2019) that integrates physical, social, political, and economic attributes (Albrecht & Gerlak, 2022; Biswas & Tortajada, 2022, 2023). Water security is a powerful and multidimensional option that includes water availability, accessibility, use, and stability across time (Miller et al., 2021; Miller & Young, 2023; Young et al., 2021). Water security is a key to planetary resilience for human society to flourish in the face of global change (Keys et al., 2019). In the framework of UNESCO's International Hydrological Program's (IHP) Strategic Plan, Water Security was globally defined as "The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human wellbeing, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (ESCAP, U. N., 2013; Kaur et al., 2023). This implies that water security is a cycle with the implication of multiple interconnected and interdependent sectors or dimensions at local, national, regional, and global scales (Moumen et al., 2019). Addressing water security concerns requires more comprehensive planning, policy and management, technological innovations, and closer collaboration across sectors, communities, and political borders (United Nations University, 2013; Zeitoun, 2011). On the hand, water insecurity, defined as "The lack of sufficient water of good quality to meet basic human requirements and can be broadly conceptualized across the domains of access, affordability, adequacy, reliability, and safety" (Jepson et al., 2019; Ray & Shaw, 2019; Tallman et al., 2023), leads to the inability to access and benefit from affordable, adequate, reliable, and safe water (Jepson et al., 2019; Stevenson, 2019; Stevenson et al., 2012). Hence, evidences depicted that poor and unsustainable land management techniques also worsen the situation.

Nowadays, water security, aims simultaneously to guarantee the three pillars of sustainability (economic, social and environmental), is most commonly understood through four key dimensions, namely, economic welfare, social equity, long-term sustainability, and water-related risks (Hoekstra et al., 2018; Marttunen et al., 2019). Water security has four domains such as availability (refers to the physical existence of water), accessibility (acceptable and safe water for all), use, and stability (or reliability; refers to the continuity of availability, access, and use without change across time) (Gain et al., 2016; Young et al., 2021; Figure 1). Despite the well-researched overall benefits of SLM practices, the collaboration between WLRC and the University of Oxford has shed critical insights on the water security benefits, and the gendered and water quality challenges that remain. In order for communities to fully and equitably benefit from SLM practices, barriers must be addressed and should be part of the SLM design. In this regard, REACH-improving water security for the poor internal meetings in Ethiopia (2017) and in Oxford (2019) have played a central role in ensuring cross-learning and discussion on water quantity and quality. Moreover, researches have been attempted to quantify the impact of SLM for water security (Fikadu et al., 2022; Mersha et al., 2022b). Access to safely managed drinking water and sanitation is still a pipe dream for more than half the global

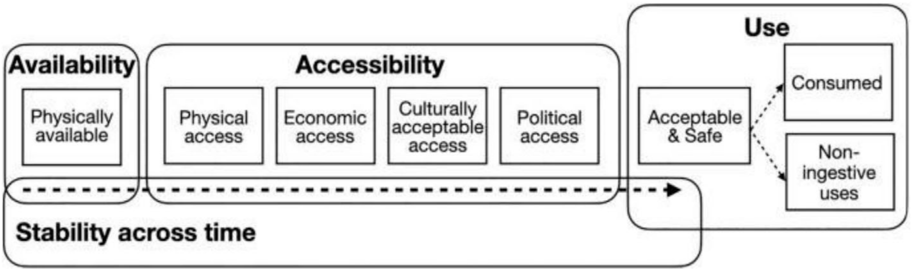

FIGURE 1 The four domains of water security are availability, accessibility, use, and stability (Gain et al., 2016; Varis et al., 2017).

population. More than 70% (close to 5.5 billion) do not have safe water access, with Africa having the lowest levels of access, at only 15% of the region's population (MacAlister et al., 2023). Worldwide, 2.1 billion people lack access to safely managed drinking water services (UNECE, 2015; World Health Organization/UNICEF, 2017). Globally, 80% of water scarce households appoint women and girls to fetch water (UN Water, 2018). While all regions have countries with low levels of water security, least developed countries (LDCs) like Ethiopia in particular face critical levels of water security due to a range of compounding factors. According to the Global Water Security assessment report (2023), Ethiopia, owning around 122 billion Metric Cube of water resources (MOWE, 2023), is among the 16 LDCs that are critically water insecure. This evidence implied that abundant natural water availability does not necessarily ensure water security as it might be poor water quality, inaccessible, and unsafe.

