Creating multifunctional climate resilient landscapes: approaches, processes and technologies

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Summary

The report outlines major activities related to efforts to create multifunctional climate resilient landscapes under various projects. The interventions were mainly in the highlands of Ethiopia but the lessons can be scaled to other regions. The key objectives were: (1) co-identification and co-implementation of land water management options at landscape scale; (2) generation of evidences about the performances of the various soil and water conservation practices implemented in learning watersheds and upscaling sites; (3) provide capacity building to different stakeholders in the study areas. The first two are continuation of the implementation and monitoring processes in place to restore degraded landscapes and evaluate dynamics over time while the latter one focuses on providing trainings to different actors as identified during stakeholder consultations. The results show the need for: (a) sectoral coordination to sustain interventions, (b) continuing awareness creation to communities on the benefits of land and water management interventions, (c) creating evidences about the performances of interventions to learn lessons and scale successful ones, and (d) build capacity of stakeholders on both problems analysis, technology identification, matching options with context and evidence generation. Engaging stakeholders who are activate in the study sites has been instrumental to enhance coordination and promote synergy.

1. Background and justification

The recent IPBES report provides a demining picture about the impacts of land degradation on the environment and humanity revealing its far reaching implications, impacting food, water and energy supply, as well as the livelihoods of at least 3.2 billion people (IPBES, 2018). Land degradation affects between 25% and 30% of all land on the planet, and over 40% of all agricultural land (ELD Initiative, 2015). Global estimates suggest the world lost USD 4-20 trillion per year in ecosystem services owing to land-cover change (Costanza et al., 2014) and USD 6.3-10.6 trillion per year from land degradation (ELD Initiative, 2015). Projected increases in world population, continued unsustainable land use practices, lifestyle changes and associated changes in consumption demands will pose additional pressures on land.

In Ethiopia, land degradation is a major problem of livelihoods and economic growth. The cost of land degradation between 2001-2009 periods is about 35 billion USD in Ethiopia (Gebreselassie et al., 2016). This represents about 23%, of GDP in Ethiopia. The annual cost of land degradation associated with land use and cover change in Ethiopia is estimated to be about $4.3 billion (Gebreselassie et al., 2016). Only about 51% of this cost of land degradation represents the provisioning ecosystem services while the remaining 49% represent the loss of supporting and regulatory and cultural ecosystem services (Gebreselassie et al., 2016). The effect of land degradation is more compounded by increasing human population and climate change. The human population in the country will reach over ca. 170 – 210 million by 2050 (Bekele and Lakew, 2014; Dayno et al., 2017)) whereby crop production must be increased by 60–100% to meet the nutritional needs (Yohennes, 2020). A study shows that the economy-wide and regional effects of climate change on national GDP can reach up to -8% with uneven regional effects ranging from -10% in agrarian regions to +2.5% in urbanized regions (Yalew et al., 2017). The costs of action to rehabilitate lands degraded during the 2001–2009 period through land use and cover change were found to equal about $54 billion, whereas if nothing is done, the resulting losses may equal almost $228 billion during the same period (Gebreselassie et al., 2016). The costs of action against land degradation are lower than the costs of inaction by about 4.4 times, implying that a dollar spent to rehabilitate degraded lands returns about 4.4 dollars in Ethiopia (Gebreselassie et al., 2016).

Widespread efforts are being made to curb the impacts of land degradation and to ensure the provision of food, water, and other ecosystem service to future generations through land restoration, increased land use efficiency and adoption of sustainable land management practices (Godfray et al., 2010; WRI, 2019). These efforts are reflected in the global agendas through the various targets related to the Sustainable Development Goals (SDGs), the Convention on Biological Diversity (CBD), the United Nations Framework of the Convention on Climate Change (UNFCCC) and the United Nations Convention to Combat Desertification (UNCCD). In particular target 15 “Life on Land” has been devoted to the protection, restoration and sustainable use of terrestrial ecosystems (UN, 2015).

In Ethiopia concerted efforts have been made to restore degraded areas and promote sustainable land management options since the 1970s. The Ethiopian government realized that the business-as-usual path of development would worsen the level of degradation of natural resources. Hence, promoting sustainable intensification, protecting and properly managing existing land, water and forests and woodlands, and establishing new forests through afforestation and reforestation have been identified as priorities of the government in its 2011 Climate Resilient Green Economy (CRGE) Strategy. The strategy was designed to foster a green economic development path, and support adaptation to climate change by limiting emission of GHGs to the 2010 level, estimated at 150 Mt CO_2e (CRGE, 2011). The ongoing 5-year development plan of the government aims to put 2 million ha of natural forests under Participatory Forests

Management (PFM), while identifying and demarcating 4.5 million ha of degraded land for afforestation or reforestation and supporting national tree planting initiatives to increase national forest cover by 4.5%. As part of the Bonn Challenge, the government also pledged to rehabilitate 15 million ha of degraded landscapes by 2025, a pledge that was increased to 22 million at the 2014 UN Climate Summit in New York. The county has also been investing about $1.2 billion annually on land restoration only in the four-major region over the last 10 years (Adimassu et al., 2018).

Though the extent varies from place to place, evidences suggest that the landscape restoration, reforestation, development and management interventions have had reasonable impact on improving ecosystem health and livelihoods of millions of people in Ethiopia. Visible signs of resilient landscapes and communities are also emerging in association with restoration initiatives. However, the adoption of sustainable land management practices and the associated benefits are limited compared to the level of effort being put in place every year. Some of the reasons include the top-down nature of the planning and implementation and lack of awareness by communities as they were engaged in soil and water conservation works on the basis of food-for-work program, especially during the earlier stages. In addition, biophysical measures were dominantly used, which generally were not very effective. Lack of integrated approaches that can bring complementary benefits was another problem that undermined widespread success. Because land restoration benefits accrue over long-time there should have been concerted effort to implement income generating options. In the later stages, most of the problems have been addressed whereby community engagement is more of participatory based and physical, biological and water harvesting options were integrated. However, there are still challenges in identifying priority areas of intervention, identifying local specific and suitable management practices and in generating evidences of impacts of the interventions to promote data-based and knowledge informed decision making while targeting and scaling technologies. The sustainability of the current approach where the farmers have to do backbreaking work every year with a need to frequently maintain those structures are questionable. In some cases, restoration/conservation efforts do not consider potential tradeoffs with crop and livestock production systems.

The main aim of the project is to develop frameworks and tools that can facilitate employment of integrated climate-smart technologies and practices to 'create' multifunctional landscapes that can provide multiple benefits to multiple users across landscapes. It also aims to develop strategies in order to support generating comprehensive evidences related to the impacts of land restoration efforts. Despite various efforts to restore degraded areas, the benefit of restoration is hugely underestimated and undervalued mainly because the multifunctional services of parcels are not considered adequately. Inability to account the direct and indirect benefits can also undermine the true impacts of land degradation and can dilute the urgent-ness of the measures to be taken to tackle the problem.

2. Objectives

The aim of the study was to create resilient landscapes through integrated climate-smart land and water management options. The main objectives include: (1) co-identify and characterize priority areas of intervention to understand constraints and potentials; (2) identify and implement suitable land management technologies in a participatory manner; (3) generate quantitative evidences about the performances of the interventions in terms of multiple ecosystem services; and (4) build capacity of stakeholders in terms of technology targeting and evidence generation.

3. Overall approaches

3.1. Develop operational framework

Restoring landscape health requires undertaking a sequence of steps starting from deciding where to prioritize (hotspot diagnosis) to assessing whether the investments where worthwhile. The pathways of restoration can vary from place to place as every landscape and country is different, but the overall engagements can be defined in three steps that can be followed during land restoration efforts so that potential pitfalls are avoided and successes are accelerated. The three steps are (WRI, 2019; Buckingham et al., 20219): (a) understand the 'land condition' and be participatory; (2) define goals and set choices; and (3) build system to track progress. Unpacking the three steps into mode details can result in ten interlinked activities that need to be performed when restoring landscapes (Fig. 1). Defining such detailed framework and monitoring implementations can enable tracking progress and making relevant adjustments when necessary.

