Characterizing and evaluating the impacts of national land restoration initiatives on ecosystem services in Ethiopia

Wuletawu Abera1 | Lulseged Tamene1 | Degefie Tibebe2 | Zenebe Adimassu3 | Habtemariam Kassa4 | Habtamu Hailu5 | Kindu Mekonnen6 | Gizaw Desta7 | Rolf Sommer8 | Louis Verchot9

1International Center for Tropical Agriculture (CIAT), Agroecosystems and Sustainable Landscapes (ASL), Addis Ababa, Ethiopia
2Ethiopia Institute of Agricultural Research (EIAR), Climate, Geospatial and Biometrics Research Program, Addis Ababa, Ethiopia
3International Water Management Institute (IWMI), Agricultural Water Management Research Group, Addis Ababa, Ethiopia
4Center for International Forestry Research (CIFOR), Sustainable and Livelihoods Research Team, Addis Ababa, Ethiopia
5Sustainable Land Management Program (SLMP), Ministry of Agriculture, Addis Ababa, Ethiopia
6International Livestock Research Center (ILRI), Sustainable Livestock Systems (SLS), Addis Ababa, Ethiopia
7Water and Land Resource Centre (WLRC) of Addis Ababa University, Addis Ababa, Ethiopia
8International Center for Tropical Agriculture (CIAT), Agroecosystems and Sustainable Landscapes (ASL), Cali, Colombia

Correspondence
W. Abera, International Center for Tropical Agriculture (CIAT), Addis Ababa, Ethiopia.
Email: wuletawu.abera@cgiar.org

Funding information
United States Agency for International Development

Abstract
Land restoration is considered to be the remedy for 21st century global challenges of land degradation. As a result, various land restoration and conservation efforts are underway at different scales. Ethiopia is one of the countries with huge investments in land restoration. Tremendous land management practices have been implemented across the country since the 1970s. However, the spatial distribution of the interventions has not been documented, and there is no systematic, quantitative evidence on whether land restoration efforts have achieved the restoration of desired ecosystem services. Therefore, we carried out a meta-analysis of peer-reviewed scientific literature related to land restoration efforts and their impacts in Ethiopia. Results show that most of the large-scale projects have been implemented in the highlands, specifically in Tigray and Amhara regions covering about 24 agroecological zones, and land restoration impact studies are mostly focused in the highlands but restricted in about 11 agroecological zones. The highest mean effect on agricultural productivity is obtained from the combination of bunds and biological interventions followed by conservation agriculture practices with 170% and 18% increases, respectively. However, bunds alone, biological intervention alone, and terracing (fanya juu) reveal negative effects on productivity. The mean effect of all land restoration interventions on soil organic carbon is positive, the highest effect being from “bunds + biological” (139%) followed by exclosure (90%). Reduced soil erosion and runoff are the dominant impacts of all interventions. The results can be used to improve existing guidelines to better match land restoration options with specific desired ecosystem functions and services. Although the focus of this study was on the evaluation of the impacts of land restoration efforts on selected ecosystem services, impacts on livelihood and national socioeconomy have not been examined. Thus, strengthening socioeconomic studies at national scale to assess the sustainability of land restoration initiatives is an essential next step.
1 | INTRODUCTION

Land degradation is a major global environmental and developmental challenge of the 21st century (Hartmut, 2005; Gashaw, Bantider, & Silassie, 2014). Nearly 5 billion hectares (about 43% of the Earth’s vegetated surface) have been degraded through soil erosion, deforestation, and loss of tropical forest (Hartmut, 2005). Global economic losses from land degradation are estimated to lie somewhere in between US$ 300 billion (Nkoya et al., 2016) and US$ 10.6 trillion annually (ELD Initiative, 2015). The Montpellier Panel (2014) estimated that 180 million people are affected by land degradation with an estimated annual economic loss of US$ 68 billion in sub-Saharan Africa. Among the sub-Saharan Africa countries, Ethiopia experiences the most severe land degradation with an annual cost of US$ 4.3 billion (Gebreselassie, Kirui, & Mirzabaev, 2016). A recent report shows that about 14.3 million hectares of land in Ethiopia (about 50% of the Highlands) is severely degraded (FDRE, 2015; Gashaw, 2015).

Soil erosion by water is the most widespread form of land degradation in Ethiopia under different land uses. Estimates of average soil losses range between 3.4 and 84.5 t ha\(^{-1}\) yr\(^{-1}\) with maximum rates reaching 300 t ha\(^{-1}\) yr\(^{-1}\) (GIZ, 2015; Haile et al., 2006; Hurni et al., 2015; Gashaw, 2015). Relative to other land uses, the highest rate of soil loss occurs on cultivated lands, ranging from 50 t ha\(^{-1}\) yr\(^{-1}\) (Adimassu, Mekonnen, Virga, & Kessler, 2012) to 179 t ha\(^{-1}\) yr\(^{-1}\) (Shiferaw & Holden, 1999). Due to the negative on-site impacts of soil erosion, the potential of agricultural intensification to enhance land productivity is limited (Adimassu et al., 2012; Gebrehiwot, Bewket, Gärdenäs, & Bishop, 2014). National-level nutrient depletion rates were estimated to be 122, 13, and 82 kg ha\(^{-1}\) yr\(^{-1}\) for N, P, and K, respectively (Haileslassie, Priess, Veldkamp, Teketay, & Lesschen, 2005, 2006). This nutrient depletion results in decline in agricultural productivity that continues to significantly affect the performance of the national economy. Soil erosion also has tremendous off-site effects. Specifically, siltation of lakes, reservoirs, irrigation canals, flooding, and deterioration of ecosystem services are issues of great concern. Due to rapid siltation caused by high erosion, the potential contributions of the various water harvesting schemes developed for supplemental irrigation have been compromised (Tamene & Vlek, 2007; Tamene & Le, 2015). High erosion in the upper Blue Nile Basin at annual rate of 380 million t (Hurni et al., 2015) also poses a serious challenge to the Great Ethiopian Renaissance Dam, and it may reduce the capacity to generate electricity in the short to medium term.