Importantly, assessment of water security using the existing global data at a national level do not represent the individual or household experience of water insecurity (MacAlister et al., 2023). Therefore, national and local level of SLM and water security linkages, impacts, and policy implications must come onboard in the least developing countries like Ethiopia.

WLRC is leading policy change in Ethiopia to recognize water security as a critical development outcome of SLM. WLRC is advocating for inclusion of water availability as one indicator of SLM success at national level in the design of the SLM Knowledge Management and Information System (SKMIS). The SKMIS is a software designed by WLRC for the national SLM program financed by the World Bank, KFW, and other consortium members worth 200 million USD. WLRC is coordinating the national project design for the National SLM technical committee on behalf of the Ministry of Agriculture, Ministry of Water, Irrigation and Electricity, and the Environment, Forest and Climate Change Commission. One of the objectives is to ensure water security improvements are formally recognized as a measurable outcome indicator from SLM interventions. In Ethiopia, the most commonly observed deliverable of SLM are the improvement of ecosystem services and functions, availability of water for domestic and irrigation, and the improvement of households' livelihoods as they can produce more goods and services.

3.1 | SLM and water security linkages: direct, indirect, development impacts

The interconnections between SLM and water security are intimate and numerous (Bob et al., 2021; Eekhout & de Vente, 2019; Giordano & Shah, 2017; Mersha et al., 2022b). SLM has important benefits for water conservation and improving water security (Kato et al., 2019). Appropriate land management is crucial to achieve economic growth, improved biodiversity, create sustainable agricultural systems, attain food security, eradicate poverty, address climate change, and improve water availability (Bob et al., 2021; Marques et al., 2016). In spite of such general facts, the linkage between SLM and water security in Ethiopia is not yet well understood and addressed due to a lack of evidence indicating the role of SLM for ensuring water security, because there are lots of water security problems affecting the livelihood of smallholder farmers. IFPRI conducted a household survey in two WLRC watersheds with SLM programming and two adjacent watersheds without such programming (Kato et al., 2019; Murgatroyd et al., 2021). They also outlined the direct, indirect, and development water security impacts linkage between SLM interventions and water security. A total of 561 households with 2900 plots were interviewed from the four watersheds. Results indicated that compared to households in control watersheds, households in SLM-supported learning watersheds have increased access to groundwater for irrigation and have experienced improved water availability for livestock production; increased household income from livestock production (+31%) and crop production to a lesser extent; higher crop yields, particularly for maize, mango and millet. Eventually, water security is thus also linked to the broader foundations of societal security such as food security, nutrition security, and energy security (Moumen et al., 2019; Varis et al., 2017; Figure 1). Social, economic, environmental, and political instability all can affect the stability of water security. Household water insecurity occurs when any of these domains are not present. Stability (or reliability) is represented by the arrow spanning availability, access, and use (Calow et al., 2013; Nounkeu & Dharod, 2019; Rosinger & Young, 2020; Young et al., 2021).