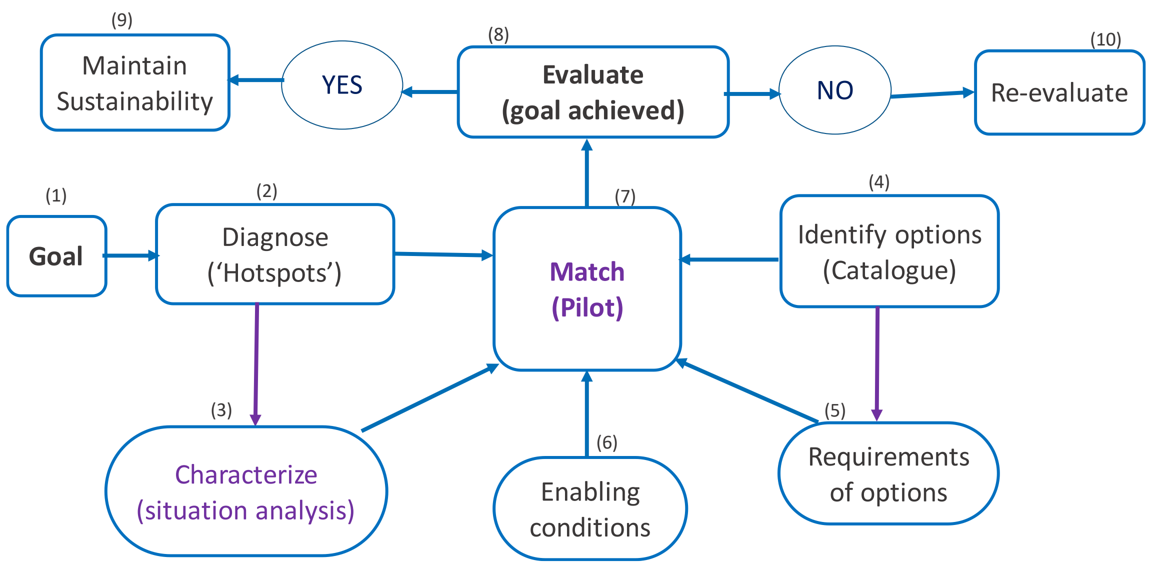


Figure 1. Framework to guide identification of hotspot areas (diagnose), characterize the areas (constraints, potentials), identify SLM options to target the hotspots, characterize the options (requirements, constraints, potentials), match options with context (implement options), and assess impacts including tradeoffs

Fig. 1 highlights that setting a goal is essential and primary step in landscape restoration schemes so that adequate preparation can be made about the subsequent activities. Realizing that degraded landscapes cannot be returned to their original status, it will be wise to define an achievable goal with reasonable time and resources. It is also necessary to make sure that goals are not understated not to spend time, energy and resources for a little target that will not bring much benefit. The evaluation step (step 8 in Fig. 1) will then be geared towards the stated goals. Once the goal of what to achieve is decided, the next steps will be about the where, what and how. Because all parts of a potentially degraded landscape cannot be restored, diagnosing hotspot where interventions should be prioritized and characterizing in terms of constraints and potentials will be necessary. Once landscape characteristics and environmental conditions are known, suitable technologies/practices can be identified and their characteristics and requirements assessed. This is an essential step and needs to be done in a participatory manner. The options should not only be suitable to the area but also should be those which can generate income, provide multiple benefits and do not lead to tradeoffs. Ex-ante analysis can be conducted to determine the types and optimum combination of suitable technologies. This can then be followed by matching the options with the corresponding landscape conditions during implementation. Model-based scenario analysis can be instrumental to estimate potential gains under given management options and assess tradeoffs before implementation.

Since landscape restoration is a complex process that takes long time to accrue benefits, it is essential to assess progress frequently to make sure that the efforts do not resort to tradeoffs and negative impacts. There are some cases in Ethiopia that 'wrong' placement of land and water management options (e.g., ungraded trenches on some soils) have led to water logging undermining crop production.

3.2. Co-identify and co-implement linked options following the landscape continuum

As indicated in Fig. 1, matching options with context is the central component of landscape restoration efforts. This is the stage where plans are put into practice and care should be taken to maximize benefits while avoiding negative externalities. Since restoration is not intended to fix a single problem at a given spot, it is necessary that technologies be placed across the landscape continuum (Fig. 2). Though local variations are expected due to variable in landscape attributes (including land use/cover types) and the associated requirements of land and water management technologies, the general tendency is that a mosaic complementary and linked technologies are placed across the landscape. Afforestation/reforestation are common practices on the upper part of the landscape baring than competing uses do not exist. Soil and water conservation structures occur at the upper landscape; water harvesting schemes at the middle and lower landscape, and different soil improvement and water storage technologies within the respective farmlands. These options can be co-located and/or staggered across space considering complementary. Soil and water conservation measures are generally completed with biological options with multiple benefits to retard soil erosion, enhance soil moisture, improve soil health, and provide fodder for livestock. In addition, fruit/vegetable crops can be integral components manly associated with homesteads and water harvesting sites.

3.3. Integration across sectors and scale

Landscapes may not necessarily be bounded by hydrological or biophysical units. Rather, they can be extended beyond watershed boundaries as they encompass land users and social groups outside of a given hydrological zone. This means that the probability of the existence of various land uses and users will be high. In areas where different interest groups with varies land use preferences exist the kind of management options can also vary. In addition, the landscape can include upslope-downslope configurations with different needs and priorities. At the landscape scale institutes and stakeholders who are set to manage water, land and forest can have their own competing interests (Fig. 3). Even within a given farm, there can be competing needs in terms of crop, livestock and fodder management (Fig. 3). Then there is interaction of processes between the different scales that can influence processes at the other scale. There is thus a need to consider and account competing uses and users of resources when planning landscape restoration. This means bringing various stakeholders together to discuss priorities, needs, preferences and develop working modalities. Detailed tradeoff analysis between overall production-conservation goals and competing needs and uses within each will be essential. This can enable identifying and implementing land and water management interventions that consider the landscape configuration, potentials, upslope-downslope interactions, and that provide multiple benefits to enhance both productivity and resilience of landscapes and communities. Such approach that also enable to promote sectoral/institutional integration and implement complementary options across the landscape continuum to enhance both ecological, economic and socio-cultural benefits and ultimately sustain peoples' livelihoods and economic growth in a sustainable manner.

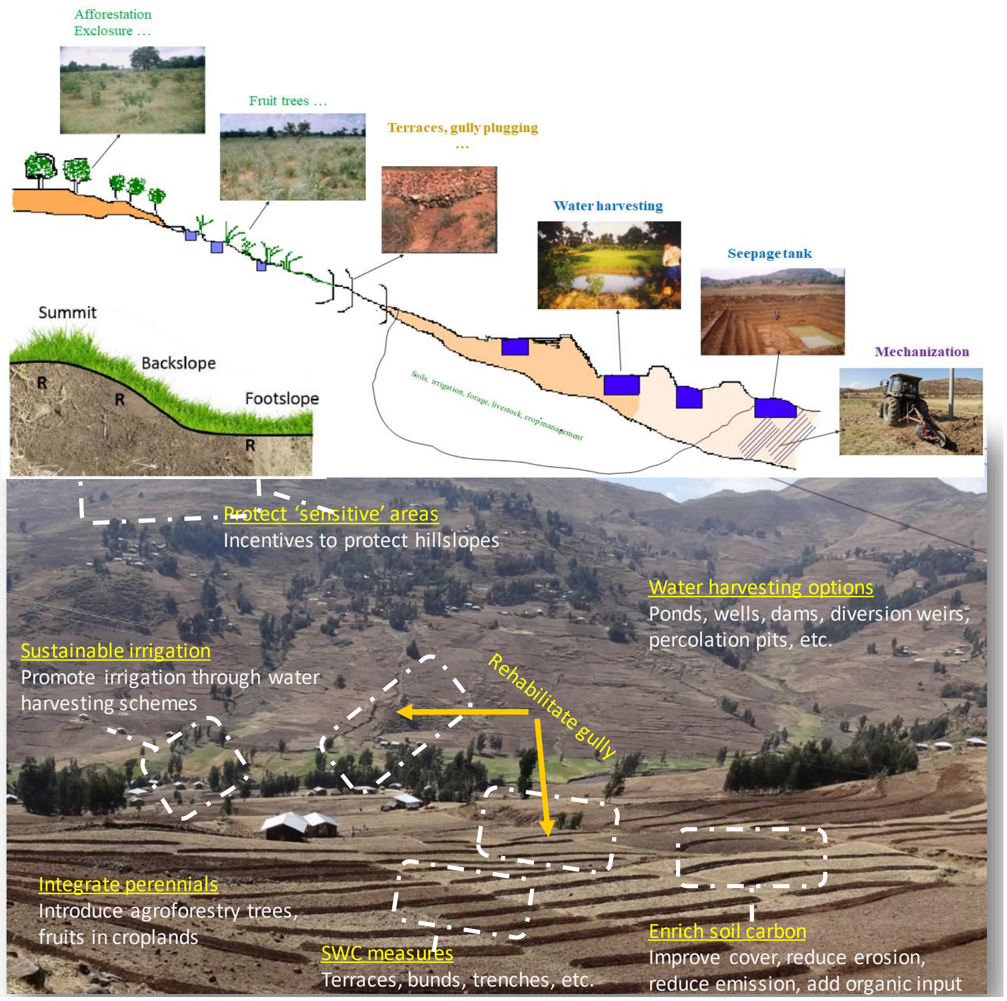


Figure 2. Land and water management technologies that can be implemented across the landscape continuum to address different problems and maintain complementarity. Top figure modified and adapted from Desta et al. (2005).