Considering the severity of land degradation and its impact on food security and economic development, Ethiopia has ventured into one of the largest land restoration efforts, with several soil and water conservation (SWC) and sustainable land management (SLM) programmes that have been implemented across the Country. Following the droughts of the 1970s, SWC work expanded in most parts of the Ethiopian Highlands (Girma, 2001; Kebrom, 2001; Nedessa & Wickrema, 2010). In the 2000s, the government and its key development partners have taken steps to learn from the strengths and weaknesses of the past environmental rehabilitation initiatives and embraced a multistakeholder and multisectoral programmatic approach addressing land and water degradation. A major programmatic breakthrough came with the formulation of the Ethiopian Strategic Investment Framework for Sustainable Land Management (ESIF) in 2008. ESIF is a holistic and integrated country-specific strategic planning framework that aims at guiding the broad spectrum of government and civil society stakeholders towards promoting SLM upscaling in all agroecological zones and agricultural production systems in the Country. Recently, the Sustainable Land Management Program (SLMP) has been leading the coordination and implementation of large-scale SWC, SLM, and water harvesting options. Over the past few years, annual government-led mobilization of communities has resulted in undertaking SWC work in large areas and in the plantation of hundreds of millions of tree seedlings in the Ethiopian Highlands. According to a recent study, Ethiopia invested more than US$ 1.2 billion per yr over the past 10 years for land restoration in four regions (Amhara, Oromia, Tigray, and Southern Nations, Nationalities, and Peoples’ Region [SNNP]) of the Country (Adimassu, Langan, & Barron, 2018).

Despite the various land restoration efforts for over 40 years, impacts and achievements have not been comprehensively assessed. Except for some studies related to area enclosures (Angassa & Obi, 2010; Mekuria & Yami, 2013; Seyoum et al., 2015), there is no clear/quantitative evidence about the performance of the restoration efforts and information on their contribution to improvement of livelihoods and enhancement of ecosystem services across scales. The results of the few studies that have been done are less comprehensive and based on limited spatiotemporal analyses. Comprehensive studies that compare the ‘drawbacks versus successes’ of interventions to gain lessons and develop sustainable reforestation and landscape restoration programs are lacking. As a result, our knowledge about what works, where, and how, and the risks to scaling up land restoration practices remain limited. It is thus not possible to understand well the return on investment made in restoring degraded landscapes and their sustainable management in the Country. This also undermines the negotiating power to facilitate payment for ecosystem services. This study intends to contribute to closing this knowledge gap. The specific objectives of the study include (a) collate and map the major land restoration efforts and information on their contribution to improvement of livelihoods and enhancement of ecosystem services in the country; (b) review, synthesize, and map literature related to the impacts of land restoration across the country that are published in peer-reviewed journals; and (c) investigate the impacts of landscape restoration efforts on landscape ecosystem services in the country.

2 | METHODOLOGY

2.1 | Mapping and synthesizing land restoration projects in Ethiopia

We consulted literature and experts to document and map the spatiotemporal distribution of the various land restoration efforts in the country. Publications, reports, proceedings, and PhD theses were screened to identify candidate projects for analysis, and to determine when and where they were implemented, and document their
attributes. Visits were also made to various governmental and regional offices, research and academic institutions, and offices of programs and projects that have been engaged in the coordination and/or implementation of land restoration across the country. Major land restoration initiatives, such as the Productive Safety Net Programme (PSNP) (Devereux et al., 2008), the Managing Environmental Resources to Enable Transition (Nedessa & Wickrema, 2010), the SLMPs (SLMP I and SLMP II), and smaller projects supported by different nongovernmental organizations were also reviewed.

Preprocessing steps involved scanning hard copy documents, georeferencing, digitizing, and entering project sites into Geographic Information System environment. Georeferenced datasets were directly integrated into the Geographic Information System after relevant projections were made. In addition to project intervention sites, other spatial data, such as topography (SRTM data https://cgia.cr.usgs.gov/community/data/srtm-90m-digital-elevation-database-v4-1/), land use/cover (Regional Center for Mapping Resources for development, 2008), agroecology (Ministry of Agriculture, 2000), soil carbon (International Soil Reference and Information Center, 2015), and population density (Central Statistics Authority, 2007), were collected and used as explanatory covariates. The land restoration sites were then integrated with different covariates including administrative region, farming system, time (age) of intervention, terrain characteristics such as elevation and slope, and population density. Figure 1 summarizes the procedure followed for data acquisition, processing, and analysis.