3.2 | SLM for soil moisture availability in agricultural catchments

WLRC conducted a study to assess how SLM affects in situ moisture availability, comparing soil moisture regimes in agricultural areas under traditional and improved management in Ethiopia's Blue Nile Highlands. The research found that areas under improved management have more stable soil moisture regimes over time, as well as a more uniform spatial distribution of soil moisture, than traditionally managed areas. Consistent levels of soil moisture mean that crop roots are more evenly served with water, increasing crop yield. In tests, improved management increased soil moisture content by 15.6% to 800%. Overall, results suggest that improved management of agricultural catchments through SLM can play a crucial role in benefiting agricultural water security by improving soil moisture availability and storage. The study also indicates that SLM promotes the infiltration of rainwater into the soil, enhancing groundwater recharge. Where SLM is underway, home gardens, a source of cash income, are expanding, and more people are constructing wells to access groundwater for irrigation and domestic use. SLM measures (soil bunds, contour trenches, etc.) (Mersha et al., 2022a) contributed to increased soil water recharge, significant increases in soil moisture content, increased infiltration potential, and the restoration of natural hydrological functionality (Figure 2). In the Aba Gerima catchment, Mersha et al. (2022b) also to investigate the effect of SLM on water security following paired catchment approach (treated and untreated catchments with SLM practices). They reported that the changes in soil water contents relative to a reference value recorded at the onset of the 2018 wet season are presented in Figure 3, describing soil water recharge. Noticeably, θ increased with the increase in cumulative rainfall at all experimental sites, indicating

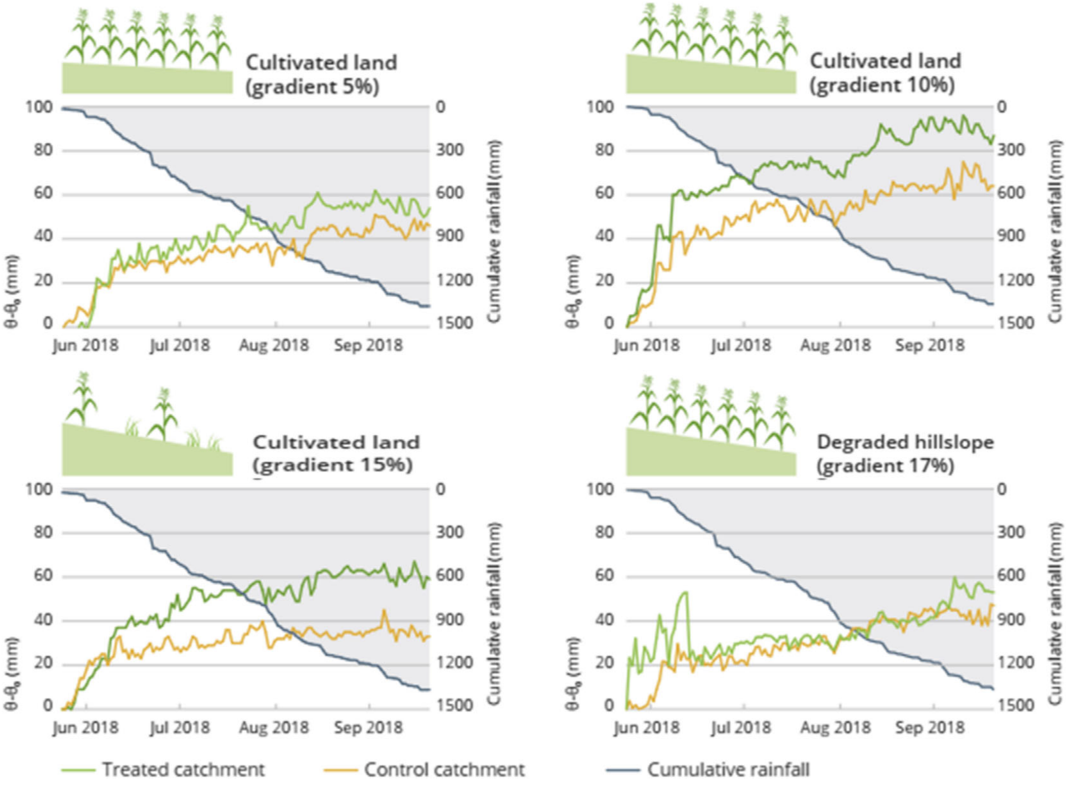

FIGURE 2 Changes over time in soil moisture compared to baseline levels measured at the start of the 2018 wet season, in four paired experimental sites in the Blue Nile Highlands, Ethiopia. Area under SLM, control area under traditional management. *Source*: Mersha et al., 2022a.

the buildup of soil moisture as the wet season progresses. However, the experimental sites in the treated catchment exhibited higher soil water recharge than their control counterparts except the one on cultivated land with 15% slope gradient, which presented little increase in soil water recharge relative to its control counterpart (Figure 2).