3.4. *Ensure participatory stakeholder engagement*

The key approaches involved stakeholder engagement to discuss on technologies to be scaled and agree on implementation modalities and implementation of integrated land and water management options at landscape scale. To achieve the former we identified key stakeholders operating in our sites of interest and discussed how we can bring forces together and co-implement activities. The latter was undertaken in a participatory manner whereby relevant stakeholders and local communities with the AR team co-identify technologies that are suitable in their environment and at the same time that can bring multiple benefits. This is an essential step mostly undermined during watershed management programs where researchers and/or development organizations tend to be prescriptive. The idea is to promote participatory selection, implementation and performance evaluation/monitoring of technologies.

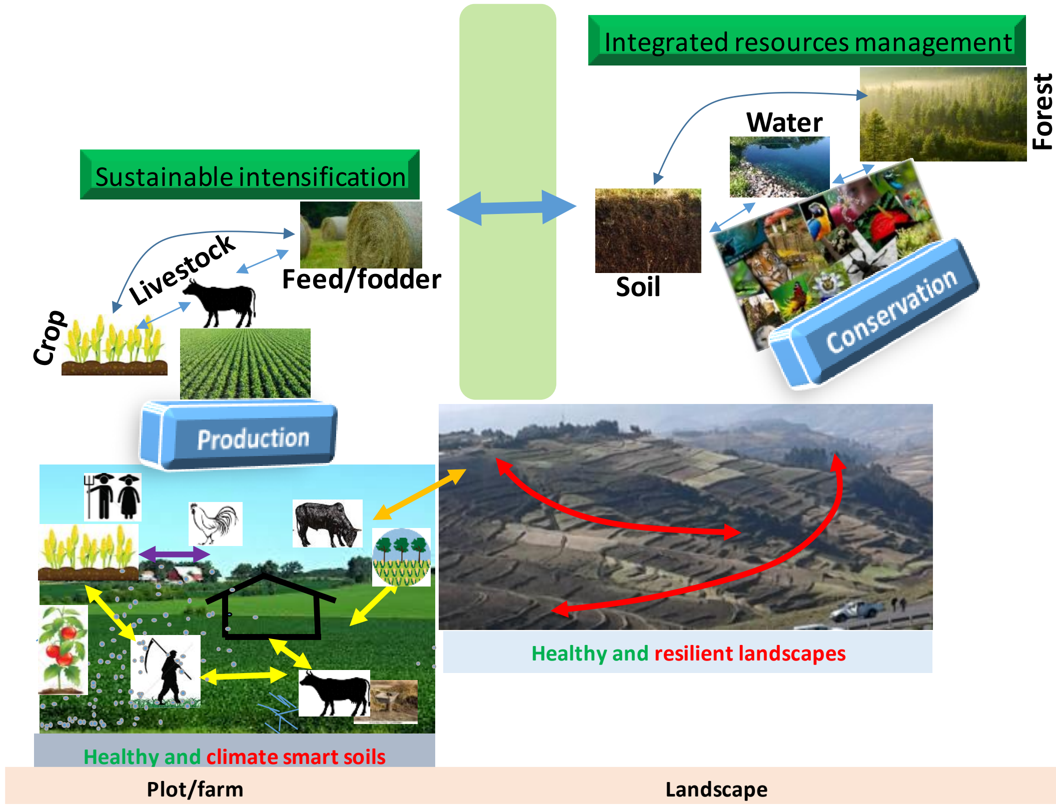


Figure 3. Interactions and feedbacks between different uses and users of land across scale

For restoration to be sustainable at landscape scale it has to be in sync with intensification at farm/plot scale. The actions and processes at the two levels can be made complementary through coupling landscape restoration and sustainable intensification efforts that promote multiple benefits to multiple users at multiple scales – what we call restoration-intensification continuum (Fig. 2, 3, 4). Integrated soil health improvement and soil fertility enhancement measures in the form of integrated soil fertility management and conservation agriculture should be implemented at farm level, as part of sustainable intensification strategy. The overall effort will be to identify practices and policy recommendations that can enhance system productivity while maintaining ecological integrity, facilitating synergies and managing tradeoffs between different uses, users and management options. This can ultimately facilitate developing land use and management plans that strike an appropriate balance between social, environmental and economic concerns.

Since managing all positions of the landscape will not be possible economically and technically, identification of priority areas of intervention in a participatory manner will be necessary. The priority area identification can focus on degradation hotspots or on those areas that can bring the maximum benefit to larger number of users' downslope.

Negotiation and understand with different land users and upstream-downstream users will be essential because in most cases restoration efforts upslope generate more benefits upslope. Developing benefit sharing strategies can be important to sustain both the interventions and their associated benefits.

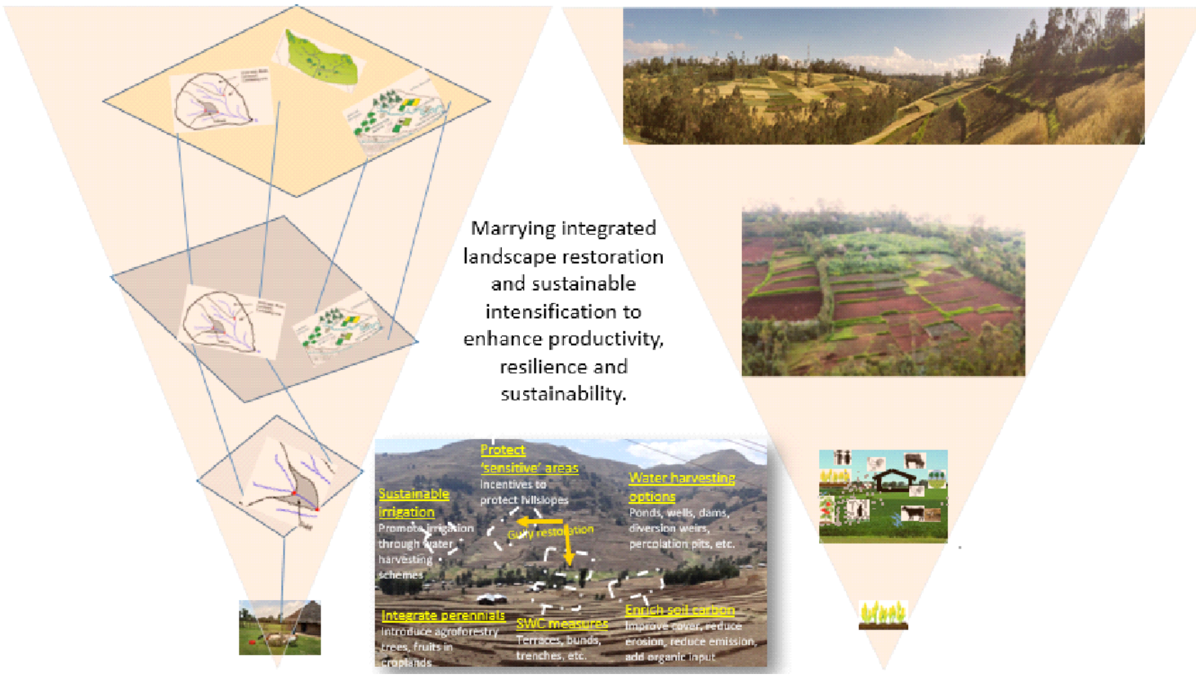


Figure 4. Integrated implementation of landscape restoration and CSA practices across scale (restoration-intensification continuum) to enhance productivity and resilience of systems through promoting complementarity and synergy

4. Technology implementation

Based on the above approaches, integrated land and water management technologies were implemented in various learning landscapes (Fig. 5) in collaboration with local partners and communities. In this report, we present the key interventions made at four of the landscape: Gule, Hocheche, Ginaberet and Tula. In both cases, local partners and actors were engaged during problem analysis, technology identification, implementation and impact evaluation to build buy-in and enhance adoption. In addition, technologies were principally implemented by local communities with the support of development and government organizations.

Considering our resources and time availability, different discussion and engagements were made with partners of the sites. In these sites management consortium and "multi stakeholder platforms" were established to support and coordinate project implementation. In some of the cases detailed discussions were made to develop integrated land and water management master plan for sustainable management of landscapes. For some engagements MoUs are being developed to 'formalize' the partnership and enable closer collaboration even beyond the project cycle. Once partnerships were arranged, implementations of technologies were conducted in the various sites. Examples of major activities and corresponding outputs are presented in the following sections. When necessary reference links are provided. For some separate reports are available that will be published in due course.