2.2 Mapping and synthesizing landscape restoration impact assessment studies in Ethiopia

To synthesize the performance of land restoration activities and produce national level evidence, we collected peer-reviewed papers that have investigated the impacts of land restoration in Ethiopia. Five steps were followed to collate publications related to the impacts of land restoration and management practices in Ethiopia. The first step involved collection of case-studies related to land restoration activities using a bibliometrics approach (Eva, 2001). We used the Web search function involving keywords ‘landscape restoration in Ethiopia’, ‘impacts of landscape restoration in Ethiopia’, ‘soil and water conservation practices in Ethiopia,’ ‘impacts of soil and water conservation practices in Ethiopia,’ ‘sustainable land management in Ethiopia,’ and ‘impacts of sustainable land management in Ethiopia.’ We collated peer-reviewed publications until August 2018. The next step involved developing database related to the collated dataset using predefined template. The database so developed is organized considering different attributes of the studies such as author(s), year of data collection and/or publication, location of study site, intervention type, year of intervention (for how long was the practice in place), the ecosystem services assessed for impacts, and the results obtained in terms of those ecosystem services both before and after implementation (see Table A1 for the list of variables included in the database). All biophysical ecosystem services were extracted, but for statistical purposes, four ecosystem services (soil organic carbon stock [SOC], soil loss, runoff, and productivity) were selected on the basis of frequency of occurrence in the database. The third step mapped the spatial distribution of the relevant study sites using place names and/or geographical coordinates. For cases where the location of the study was not provided in latitude and longitude format, we obtained such coordinates using Google Earth based on study site description and corresponding place names. This step helped visualizing the spatial distributions and linking and analyzing data with covariates having defined spatial attributes such as regions and agroecological zones. The fourth step synthesized and characterized the dataset in terms of geographical location, administrative region, year of publication, agroecological zone, land use/cover types, terrain types, and ecosystem functions/services. Where necessary and for simplicity, similar land management practices/types such as conservation tillage, reduced tillage, mulch, green manure, and other local soil fertility enhancing techniques/technologies were grouped under the term CA. This step enabled stocktaking studies conducted in the Country and helped identify gaps related to the spatial dynamics of evidence generated about the performance of land restoration efforts. In the final step, we conducted a detailed statistical analysis and meta-analyses to understand the significances of different practices on ecosystem services. To evaluate the effects of land restorations on various soil, biological, and productivity parameters, an effect size given by a response ratio (RR) approach proposed by Hedges, Gurevitch, and Curtis (1999) and Luo, Hui, and Zhang (2006) was used. An RR is defined as the natural logarithm of the ratio of the value on land restoration treatment (after or treated) to that of without land restoration (before or control or untreated):

$$RR = \ln \left( \frac{\text{after intervention (treated) parameter value}}{\text{before intervention (control) parameter value}} \right)$$

Assuming that the effect size RR follows a normal distribution (Curtis & Wang, 1998; Luo et al., 2006), the variance, v, of RR was approximated using the following formula:

$$v(RR) = \frac{(SD_t)^2}{N_t X_t^2} + \frac{(SD_c)^2}{N_c X_c^2}$$

where SD_t and SD_c are the standard deviation of treated site parameter values and control (untreated) site parameter values, respectively; N_t and N_c are the numbers of case-studies for the treated (after) and untreated (before) groups, respectively; and X_t and X_c are the mean value for treated and control parameter, respectively. The variance is useful to quantify the weights for minimizing the influences of studies with low statistical powers through estimating sample variability in RR. For comparing the effect size of land restoration intervention types, we used the nonparametric weighting function (w) of case-studies (Hedges et al., 1999) calculated as an inverse of the pooled variance (1/v(RR)). Then, the weighted RR (RR') is obtained as follows:

---

1. The intervention types are any kind of land management, water harvesting, and conservation agriculture (CA) practices commonly implemented in Ethiopia to improve land ecosystem services.

2. Biological refers to options including agroforestry and tree/forage planting as part of restoration, intensification, and/or diversification options.
The final mean effect size for each intervention and ecosystem service was calculated by

\[ RR' = w^*RR. \]

The bias-corrected 95% confidence intervals (CIs) of the mean were generated by a bootstrapping procedure (Song et al., 2014). The effects of the land restoration intervention on ecosystem services were considered significant at \( P < .05 \) if the 95% CIs did not include 0 (Guo & Gifford, 2002). For convenience, the effect size was converted from the natural logarithm to percentage using the equation \( (e^{RR} - 1) \times 100 \) (Luo et al., 2006). This provides the actual response of the intervention in percentage.

The established case-study map that represents the spatial distribution of sites was used to evaluate the geographical representativeness of case-studies. We used intervention response times and duration of interventions of the studies to explore the relationship between age of interventions and ecosystem responses.

To summarize the ecosystem services related to each intervention type, we aggregated them into major ecosystem services, that is, provisioning, regulating, and supporting and cultural services. Accordingly, yield and biomass productivity and water quantity are categorized as provisioning services. Most soil properties (soil pH, soil moisture, SOC, total nitrogen, and available phosphorus), soil erosion and event runoff are considered to be regulating services, and biodiversity is considered to be a supporting service. We reported limited cultural-related services in the review papers. Thus, we have not included those in our analysis.

3 | RESULTS AND DISCUSSION

3.1 | Distribution and characterization of land restoration interventions in Ethiopia

Land restoration efforts in Ethiopia generally attempt to respond to severe land degradation problem caused by population pressure and climate change (Tadese, 2001). The 1970s SWC measures were designed around a food for work principle focusing on welfare safety nets for poor communities in food insecure areas. Details of the interventions and approaches of food for work implementation in Ethiopia can be found in Holt (1983) and Bezu and Holden (2008). Considerable natural resource rehabilitation and development work has been conducted between mid-to-late 2000s within the framework of the PSNP and under Managing Environmental Resources to Enable Transition projects implemented under the auspices of the World Food Programme. Other small-scale projects have been implemented with support from bilateral and multilateral and United Nations agencies and executed by governmental and nongovernmental organizations. In 2008, a major programmatic breakthrough came with the formulation of the ESIF for SLMP. ESIF is a holistic and integrated strategic planning framework that aims at guiding the broad spectrum of government and civil society stakeholders towards promoting SLM upscaling in all agroecological zones and agricultural production systems.
The first phase of SLMP started in 2008 and lasted until 2013 with various accomplishments including implementation of water harvesting and agroforestry options. The second phase of SLMP started in 2013 and was planned to operate until 2018. Under the various programmes, it is claimed that large areas of degraded hillsides and grazing and farm lands have been rehabilitated using area exclosures to protect sites from grazing animals; degraded communal lands are conserved through the construction of terraces, deep trenches, and percolation ponds, and according to the government reports, billions of seedlings have been planted in the midlands and highlands of the country (Meaza, Tsegaye, & Nyssen, 2016). Figure 2 outlines the temporal sequence of major SLM initiatives in Ethiopia.