3.3 | SLM effects on soil-water (infiltration-runoff) dynamics

A 9-year study (2010–2018) in the Debre Mewi watershed found that the maximum runoff coefficient was found in the main watershed (0.34) in 2010, before SLM practices implementation, and the minimum was 0.05 in 2018, after SLM practices implementation. Runoff coefficients and sediment concentrations decreased steadily throughout the 9 years (Mhiret et al., 2020). Mersha et al. (2022b) reported that runoff potential is higher in the control than in the treated catchment with SLM practices. Water infiltration rate and cumulative infiltration (cm) varied significantly with SLM. The impact of SLM practices on infiltration-runoff (soil-water) dynamics was assessed using a paired-catchment approach at two agricultural catchments (treated with SLM practices and traditionally managed or control) of Aba Gerima catchment in the headwaters of the Blue Nile basin (Mersha et al., 2022b). They reported that SLM interventions promoted significant reductions in CNs, recovery of infiltration potential, increased soil water

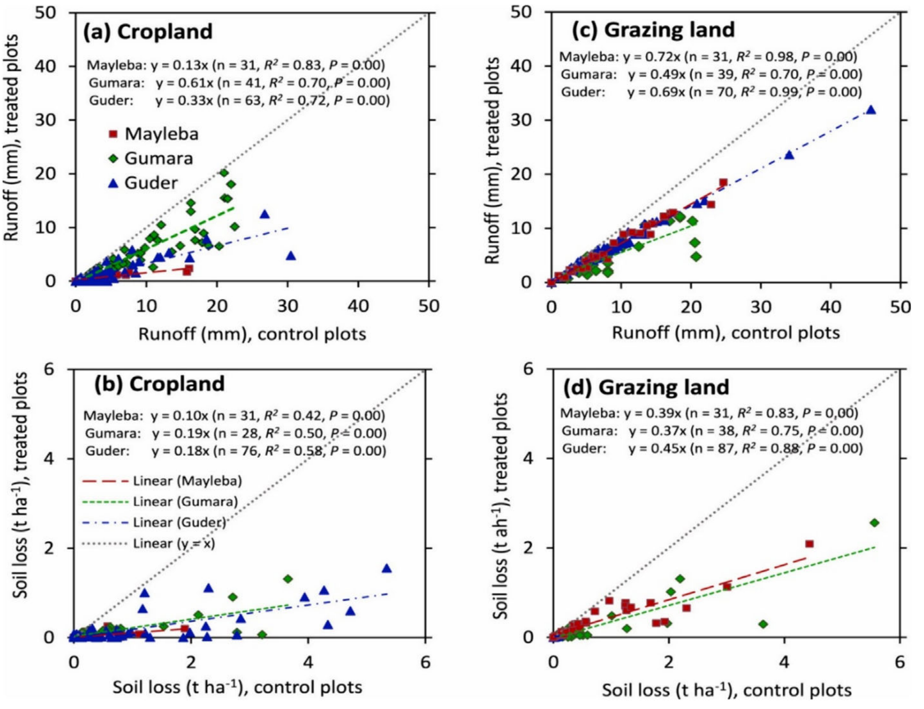

FIGURE 3 The daily runoff and soil loss records of control versus treated plots on (a,b) cropland and (c,d) grazing land at Mayleba, Gumara, and Guder. Curves with $P < .05$ indicate a significant association of runoff/soil loss b/n plots with and without SWC. *Source*: Ebabu et al., 2023.

content, improved soil water recharge and retention, and restoration of the natural hydrological functionality.