Implementation of different soil and water management options was a continuation of the previous work under the Africa RISING and WLE supported activities (Tamene et al., 2019). The prioritized interventions were based on observed major problems in the respective sites identified based on participatory engagements. In order to enhance sustainability, the identified technologies were based on their potential to bring multiple benefits of restoring degraded areas, sustaining catchment-scale benefits and enhancing farmers' resilience.

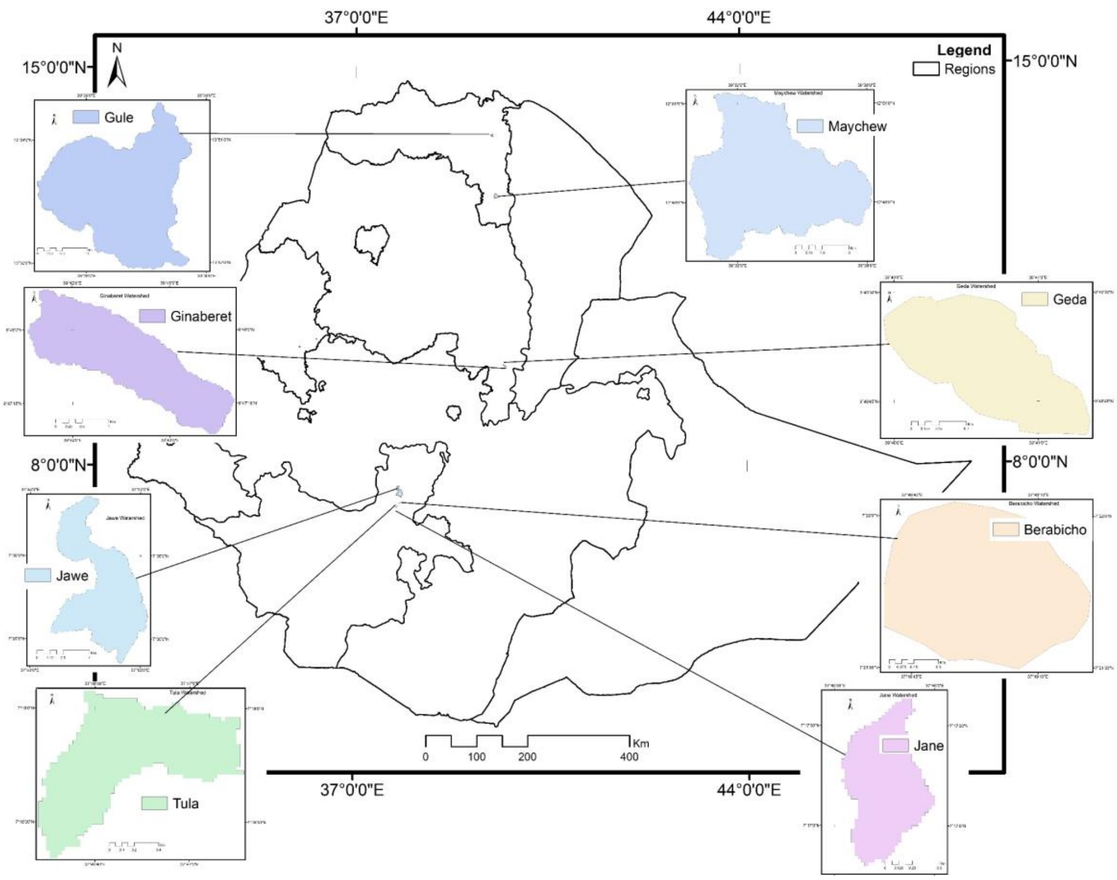
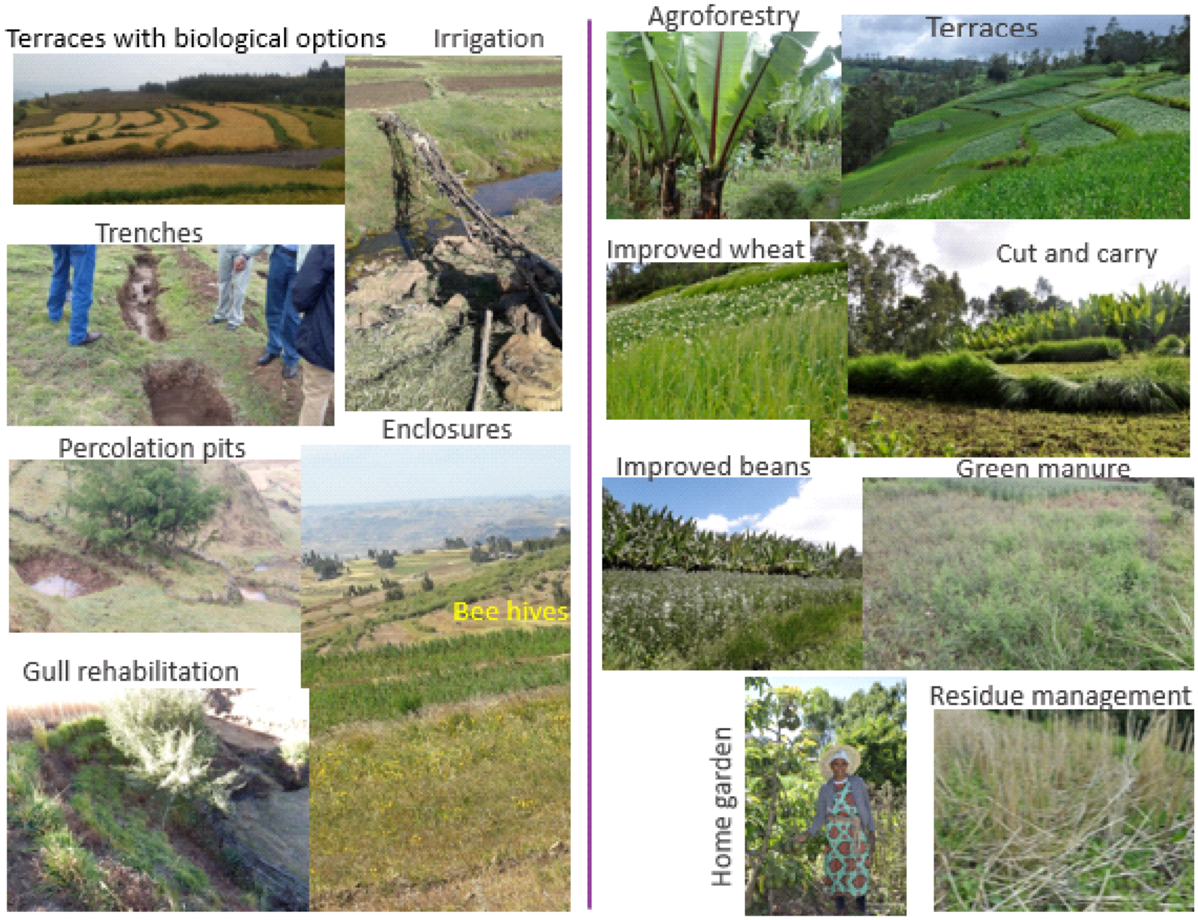


Figure 5. Location of the major learning watersheds in Ethiopia under the 'creating multifunctional landscapes' project

In the Debrebirhan (Godoberet-Adisge) site, the main focus included maintaining damaged terraces and continuing the restoration of the deep gully that damaged agricultural land in the area (Fig. 6a). This is also considering the fact that soil erosion was identified to be the major problem. A participatory land degradation and restoration priority mapping involving local communities and development workers indicated that soil erosion was the major problem of the communities in the area. This was due to absence ground cover, high rainfall and lack of widespread land management practices. The next critical problem identified by the communities was poor soil fertility and shortage of livestock feed.

In the Doyogena site, the main concerns of the local communities were shortage of drinking water (for people and livestock), shortage of feed for livestock due to competition from cropping land (because of high population density) and soil erosion. Accordingly, the main engagements focused on bringing in new forage-based interventions to complement the widespread practices by Inter Aide (Fig. 6b). Soil protection options through integrated soil terraces and biological measures were also key interventions. Due to the shortage of resources, water harvesting options were not introduced despite those are the priority needs of the community. With continued land

and water management practices underway there can be an opportunity to enhance baseflow and increase the potential for water harvesting options.



a. (b)

Figure 6. Glossary/Compendium of major CSA technologies implemented in the (a) Godoberet and (b) Doyogena sites. Note that the former is mainly coordinated by local stakeholders while the latter is by Inter Aide

Under the above engagements, more than 10 CSA practices_such as terrace with forages particular Desho grass, control grazing, improved verities (wheat, bean, and potato), crop rotation, crop residue, green manure, agroforestry, and cut and carry system were implemented were implemented in the Tule area. An approximate area of 400 ha was covered with these practices. Around 600 households benefited from the CSA practices. For the Ginaberet site, more than 6 CSA options such as terraces, terrace with biological measures, trenches, enclosure, percolation pits, check dam, and gully rehabilitation technologies were implemented. Approximately, about 1000 ha of land is covered with these practices. About 500 households benefited from the interventions.