The results of our analysis showed that the spatial distribution of the major land restoration initiatives that have been implemented in Ethiopia in the last four decades was mostly concentrated along the escarpment of the eastern and western mountains of the country (Figure 3). The administrative zones with large numbers of projects and intervention sites include South Wollo, Central Tigray, Southern Tigray, Northern Shewa, and East Haraghe (Figure 4a). Scattered intervention sites, mainly belonging to SLM projects, are present in the western parts of the country. The Somali, Afar, and Benishangul lowlands have seen relatively little land restoration interventions. The PSNP intervention sites were focused on the eastern and northern parts of the country, whereas SLM interventions targeted the western part. This may be because PSNP mainly focused on food insecure low and dryland areas (Ministry of Agriculture and Rural Development, 2014), whereas SLM engaged more in the highlands with high agricultural potential. In terms of agroecologies, land restoration interventions were carried out in about 24 agroecological zones. The tepid submoist, tepid moist, and tepid subhumid midhighlands are the most widely covered agroecologies by land restoration initiatives (Figure 4a). Most of the land restoration interventions are concentrated in midhighlands (Figure 4b) with high population densities (Figure 4c). Given the associated increased pressure on natural resources, the highlands have been, and are, experiencing land resource depletion, which could have been the factor that attracted the land restoration projects. It is important to note that there are very few intervention projects in the lowland peripheral parts of the country where the settled population density is low and some of the places are less accessible.

Intrusion of cropping land into forest and grazing areas is one of the main causes of resource depletion and consequently land degradation. As a result, most of the land restoration process have targeted cultivated lands—that is, to sustain existing cropping areas and avoid further encroachment. This is shown clearly in Figure 4d with notable land restoration interventions occurring on annual croplands. Considering that agriculture supports more than 85% of the population of the country, it is not surprising to see more focused conservation efforts targeting croplands. Grazing areas and hillsides dominated with shrublands and exposed to land degradation risks were targeted for land restoration (Figure 4c). Relating the land restoration intervention sites with a soil health indicator, the majority of interventions have been implemented on soils whose soil organic carbon concentration is between 11 and 40 g kg\(^{-1}\) as shown in Figure 4e. This is an indication that most of the interventions are concentrated on degraded lands that have lost significant amounts of their original soil organic matter.

The spatial distribution of the land restoration intervention sites and associated brief characterization given above can facilitate planning and informed decision making. Researchers, planners, and decision makers can use this information to understand where major projects have been implemented and undertake further assessments to plan studies and/or prioritize further interventions as well as exploring options for targeting SLM investments. Stakeholders who are and/or will be engaged in land restoration efforts can utilize such information to prioritize, and those who are coordinating and/or monitoring such exercise can use the database and maps to update progress.

3.2 | Distribution and characterization of land restoration interventions impact assessment studies in Ethiopia

This section assesses studies that have been conducted to evaluate the impacts of land restoration efforts in the country. Our literature search identified 103 peer-reviewed papers containing 445 case-studies from 142 sites in which evidence on the contribution of land restoration intervention activities in Ethiopia was documented. The dominant land management practices studied and incorporated in our review include soil and stone bunds (60 case-studies) followed by various forms of CA (53 case-studies), exclosures, and a combination of bunds and biological interventions (Figure 5). The two most common bunds studied were stone bunds and soil bunds. Various forms of CA interventions such as fallow, manuring, and tillage practices were implemented for improving traditional agricultural systems in Ethiopia. The most common CA practice documented by the different studies is tie ridging followed by minimum tillage. Most studies dealing with CA targeted provisioning ecosystem services, mainly crop production (Figure 5).\(^3\)

The third largest category of land restoration interventions that has been analyzed is exclosures aimed at reducing grazing pressure. These studies are the most prevalent in the Tigray Region, and the focus of the case-studies related to exclosure was on supporting and regulating ecosystem services. One of the commonly criticisms of

\(^3\)CA refers to various land management practices such as conservation tillage, reduced tillage, mulch, green manure, and other local integrated soil fertility management technologies. Enclosure is complete area closure from grazing and cultivation for a specific duration of time. *Fanya juu* is a special kind of bund constructed by digging trenches along the contour of the slope and heaping the soil on the uphill side. Biological is a bundle of practices (trees, grass strips, vegetative bund stabilizers, etc.).
exclosure interventions is that provisioning cobenefits (such as beekeeping) are limited, and this appears to be borne out in the literature on these interventions.

In terms of time coverage, the earliest peer-reviewed papers that evaluated the impacts of land restoration interventions are from 1998 (Figure 6). In the last 5 years (2014–2018), the number of case-studies published decreases in comparison with the previous years (2011–2013). It is important to note that detailed analysis of the impacts of restoration interventions mainly focused on provisioning services followed by regulating ecosystem services, whereas studies on supporting services emerged in 2006.

Figure 7 shows the spatial distribution of the study sites across the country. The majority of the studies are located in the highlands, corresponding to large land restoration efforts. Most of the impact assessments took place in the Tigray and Amhara regional states, followed by Oromia and SNNP regional states. The highest geographical representation of the studies available in literature appears in Amhara (40 sites), followed by Tigray (35 sites), Oromia (30 sites), SNNP (17 sites), and Somalia (three sites) regional states. We did not find impact assessment studies published in peer-reviewed journals covering the Gambella and Binshangul–Gumuz regions, although land restoration projects have been implemented there (Figure 3). When normalized by the area of the regions, Tigray emerged as the region with the highest density of case-studies, followed by Amhara and SNNP.