The impact of SLM on soil water availability can be attributed to the change in soil physical properties (e.g., Soil water content) as a result of land management activities (Dagnachew et al., 2020; Sultan et al., 2018). Water availability (described in terms of water balance components, such as infiltration, soil water storage, surface flux, bottom flux, evaporation, and transpiration) of a watershed is manifested by increased soil water storage and reduced evaporation. Studies indicate that SLM practices make a significant contribution to soil hydraulic properties of the watershed (Fikadu et al., 2022). Generally, SLM practices in Aba Gerima were found to be successful in increasing the soil water availability of the watershed through maximizing recharge, surface flux, and soil water storage and minimizing evaporation, transpiration, and surface runoff. The current practices of SLM in Ethiopia involve a variety of structural and nonstructural elements integrated at the catchment scale, providing different roles in managing water resources in situ. For instance, the structural measures (soil bunds, contour trenches, etc.) significantly improve infiltration and water storage potential of the agricultural landscapes in the study area. On the other hand, the nonstructural measures, such as the elimination of open grazing on communal grazing land and the abandonment of postharvest grazing on cultivated land, help improve the water retention capacity of the soils and reduce nonproductive evaporative water losses. In addition, the current practices of SLM attempts to sustain diverse land use mosaics at the catchment scale, including protected areas (gullied lands and communal grazing lands), cultivated land and home gardens, with the aim of harnessing potential uses, services, and values from a catchment (Haregeweyn et al., 2012).

3.4 | Effectiveness of SLM technologies in reducing runoff and soil loss

A study conducted in three sites (Mayleba, Gumara, and Guder) representing the three of different climatic environments of the Ethiopian highlands: semiarid (Mayleba), dry subhumid (Gumara), and humid (Guder) revealed that at all sites, both runoff and soil loss values from SLM-treated plots were found to be significantly lower than in corresponding plots without SLM practices (Ebabu et al., 2023). The implementation of SLM technologies like SWC measures reduced seasonal runoff by 23%–80%, and soil loss by 41%–86%, indicating the substantial effectiveness of SLM in reducing runoff production and associated loss of soil. For example, stone bunds with trenches at the semiarid site was found to be the most effective (reduced runoff by 80% and soil loss by 86%) (Ebabu et al., 2023). Higher slope and R^2 values of regression curves fitted to daily runoff and soil loss records from control versus treated plots at Gumara and Guder (Figure 2) further indicate lower effectiveness of soil bunds in reducing runoff (34%–47%) than in reducing soil loss (41%–70%), probably caused by a decline in the storage capacity for infiltration excess runoff (Ebabu et al., 2019, 2023).

4 | IMPLICATIONS OF SLM PRACTICES ON WATER AVAILABILITY

A group of WLRC researchers examined the implications of SLM practices on water availability in the Aba Gerima watershed in the Upper Blue Nile Basin using the Hydrus 1D model simulations. They found that the cumulative evaporation estimated for 365 days for control sites (watershed without SLM practices) was 37.6% higher than that of sites with SLM practices. Surface and bottom fluxes in the sites under SLM were 4.6% and 12.5%, respectively, higher than the control sites. This could be attributed to the increased soil water availability resulting from the implemented SLM practices in Aba Gerima, and the results of this study can be used as empirical evidence of the positive implications of SLM on water availability. The impact of land management on soil water availability can be attributed to the change in soil physical properties (e.g., soil water content) as a result of land management activities (Dagnachew et al., 2020; Sultan et al., 2018). Water availability (described in terms of water balance components, such as infiltration, soil water storage, surface flux, bottom flux, evaporation, and transpiration) of a watershed is manifested by increased soil water storage and reduced evaporation. Studies indicate that SLM practices make a significant contribution to soil hydraulic properties of the watershed (Fikadu et al., 2022). Generally, SLM practices in Aba Gerima were found to be successful in increasing the soil water availability of the watershed through maximizing recharge, surface flux, and soil water storage and minimizing evaporation, transpiration, and surface runoff.