For the Gule site, the major problem identified by the communities was soil erosion followed by shortage of water and livestock feed and poor soil health. The major interventions thus involved included water harvesting structures of various forms and soil and water conservation measures. Because of these integrated interventions, widespread benefits including small-scale irrigation are being enjoyed by the local communities. The youth are engaged in irrigation practices using pumps ad renting lands from their elderly parents. The key proponents and supports of the land and water management efforts of the development in the Gule site are the

Wukro St. Marry School. The Alliance mainly support evidence generation and capacity building components. The area is well developed and is acting as one of the exemplary model watersheds.

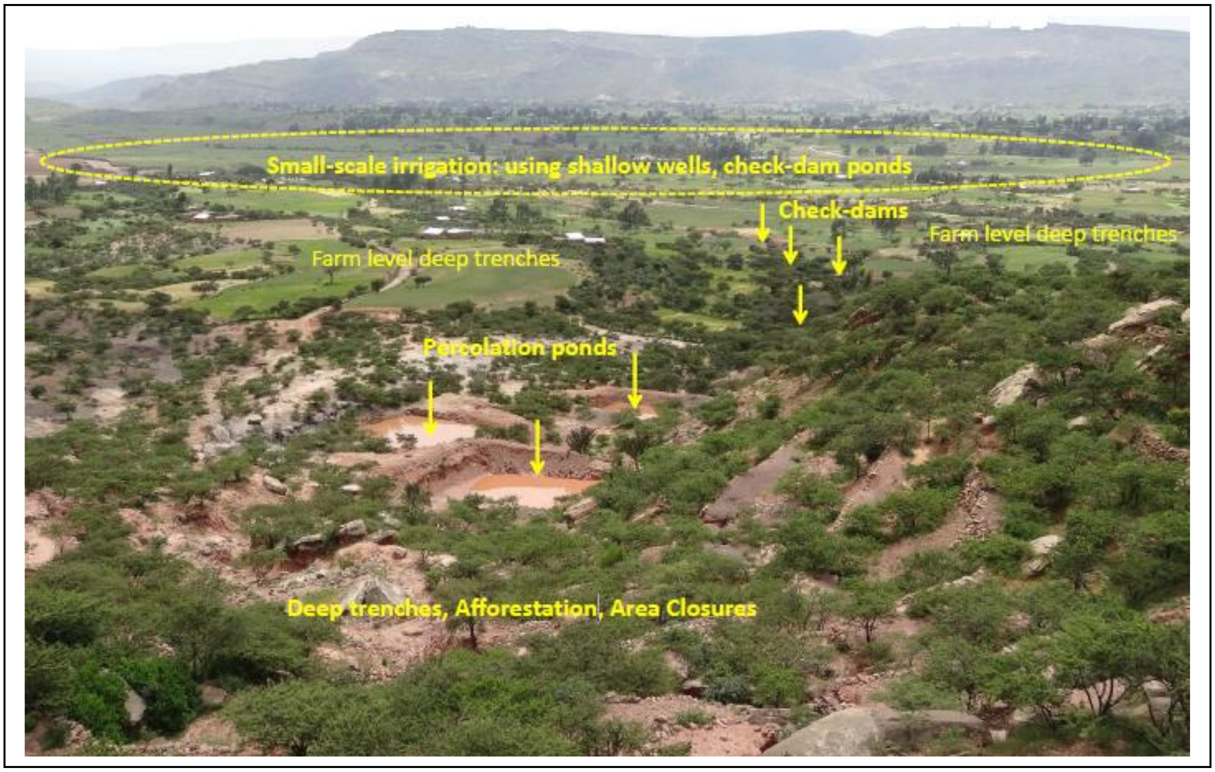


Figure 7. Complementary/linked technologies along the landscape continuum in the Gule watershed, Tigray, Ethiopia

The case of the Hocheche catchment is slightly different from the above sites. The landscape management work came from a request of the Borena Woreda Mekaneselam City Council in the south Wollo zone of the Amhara region to identify suitable location to construct a dam to provide drinking water for the population of city and its surroundings. Mekaneselam is an upcoming city with a population close to 100, 000. The city is attracting investment, small factories are booming and now the city hosts one of the campuses of Meqdella University. However, there is a serious shortage of drinking water, an answered question for many years.

A team of experts from the Alliance and the Africa RISING project (ILRI) travelled to the site to discuss with partners on the needs and priorities, evaluate the level of demand and assess the potential supply that can meet the available demand. This exploration led to the identification of a potential site (Fig. 8) accompanied by a detailed report which led the Amhara Region to move forward and allocate resources for the construction of a dam for drinking water (see brief here). Encouraged by the decision of the regional government for its preparedness to address the huge demand for drinking water, the team continued to provide support related to integrated land and water management options so that the dam will provide its intended services for the intended period of time. Since the Hocheche dam is located close to hilly/steep mountain chains with steep slopes and high erosion risk, siltation will be critical challenge unless measures are taken at early stages. Accordingly, the team discussed with relevant stakeholders to develop a detailed 'master plan' that can enable management of the dam catchment in a sustainable manner. Considering the fact that landscape restoration is an expensive venture and that research organizations are not meant to be involved in 'development-oriented interventions', our approach was focused on collaborating with government and development organizations in the areas of interventions. In this case, we established a partnership with the Amhara Bureau of Agriculture and Rural Development to support 'on the ground implementation of option and supervision'. We also co-developed a management consortium of "multi stakeholder platforms" that can support and coordinate project implementation.

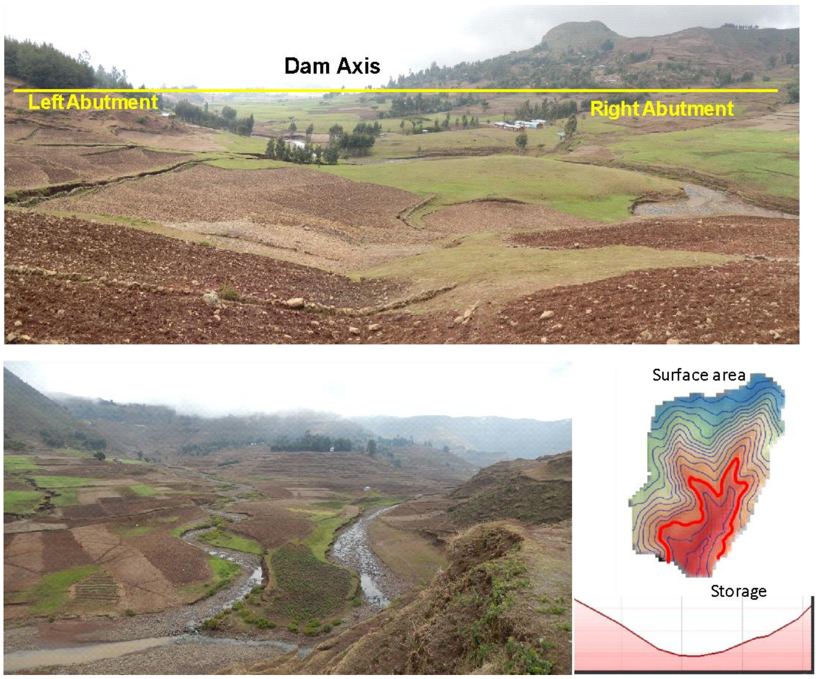


Figure 8. Location of the watershed and dam axis for proposed water supply dam

In order to create synergy and integration, we mapped stakeholders operating in the area and who can potentially support the watershed management work. Accordingly, key stakeholders and partners such as the Amhara Region NRCM, Borena-Saint National Park, Menschen für Menschen Foundation, KfW (Kreditanstalt für Wiederaufbau), Mekaneselam city council, Borena Woreda Admin, Hocheche Kebele admin and representatives of other offices were invited for joint discussion. As part of this exercise, a sub-committee was formulated to coordinate the overall dam construction and watershed management works.

During the discussion, stakeholders agreed to contribute their part to manage the dam catchment through integrated land and water management options. Income generating options such as agroforestry, fruits, vegetables, sheep fattening, bees and fishery were the key options suggested to be co-implemented in the area. It was also agreed that the dam along with the park can be a tourist attraction, which can create employment for the youth. There were also suggestions that people in the town will contribute their share to support the above endeavors and improve the livelihood and resilience of farmers in the watershed and surrounding areas of the dam. Since some farmers have already been displaced because of the dam construction and some will also be displaced for enclosures, it is necessary to support those livelihoods. In addition to the above options, payment for ecosystem services by those beneficiaries (downstream) need to be considered. This can be an exciting development because the possibilities to succeed are real as the commitment of the stakeholders/participants is very strong. This intervention in this location can be a typical case where we can demonstrate: (a) the need for "moving from mitigation to prevention of lakes/reservoirs from siltation hazards, and (b) multi-dimensional benefits of a well-planned and system based approach of integrated land and water management linked with other income generating activities and ecosystem services.