We were able to trace land restoration projects that have been implemented in more than 24 agroecological zones, whereas
scientific evidence is available for activities in only nine agroecological zones. Large proportion of the land restoration projects (Figures 3 and 4) and most of the evidence generated about the impacts of intervention practices (Figure 7) have mainly focused in the tepid moist agroecological zone (Figure 8). This highlights the need for spatially targeted studies focusing on improving the representation of agroecological zones where performance studies are lacking. We also observe that there is a wide variety of land restoration intervention practices in the highland case-studies, whereas intervention practices in the lowland zones are more limited (Figure 8).

In terms of land use/cover type, most studies reviewed cover agricultural land use (80%), followed by forest land (10%). This implies that the majority of the studies focused on cultivated areas that mainly provide provisioning ecosystem services. Also, the majority of the studies focused their analysis on plot level (92% of the cases) with a few cases of watershed and farm/field-scale analysis.

Out of 313 case-studies with the duration of the intervention reported in the paper, we found that about half (48%) were conducted over 5 years or less after the implementation had begun (Figure 9). This implies that there is only limited evidence related to impacts of long-established land restoration efforts. Interventions where activities have been undertaken 10 years or more are limited. Because land restoration practices generally bring meaningful impacts after longer periods, it will be essential to conduct impact assessment of long-established restoration sites in the future. Based on a meta-analysis of soil erosion at the global level, Garcia-Ruiz et al. (2015) indicated that a period of at least 20 years of measurements is required to obtain reliable estimates of soil erosion rate reductions that take extreme events into account.

### 3.3 | Impacts of land restoration interventions on ecosystem services

In this section, we focused on assessing the impacts of major land restoration practices on selected ecosystem services based on the effect size statistics (Figure 10). Here, we present the mean effect size of land restoration on four selected ecosystem services (SOC, soil...
erosion, productivity, and runoff) associated with different interventions. These ecosystem services are presented in detail because the review shows the majority of the studies have considered these components in their analysis. Within the productivity category, the most reported indicator is crop yield. In Figure 10, the vertical lines along the zero (X axis) show the boundary between negative and positive effects and the distribution of the 95% confidence intervals reflect the variability of the land restoration impacts in relation to the respective ecosystem services. In cases where the error bars cross and/or touch the vertical lines (when mean effect size is zero), the effects of
**FIGURE 7** The spatial distribution of land restoration impact assessment case-studies in Ethiopia. CA, conservation agriculture [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 8** Number of published case-studies on the impacts of landscape restoration interventions on ecosystem services by agroecological zones in Ethiopia. CA, conservation agriculture [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 9** Number of studies published for land restoration interventions with different length of period after implementation in Ethiopia
the land restoration technologies on the status of the respective ecosystem services are considered to be not significantly different from 0.

*Fanya juu* significantly reduced soil erosion and runoff; the impact on productivity was not significant, but there was a significant improvement in SOC. The mean effect size of biological systems on soil erosion and runoff was \(-77\%\) (range \(-90\%\) to \(-68\%) and \(-38\%\) (range \(-48\%\) to \(-21\%\)), respectively. In both cases, the 95% CI did not cross zero (Figure 10), showing a significant effect of biological interventions on reducing soil erosion and runoff. The effect of biological systems on productivity was slightly negative (mean effect size of \(-10\%\)) but not significant at 95% CI (Figure 10). The effects of bunds in reducing runoff (effect size of \(-69\%\)) and soil erosion (effect size of \(-78\%\)) were significant (Figure 10). Bunds reduced productivity slightly (effect size of \(-9.4\%\)) and had a small positive effect on SOC (effect size of 4.9%), but the effect was not significant. A similar result of yield reduction due to these physical measures was reported by Balehegn, Haile, Fu, and Liang (2019) using a review analysis in Tigray Region. In areas where bunds were integrated with suitable biological systems, there are higher possibilities of yield increase due to complementary benefits. We found a significant positive effect of combined bunds and biological interventions on productivity (mean effect size = 170%, with a range of 97–318%). Bunds and biological options also show significant positive effect on SOC (mean effect size = 139% with a range of 89–164%). These combined interventions reduced runoff (mean effect size of \(-58\%\) [ranging between \(-77\%\) and \(-34\%)], but there was inadequate assessment of erosion effects in the studies for us to assess this impact (Figure 10). These observations show that physical measures such as *fanya juu* terraces (Figure 11a) and bunds (Figure 11b) alone have a negligible effect productivity
despite the direct benefits to soil conservation that they can offer (Balehegn et al., 2019). This suggests that loss of cultvatable area offsets productivity gains.

The biological measures such as agroforestry (Figure 11c) when implemented alone also did not bring positive change to productivity. However, when bunds are integrated with fodder or multipurpose tree species (Figure 11d), the decline in productivity is less. This could be due to the compound effect of integrated options in improving soil moisture, reducing soil loss, and enhancing soil fertility that could ultimately benefit crop production. However, it is important to note that the negative impacts of these measures on productivity are not significant.