4.1 | SLM contribution to water quality improvement

Water quality remains a considerable challenge, with 95% of water sources sampled considered to be unsafe for both human and animal health. SLM can contribute to increased water availability for wells that can be used for drinking water and other domestic uses. However, the expansion of shallow, unprotected wells for irrigation in an area with limited improved drinking water sources has increased use of water that is of poor quality, including for drinking.

Research led by IRC found that 90%–95% of water sources sampled ($n = 156$) in Aba Gerima and Debreyakob watersheds were contaminated by Fecal matter, while this was higher for the more prevalent traditional shallow wells, contamination was also high in improved wells (Afridev) designed for drinking water. One of the reasons suggested for the lack of focus on and investment in water quality is the assumption that wells would be exclusively used for irrigation, rather than for multiple purposes. IRC's survey also highlighted that the poorest were late-entrants into well ownership, gaining access more rapidly after the SLM interventions commenced, possibly due to the increasing accessibility of groundwater.

4.2 | Policy implications of SLM for water security

Human settlement and agriculture have a long history in Ethiopia (Gumma et al., 2022), predominantly in the Highlands, where over 90% of the country's population live. Agriculture plays a great contribution of 47% of the GDP, 90% of the exports, and 85% of the employment (Asfaw et al., 2018; Simane et al., 2016). In Ethiopia, the extreme hydrologic variability and chronic land degradation have endangered the productivity of subsistence rainfed agriculture, which in turn significantly influences soil-water availability and storage (Berhane et al., 2014; Fikadu et al., 2022; Mersha et al., 2022a).

Though the highlands Ethiopian receive sufficient rainfall, the productivity of the rainfed agriculture is constrained by management-induced water scarcity. Land degradation has reduced the depth, water holding capacity, and organic carbon content of the soils in the Ethiopian Highlands, affecting local rainfall partitioning and, hence, soil-water availability and storage (Betrie et al., 2011; Bossio et al., 2010; Kirui et al., 2021; Mersha et al., 2022a; Zaitchik et al., 2012). Hurni et al. (2005) reported that the Ethiopian Highlands showed increases in rainwater losses (five to 30 times) through surface runoff triggered by the clearing of forests for agricultural expansion. Improved catchment management options in the Blue Nile Highlands have helped improve green water storage in the rooting zone by up to 16%–800% compared with traditional practices (Mersha et al., 2022a). Improving the management of agricultural catchments will greatly benefit subsistence rainfed agriculture by securing water availability, access, and safety, and by building resilience to cope with future water security risks and uncertainties (Lebel et al., 2015).

SLM interventions contributed to significant reductions in CN and increases in volumetric soil moisture content and restored the natural hydrological functionality of the agricultural landscapes, leading to recovery of infiltration and soil water retention potentials. Therefore, integrated and SLM is crucial to create sustainable agricultural systems (Mirzabaev et al., 2015) and improving water availability (Mersha et al., 2022b). Links between water security and the best SLM techniques have been made reviewed from various sources (Kato et al., 2019; Mersha et al., 2022b). The research outcomes review depicted that SLM promises in mitigating the impacts of land degradation and climatic variability and change on freshwater availability and hence on water security. Hence, SLM-water security policy is crucial in successful SLM because governments/higher officials are capable of promoting well-informed water security decisions. Policy instruments include local, regional, and international legislation and regulations, but probably the most effective policy tool for the implementation of SLM-water security is public education. Lamentably, the major reason for insufficient implementation and adoption of environmentally sound land management is the lack of efficient channels to transmit knowledge and technology between the scientific evidence and policy (Marques et al., 2016). To achieve effective communication of scientific knowledge to policy, findings must be interdisciplinary and have cross-sector applications like SLM technologies and approaches. Moreover, considering the principles and concepts of water security alongside of SLM interventions will strengthen the linkage between SLM and water security in Ethiopia.

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CONFLICT OF INTEREST STATEMENT

We all declare that there is no conflict of interest.

ORCID

Melku Dagnachew https://orcid.org/0000-0003-2044-1009

ENDNOTES

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