Once the main actors were identified and agreements were reached for a collaborative engagement, the next step was to develop an 'integrated watershed management plan' for sustainable management of the dam catchment. For this, the stakeholders met and discussed tentative management plans to guide on-site implementation during mass mobilization (Jan.-Feb., every year) and also prepare logistics for the summer (mainly seedlings) and capacity building needs. After consecutive meetings as well as field visits, preliminary management plan was designed considering the landscape continuum of the watershed (Fig. 9). This plan considered the landscape characteristics and the potential of different land and water management options.

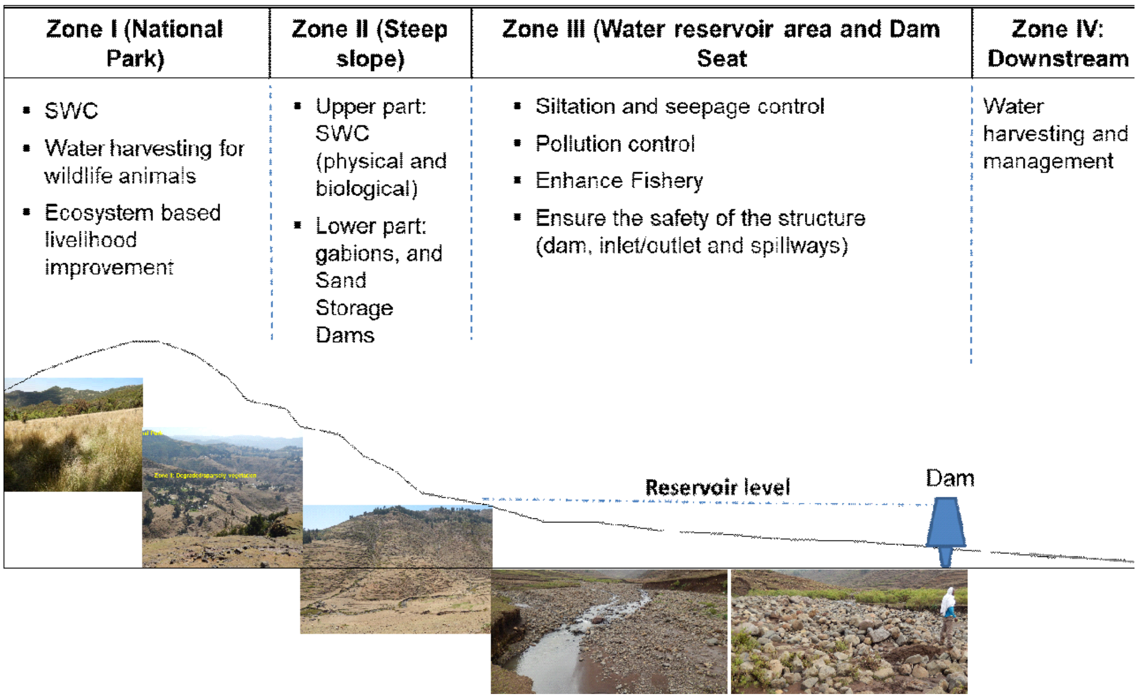


Figure 9. Preliminary watershed management plan of Hocheche dam in south Wollo

For operationalization purpose, the landscape was categorized into four zones and the potential intervention within each zone were mapped (Fig. 9). Zone I is part of a national park which is protected from interferences and has very good vegetation cover (Fog. 10). To promote wildlife conservation and ensure the sustainability of the forest, the possible interventions in this area include protection from interference (livestock and people) and promote water harvesting for various purposes (wildlife, reduce flooding, enhancing groundwater recharge, etc.). Generally, there will be no need to promote extensive plantation, rather agroforestry plantations at the lower part of the park can be useful.

The next level (zone II) has variable topography and is more degraded and has sparse vegetation cover (Fig. 10). This zone is expected to be the hotspot area for sediment supply to the reservoir for several reasons: (i) the area is steep with low vegetation cover, (ii) there are settlements in those areas, and (iii) there are signs of mass movements (small debris slides) which could endanger siltation of the dam. For this purpose, Zone II needs special attention in terms of land management. The key interventions recommended include (a): extensive SWC (area closures, biological measures, physical structures, etc.) at upper section of Zone II and (b) gabions and (sand storage dams) at lower section of the zone in order to trap sediments coming from the upstream areas before reaching the reservoir area.

Zone III is the lower part of the watershed including the area to be inundated by the reservoir water and the dam seat areas (Fig. 10). This is generally part of the sediment accumulation zone with the major part to be submersed with water when the dam starts to hold water. The possible interventions in this area include: (a) siltation and seepage control - there is a need to monitor the original ground level of the reservoir levels so that siltation rates could be monitored through time to enhance the lifetime of the dam. With the construction of the dam, some amount of seepage is expected and there is a need to monitor the amount, location and quality of seepage water from the dam (including discharge of springs); (b) pollution control- one of the advantages of Hocheche dam and its reservoir area is the fact that there are no major settlements in the watershed. The upper most part is a national park with dense vegetation cover and no pollution source is expected from this park. In the transition zone, between the park and reservoir (zone II), there are some settlements which need to be managed for the time being. In any case, since the water will be used for drinking, it is highly advisable to monitor the water quality of the water in the dam; (c) promote fishery in the dam reservoir, (d) ensure the safety of the structures - this needs proper frequent inspection and maintenance of the structures (dam, inlet/outlets, spillway, etc.).

The last part of the watershed (zone IV) covers the area below the dam. It will be good to implement proper water harvesting and management including proper utilization of seepage water, groundwater and any excess water from the urban water supply for different purposes such as small-scale irrigation. Since the amount of water available may not be enough to cover large areas it will be wise to develop appropriate plan and manage expectations to avoid conflict.

With the above overall plan and with close support of the Amhara Region NRCM team, the local communities already started implementing soil and water conservation measures – the site was given priority associated with our suggestions and the urgency of the matter (that the dam should not be constructed before sound landscape management measures are in place). The spatial configuration of the area complemented with the national park and the upcoming dam can make the site very interesting proof of concept for the realization of integrated land and water management options that provide multiple benefits to multiple users at different locations.

Figure 10. Scenery of the Hocheche dam catchment showing a partial view of the Borena-Saynt national park (upper part) and the middle and lower parts of the catchment. Note: the area where the reservoir water will lie is not visible in this picture.

As it stand now (Dec. 2020), more than ten key CSA practices such as crop rotation, intercropping, agroforestry, terraces, bunds and exclosures were implemented and will continue in the coming years. So far about 250 ha of land has been covered with the above practices and work is still under progress. About 265 households (243 male and 22 female) participated in the implementation of CSA practices in Hocheche watershed and will benefit from the interventions. When the water supply dam is finalized, it will provide water supply for the Mekaneselam town with population of more than 100, 000.

5. Evidence generation

5.1. Evidence generation from learning sites

5.1.1. In-situ soil moisture sediment concentration

Most of our reports thus far contained information about the dynamics of runoff and soil erosion associated with land management options. In this report, we focused on equally important variables that have been monitored in some of the study sites: in-situ soil moisture and sediment concentration (Fig. 11 and 12). The measurements were taken to assess the impact of *deep trenches with bunds* on soil moisture in the Gule watershed of the Tigray region.

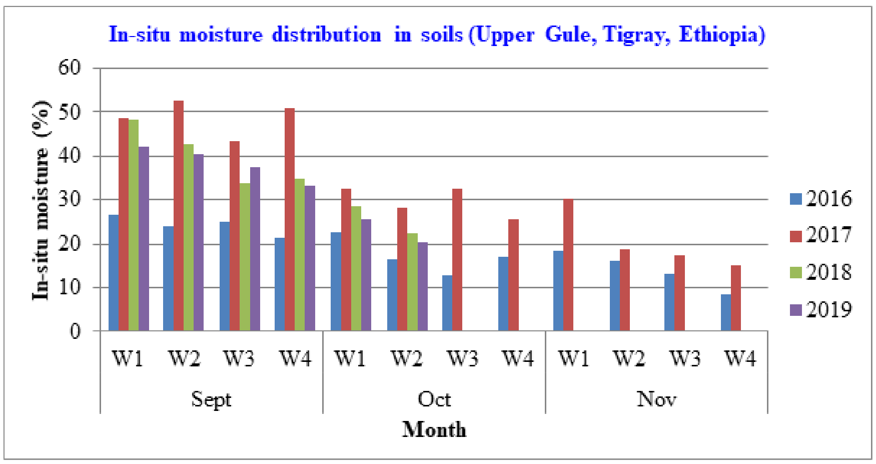


Figure 11. Effects of soil farm level interventions (deep trenches with bunds) on soil moisture in Gule watershed. Note that the intervention was done on January 2016, and the monitoring was done for the period September 2016 to October 15, 2019.