The implementation of CA practices in Ethiopia showed multifunctional benefits, with a significant decrease of soil erosion and runoff by 45% and 46%, respectively, and a significant increase of

**FIGURE 11** Example of technologies implemented as part of the restoration efforts and for which analysis [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 12** The relationship between response ratio (%) and age of land restoration interventions in Ethiopia. SOC, soil organic carbon stock [Colour figure can be viewed at wileyonlinelibrary.com]
SOC and productivity by 24% and 18%, respectively. If the whole package of CA (minimum tillage, soil cover, and rotation) is implemented properly, the positive impacts outweigh associated undesirable effects because of the complementarity between the different components (increased food production, enhanced soil carbon sequestration, reducing soil erosion, improved moisture and nutrient storage, and improvement in the water and nutrient cycle). Figure 11e shows plots with adequate surface cover that could facilitate provision of multiple benefits such as the above ones.

Exclosures played a significant role in reducing soil erosion and runoff by 53% and 91%, respectively, while enhancing SOC by 90% (Figure 10). Because most of the enclosures are found on hillside slopes (communal lands or grazing areas), there are no studies that reported impact on crop yield. Enclosures (Figure 11f) are generally protected from livestock free grazing and crop cultivation that enable them regenerate and overtime provide various ecosystem functions. When complemented with supplementary options such as apiary or planting fruit trees, their economic benefits can magnify, enhancing their sustainability.

Response of ecosystem services to land restoration interventions did not necessarily decrease with the duration of the interventions (Figure 12). For example, the impact of duration of land restoration on crop productivity showed a weak, statistically nonsignificant, negative trend (Figure 12). However, the impacts of interventions on runoff and SOC increased with the duration. The lack of proper maintenance and the decrease of storage efficiency of practices/bunds can be suggested for the tendency for runoff and soil erosion to increase with time (duration of intervention). The correlation between SOC sequestration and duration of interventions is statistically significant at 90% probability (Figure 12). Commonly, the SOC dynamics over time are described using a Sigmoid model; that is, SOC increases, attains a maximum some 5–20 years after the intervention, and then increases less notably until a new SOC equilibrium is reached (Sommer & Bossio, 2014). Our meta-analysis could not support such trend. This, however, is not surprising, as the rate at which SOC increases depends on soil texture, topography, and climate. Thus, it is unlikely that pooled data from all parts of the country will follow the “SOC equilibrium” trend.

Further disaggregation of the effect size by agroecological zones is presented in Figure 13. The statistics of effect size is calculated for agroecology and intervention combinations with 10 or more case-studies. Except for CA, which shows positive effect in many agroecological zones, the effect of other interventions on productivity is negative in all agroecological zones. Comparing the impacts of CA, the performance is higher at warm submoist lowlands followed by tepid moist midhighlands. Similarly, bunds have positive effect (32%) on productivity only in warm submoist lowlands. Runoff reduction is observed in all agroecological zones for all types of interventions; the largest reduction was found in exclosure at warm submoist lowlands (~80%). Comparing CA and exclosure, exclosure has 1970s, SWC
work expanded in most parts of positive impacts (55%) on SOC in tepid subhumid midhighlands agroecological zone, whereas it has small negative effect (−5%) in tepid moist midhighlands. Though there is a difference in magnitude, all interventions have soil erosion reduction effects irrespective of the agroecology zone. Bunds have the largest effect on reducing erosion in warm subhumid lowlands (−92%) followed by tepid moist midhighlands (−81%).

In all the above results, the variability of effects of land restoration practices on ecosystem services between agroecological zones show that success of land restoration interventions varies and it depends on the local context and human factors. As shown here, agroecology can be considered one broader context that can help to fine tune land restoration interventions for targeted ecosystem services. However, many factors such as the design of the interventions, the socioeconomic system, and the specific types of ecosystem for which services are targeted should be considered for optimized land restoration techniques. The impacts of land restoration practices on ecosystem services have been drawn from meta-analysis of literature from a range of conditions including agroecology, land use type, topography, and soil types. Regardless of specific conditions, the average effect has demonstrated the substantial benefits of different types of land restoration practices on soil loss (45–80%) and runoff (38–90%) reduction, whereas the average effect on soil organic carbon and productivity varies on the type of land restoration practices. Practices like CA and integrated physical and biological practices revealed increase in SOC and productivity. This indirectly implies that low effect of physical land restoration practices on SOC and productivity might be attributed by depletion of soil nutrients and marginal topography to serve for crop production. Thus, we have understood from the analysis of average effect size of land restoration practices drawn from the range of studies that multiple ecosystem services can be enhanced through integrated land restoration interventions including structural, biological/vegetative, agronomic, and soil management practices. We therefore recommend to design land restoration strategies and practices targeting different contexts (agroecology, rainfall regimes, and land use types).

4 | CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

This study presents national stocktaking of land restoration initiatives in Ethiopia using spatial mapping, synthesizing, and characterization and analyzes their impacts using RR effect size statistics from peer-reviewed papers. The major findings are summarized as follows:

- A concentration of land restoration initiatives and sites were observed following the central north–south orientation, whereas the most west and east were sparsely addressed. This orientation implies that land restoration in the last decades has mainly been targeted to address areas with severe land degradation and historical drought problems. Moreover, because most of the impact studies focused their analysis on the plot level (92% of the cases), there was limited evidence to understand the effect of land restoration on the landscape-scale ecosystem service benefits. Generally, it can be concluded that the number of studies conducted to assess the performances of the various landscape interventions is small—especially compared with the extent of the interventions—thus, there is lack of adequate information about successes and failures of the efforts, which can undermine evidence-based planning and decision making.

- A large proportion of land restoration-related projects and most scientific evidence generated about their impacts focus on the tepid moist highlands. However, the largest studies were carried out in the warm submoist lowland agroecological zones. Projects were implemented in more than 24 agroecological zones, whereas scientific evidences are available only for 11 agroecological zones, suggesting that further, spatially targeted studies are needed representing different agroecological zones where there is shortage of evidences related to the impacts of land restoration projects (e.g., hot subhumid and submoist zones). Once such data are available, upscaling the impact of interventions at national scale using geographically representative case-studies would help to evaluate land restoration benefits at national level and guide interventions to be site specific.

- The dominant land management practices studied were different forms of CA, followed by soil and stone bunds, and exclosures.

- For productivity, the highest effect was observed from bunds + biological intervention followed by CA practices, with 170% and 18% increase, respectively. The other interventions (bunds, fanya juu, and biological) reveal negligible effect on productivity. This indicates the need for developing integrated land management practices that enhance multiple ecosystem functions and/or identifying appropriate practices and targeting where they can generate maximum benefit.

- For SOC, the effect of all interventions is positive, the highest effect being from “bunds + biological” (139%) followed by exclosure (90%). All interventions indicated decreasing effect on both soil loss and runoff. Fanya juu has the highest effect (−98%), followed by biological (−75%) and bunds (−74%) on soil erosion, whereas the highest effect was obtained from exclosure (−91%), followed by “bunds + biological” (−58%) and bunds (−57%) for runoff. The age of intervention was found to be an important determining factor affecting the performances of interventions.

- Generally, it can be concluded that the number of studies conducted to assess the performance of the various landscape interventions are small—especially compared with the extent of the interventions—thus, there is lack of adequate information about successes and failures of the efforts, which can undermine evidence-based planning and decision making.

- Many of the studies that attempted to assess the contributions of water and land restoration interventions in Ethiopia are sectorial; that is, they are limited to one or few aspects of the contributions. Such lack of systematic, integrated, and compressive assessments can blur the ‘true’ picture of the significant biophysical,
socioeconomic, and other cobenefits of SLM and restoration efforts. In the long term, this can also undermine the negotiation power of communities and country when negotiating payment for ecosystem services. Socioeconomic and livelihood impact studies are needed to understand the social acceptance and direct and indirect benefits such as cultural ecosystem services.

- For a complete understanding of land restoration initiatives, properly designed studies are needed to assess the cost effectiveness, net social benefit, and trade-off analysis among ecosystem services for each intervention type.

ACKNOWLEDGMENT

This research was undertaken with support from the Africa RISING, a program financed by the United States Agency for International Development (USAID) as part of the U.S. Government’s Feed the Future Initiative. The content is solely the responsibility of the author/s and does not necessarily represent the official views of USAID or the US. Government or that of the Africa RISING programme. Africa RISING is aligned with research programmes of the CGIAR. The Water, Land and Ecosystems (WLE) program of the CGIAR has equally provided financial support to this research. Reproducibility: The database and R codes used to produce the results in this paper can be obtained from the first author by request.

ORCID

Wuletawu Abera https://orcid.org/0000-0002-3657-5223
Lulseged Tamene https://orcid.org/0000-0002-4846-2330
Degefie Tibebe https://orcid.org/0000-0002-5340-6077
Zenebe Adimassu https://orcid.org/0000-0002-7645-918X
Habtemariam Kassa https://orcid.org/0000-0003-4307-4889
Gizaw Desta https://orcid.org/0000-0002-3565-7665