The results show that a significant increase in moisture content (up to 100%) was detected in soils during the maturity periods of crops (September to November). This is very interesting because the interventions have contributed to significant retention of water that can be available for crops and forages. Considering climate change and soil moisture deficit experienced in most parts of the region, this evidences can be crucial to augment agriculture in dryland areas.

The other time series measurement conducted in the same site was sediment concentration conducted in 3 small sub-catchments with different land management practices. As could be observed from Figure 12, after the intervention, sediment concentration has reduced from 65gm/lit in 2016 to 18 gm/lit in the year 2018 at downstream of a treated gully (with gabion check-dams). Similarly sediment concentration has reduced from 39gm/lit in 2016 (before the intervention) to 6gm/lit in 2017 (after the intervention) at downstream of percolation ponds. The construction of different gully rehabilitation check-dams and percolation ponds has reduced sediment concentration in addition to enhancing groundwater recharge and reducing flooding.

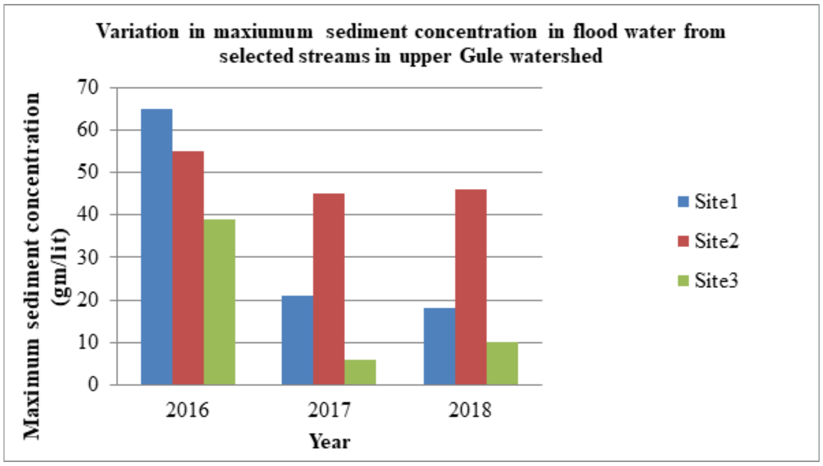
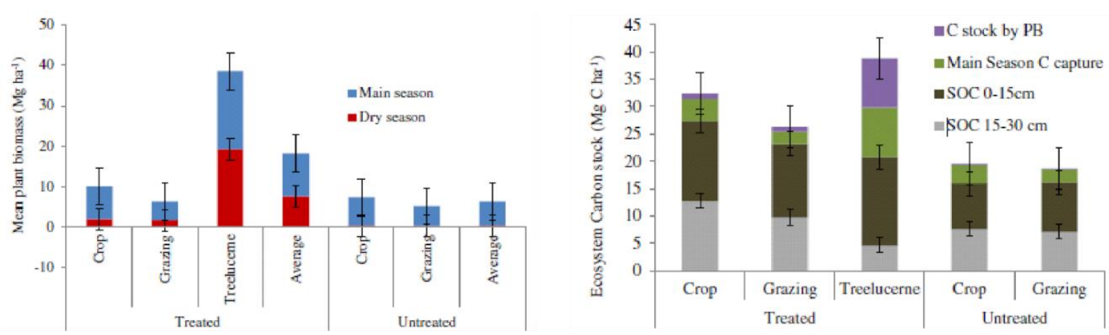


Figure 12. Variation in maximum sediment concentration in flood water from selected streams in upper Gule watershed in the period 2016-2018. Note: Intervention was done in December/January 2016 and measurement was done for 2016-September 2018 and measurement for sediment concentration was done in the months July to September. Site1 is downstream of the treated gully; Site2 is downstream of un-threated gully, and Site3 is downstream of series of percolation ponds.

5.1.2. *Impacts of CSA practices on plant biomass and carbon stock*

The impacts of SLM options in terms of different ecosystem services was assessed in various sites. In this report, we present an example study in the Ginaberet area, which was part of a PhD study (see this PhD Thesis). An on-site measurement was carried out to assess the impacts of the restoration efforts on plant biomass and carbon stock (Fig. 13). The analysis results show that plant biomass has increased in treated watersheds compared to controls (Fig. 13a). This was mainly associated with technologies such as tree Lucerne. In addition to plant biomass, available carbon stock of land use/cover types was assessed on treated and control sites. Following the introduction of tree lucerne and also higher level of biomass retention, a significantly higher carbon stock and sequestration was found in this landscape (Fig. 13b). This shows the multiple benefits of the option - its use as a livestock feed but also to store carbon and enhance soil fertility.



(a) (b)

Figure 13. Geda watershed (a) Mean plant biomass estimation by sub-watersheds and land-use types, both in the main and dry seasons. Error bars represent standard errors of the mean; (b) Ecosystem carbon stock: C=carbon, PB = plant biomass; SOC= soil organic carbon; cm: centimeters. C stock by PB is the sequestered carbon measured in the dry season. Main Season C capture is calculated from the main season plant biomass production part of which later was exported from the treated subwatershed while almost all of which was exported from the untreated sub-watershed. Error bars represent standard errors of the mean

A continuous measurement of subsurface flow was also conducted in the same watershed to analyze the impacts of upstream landscape management on enhancing water availability downslope. The positive impact of SWC interventions on water resource development at the treated sub watershed was observed by enhanced water productivity that benefited farmers from irrigating their plots. At the downstream of the treated sub watershed, irrigation beneficiary farmers increased from 25 to 29 and the irrigable land increased from 5.75 ha to 6.5 ha. Although the changes in the number of farmers and irrigable land were small, water productivity had increased adequately. Before 5 years, farmers were using low water demanding crops such as lentils and chickpeas with few farmers planting garlic; whereas, recently farmers are using high water demanding and high yielding vegetable crops such as carrot, onion and garlic. Thus, the farmers were able to increase their income from the sale of the yield and high value vegetable crops. At the untreated sub watershed, the number of farmers and irrigable land increased as well. This was not due to the increase in irrigation water but was due to the increase in farmers' understanding on the benefits of irrigation. Some farmers were able to utilize the available small water from springs to irrigate and grow few pulse crops such as lentils. This is observed as an interesting indirect effect of interventions.

5.1.3. *Impacts of land and water management options on soil loss*

Erosion plots experiments were established to compare discharge and soil loss from treated and non-treated sites to assess the impacts of management practices in place on soil loss and sediment export in the Ginaberet site (Gudoberet village) as part of this study. In this report we present sediment yield assessment results comparing treated and non-treated sub-watersheds. Sediment yield was assessed at catchment scale by considering a pair of sub-watersheds with similar terrain, soil, and land use characteristics within the study watershed. Two hydrological stations were installed at the outlet of the two sub-watersheds to measure sediment yield. The two sub-watersheds have an area of 33.83 and 22.08 ha. The former is treated with about 0.36 km ha^{-1} length terrace integrated with trench and grass strips, while the second is without any significant SWC structures in place (only in 2014). Measurements of sediment sampling were made on two gaged streams at the outlets of the two sub-watersheds. Gage readings were taken two times a day (morning and evening). If abrupt change in stream depth is observed especially during rainfall event, more than three measurements and sediment sampling were taken every day. To avoid bias on the estimation of the sediment export, data were collected as much as possible on a flow proportional basis since highest suspended sediments were observed during rainfall events.

Within 4 years, the highest mean soil loss rate (8.56 ton ha − 1) was recorded from unmanaged cropland and this is highly significantly ($P < 0.01$) compared to other land use types.

The results of the first year (2014) sediment yield assessment showed clear differences between the two sub-watersheds; with and without SWC practices. The suspended sediment yields (SSYs) of the sub-watersheds with (WS1) and without (WS2) SWC measures were significantly different ($P < 0.05$) at about 1.21 and 4.72 ton ha − 1, respectively in 2014. The SWC measures have trapped a considerable amount of sediment inside the trench in WS1. WS2 was more efficient in reducing sediment in all the three years, although, the SSY was not significantly different in 2015, 2016 and 2017. In the fourth year (2017), the SSY was 3.70 and 3.03 tons per hectare of land from WS1 and WS2, respectively. A 18% reduction in SSY was observed due to the younger (3 years old) SWC measures in WS2 in comparison with the older SWC one (5 years old) in WS1. The volume of the trench is reducing over the years due to siltation and sedimentation. As a result the efficiency of the structure (SWC) reduces as the age increases. Although, the regular maintenance of the structure is important for sustainability, it is rarely happening in the area. The statistical analysis also showed that in terms of SSY, there were no significant differences between the one, two, three and four year old SWC measures in both sub-watersheds that were observed in the second and third years of study.