REFERENCES

Adimassu, Z., Langan, S., & Barron, J. (2018). Highlights of soil and water conservation investments in four regions of Ethiopia (vol. 182). International Water Management Institute (IWMI). http://www.iwmi.cgiar.org/Publications/Working-Papers/working/wo182.pdf
Adimassu, Z., Mekonnen, K., Yirga, C., & Kessler, A. (2012). The effect of soil bunds on runoff, losses of soil and nutrients, and crop yield in the central highlands of Ethiopia. Land Degradation & Development, 25, 554–564. https://doi.org/10.1002/ldr.2182
Balehegn, M., Haile, M., Fu, C., & Liang, W. (2019). Ecosystem-based adaptation in Tigray, northern Ethiopia: A systematic review of interventions, impacts, and challenges. In Handbook of climate change resilience (pp. 1–45).
Central Statistics Authority (2007). Population census (p. 2007). Ethiopia: Addis Ababa.
Devereux, S., Sabates-Wheeler, R., Slater, R., Tefera, M., Brown, T., & Teshome, A. (2008). Ethiopia’s Productive Safety Net Programme (PSNP): 2008 assessment report. Sussex: IDS.
ELD Initiative (2015). The value of land: Prosperous lands and positive rewards through sustainable land management. The Economics of Land Degradation. Bonn, Germany: ELD Initiative.
Eva, R. (2001). Advanced bibliometrics method as quantitative core of peer review based evaluation and foresight exercises. Scientometrics, 36(1), 397–420. https://doi.org/10.1007/BF02129602
Gashaw, T. (2015). The implications of watershed management for reversing land degradation in Ethiopia. Research Journal of Agriculture and Environmental Management, 4(1), 5–12.
Gashaw, T., Bantider, A., & Silassi, H. G. (2014). Land degradation in Ethiopia: Causes, impacts and rehabilitation techniques. Journal of Environment and Earth Science, 4(9), 98–104. https://doi.org/CiteSeeX.pspu.10.1.1.1011.3015
Gebrehiwot, S. G., Bewket, W., Gärdénäs, A. L., & Bishop, K. (2014). Forest cover change over four decades in the Blue Nile Basin, Ethiopia: Comparison of three watersheds. Regional Environmental Change, 14(1), 253–266. https://doi.org/10.1007/s10113-013-0483-x
Gebreselasie, S., Kini, O. K., & Mirzaeibaev, A. (2016). Economics of land degradation and improvement in Ethiopia. In E. N. A. Mirzaeibaev, & J. von Braun (Eds.), Economics of land degradation and improvement—A global assessment for sustainable development. Switzerland: Springer International Publishing AG. https://doi.org/10.1007/978-3-319-19168-3
Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D., & Lesschen, J. P. (2005). Assessment of soil nutrient depletion and its spatial variability on smallholders’ mixed farming systems in Ethiopia using partial versus full nutrient balances. Agriculture, Ecosystems & Environment, 108(1), 1–16. https://doi.org/10.1016/j.agee.2004.12.010
Hedges, L. V., Gurevitch, J., & Curtis, P. S. (1999). The meta-analysis of response ratios in experimental ecology. Ecology, 80(4), 1150–1156. https://doi.org/10.1890/0012-9658(1999)080[1150:TMAORR]2.0.CO;2
Hurni, K., Zeleke, G., Kassie, M., Tegegne, B., Kassawmawr, T., Teferi, E., Mages, A., Tadesse, D., Ahmed, M., Degu, Y., Kebebew, Z., Hodel, E., Amidahun, A., Mekuriaw, A., Debele, B., Deichert, G., Hurni, H. (2015). Economics of Land Degradation (ELD) Ethiopia Case Study: Soil degradation and sustainable land management in the rainfed agricultural areas of Ethiopia: An assessment of the economic implications. Report for the Economics of Land Degradation Initiative. 94 pp. Available from: www.eld-initiative.org
International Soil Reference and Information Center. 2015. African soil grids 250 m, African soil map.
Luo, Y., Hui, D., & Zhang, D. (2006). Elevated CO₂ stimulates net accumulations of carbon and nitrogen in land ecosystems: A meta-analysis. Ecology, 87(1), 53–63. https://doi.org/10.1890/04-1724
Meza, H., Tsegaye, D., & Nyssen, J. (2016). Allocation of degraded hillsides to landless farmers and improved livelihoods in Tigray, Ethiopia. Norsk Geografisk Tidsskrift-Norwegian Journal of Geography, 70(1), 1–12. https://doi.org/10.1080/002919501.2015.1091033
Ministry of Agriculture (2000). Agro-ecological zones of Ethiopia on 1:2,000,000 scale. MoA, Addis Ababa: Natural Resource Management and Regulatory Department.
Ministry of Agriculture and Rural Development (2014). Productive Safety Net Programme implementation manuals. Addis Ababa, Ethiopia: Ministry of Agriculture and Rural Development, Government of the Federal Democratic Republic of Ethiopia.
Ngessa, B., & Wickrema, S. (2010). Disaster risk reduction: Experience from the MERET project in Ethiopia. Revolution from Food Aid to Food Assistance: Innovations in Overcoming Hunger.
Regional Center for Mapping Resources for Development. 2008. Major land cover types for Ethiopia. Nairobi, Kenya.
Sommer, R., & Bossio, D. (2014). Dynamics and climate change mitigation potential of soil organic carbon sequestration. Journal of Environmental Management, 144, 83–87. https://doi.org/10.1016/j.jenvman.2014.05.017
Taddese, G. (2001). Land degradation: A challenge to Ethiopia. Environmental Management, 27(6), 815–824. https://doi.org/10.1007/s002670010190
Tamene, L., & Le, Q. B. (2015). Estimating soil erosion in sub-Saharan Africa based on landscape similarity mapping and using the revised universal soil loss equation (RUSLE). *Nutrient Cycling in Agroecosystems, 102*(1), 17–31. https://doi.org/10.1007/s10705-015-9674-9

Tamene, L., & Vlek, P. L. G. (2007). Assessing the potential of changing land use for reducing soil erosion and sediment yield of catchments: A case study in the highlands of northern Ethiopia. *Soil Use and Management, 23*(1), 82–91. https://doi.org/10.1111/j.1475-2743.2006.00066.x

The Montpellier Panel (2014). No ordinary matter: Conserving, restoring and enhancing Africa’s soils. Dec 2014.

Woldearegay, K., Tamene, L., Mekonnen, K., Kizito, F., & Bossio, D. (2018). Fostering food security and climate resilience through integrated landscape restoration practices and rainwater harvesting/management in arid and semi-arid areas of Ethiopia. In *Rainwater-smart agriculture in arid and semi-arid areas* (pp. 37–57). Cham: Springer. https://doi.org/10.1007/978-3-319-66239-8_3

**How to cite this article:** Abera W, Tamene L, Tibebe D, et al. Characterizing and evaluating the impacts of national land restoration initiatives on ecosystem services in Ethiopia. *Land Degrad Dev.* 2020;31:37–52. https://doi.org/10.1002/ldr.3424
### APPENDIX

#### TABLE A1  Variables and templates used to extract data from the literatures

| ID | Authors | Year | Latitude | Longitude | Scale | Elevation | Land use | Rainfall | Intervention type | Duration of intervention | Ecosystem services (ES) or parameters | ES value at with/treated | ES value at without/control |
|----|---------|------|----------|-----------|-------|-----------|----------|----------|-------------------|-------------------------------|-------------------------------|--------------------------|--------------------------|
|    | Description | Each paper is indexed with ID to separate papers from case-studies | Authors are used to index papers | Years of publication is extracted to understand the temporal trends of studies | The latitude and longitude are extracted to locate the study areas and to overlay with other spatial datasets | Used to identify if studies are plot or watershed/landscape scale | These data are used to characterize the studies in terms of elevation, land use/cover, and rainfall | Refers to which kind of intervention(s) each paper is analyzed | For how long the intervention has been implemented | Which ecosystem services such as soil parameters, e.g., soil pH, soil organic carbon, and soil macronutrients and micronutrients; hydrological parameters, e.g., runoff, evapotranspiration, and soil moisture; and agricultural parameters, e.g., productivity | Values obtained in treated sites | Values obtained in control sites |