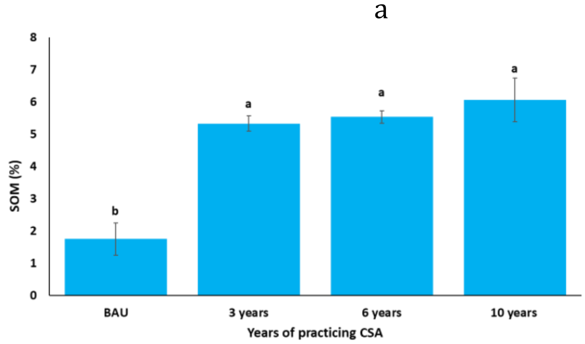
Just like the plot level observation, as the number of years since SWC measures were in place increased, their effectiveness declined. In the first year (2014), 291% more sediment yield reduction were realized due to SWC interventions at the sub-watershed level. In 2015, the older structure in WS1 was only 8% more efficient than the newer structure. SWC in sub-WS1 was 12, 17 and 18% less effective in sediment reduction than the sub-WS2 in years 2015, 2016 and 2017, respectively. As the age of SWC increases the trap efficiency of the trench reduced due to the lack of regular yearly maintenance.

5.1.4. Impact of CSA on soil health, soil moisture and GHG emission

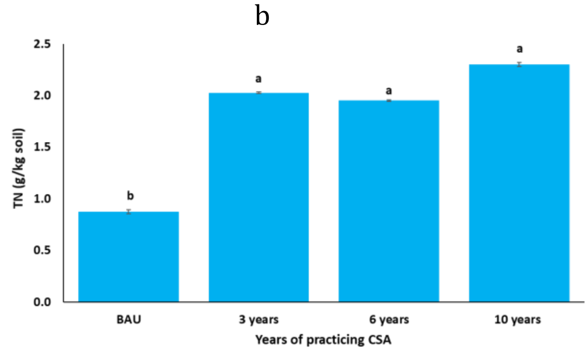
This study analyzes the impacts of CSA practices on soil health, soil moisture and GHG emission focusing on the Tula-Jana landscape in the Doyogena district of Southern Nations, Nationalities, and Peoples' Region (SNNPR). Time series Normalized Difference Water Index (NDWI) was used to assess the temporal trend of vegetation and soil moisture content and as proxy to assess water stress risk. The mitigation co-benefits of CSA were assessed from soil carbon stocks and GHG emissions reduction. The soil carbon stock was calculated from soil laboratory results.

The result of the analysis shows that soil parameters including SOM, TN and pH showed a significant improvement with CSA intervention. The lowest SOM was observed for BAU and the highest SOM was observed for 10 years of practicing CSA (Fig. 14a). The total nitrogen content of the soil under BAU is significantly lower than the nitrogen content of soil under 3 years, 6 years and 10 years of CSA practice (Fig.14b). The pH of the soil remains acidic even with adoption of CSA practices (Fig. 24c). However, comparing the soil pH of BAU with the different years of practicing CSA, improvements were observed. The site area is a high rainfall area which mainly contributed to the acidic soil. Although the mean values of BD, available P and S shows improvement between BAU and intervention, the difference was not statistically significant (Fig. 14d, e, f).

a



b



c

d

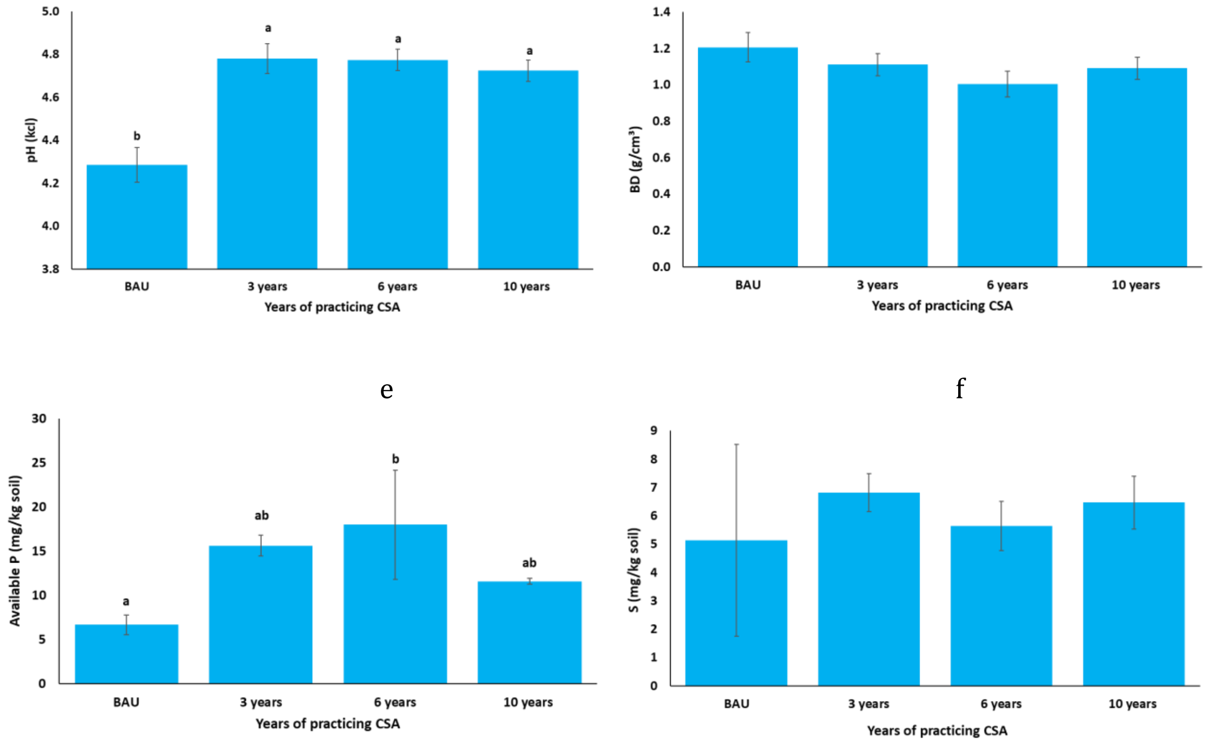


Figure 14. An overview of changes in selected soil fertility parameters (a, SOM; b, TN; c, pH; d, BD; e, available phosphorus and f, sulfur) under BAU and different years of practicing CSA

The results of NDWI analysis show improvement in vegetation and soil moisture with adoption of CSA (Fig. 15). There is a shift from low to higher vegetation and soil moisture content from 2010 to 2017. The existence of soil bunds covered by grass combined with climate-smart practices that reduced runoff, increased SOM improving water infiltration and soil water holding capacity resulted in an improved vegetation and soil moisture content. Improving water infiltration and soil water holding capacity increase soil moisture that would be available for plants.

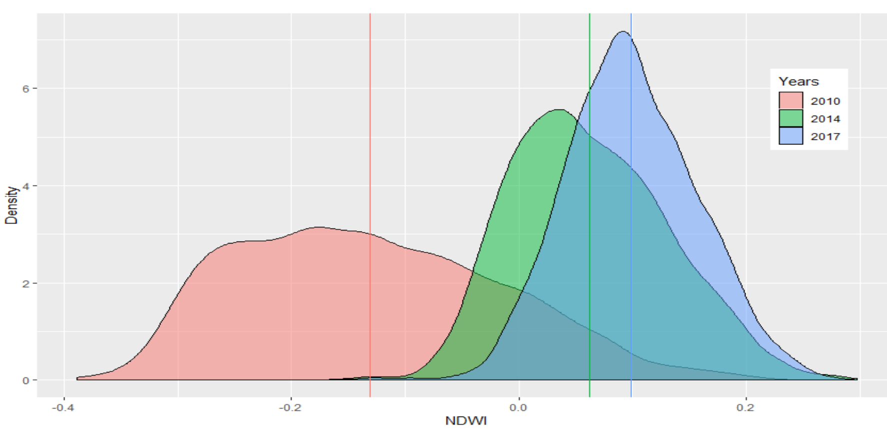


Figure 15. Time series comparison of vegetation and soil moisture content

In terms of mitigation co-benefits, we observed that agroforestry system presented the highest mean soil carbon stock of 312.1 t ha-1 (1145.4 t CO2eq ha-1) that was statistically significant compared to other land uses (Fig. 16). The multipurpose perennial Enset crop with high biomass production and has highly decomposable leaf and pseudostem parts provides significant organic matter to the soil. In addition, Enset plantation is the main beneficiary of animal manure from HH that significantly contributes to SOC. Cropland with 10 years of CSA practice had the second highest soil carbon stock of 229.4 t ha-1 (841.9 t CO2eq ha-1) mainly attributed to activities that enhanced the SOM. While cropland with 10 years of CSA practice had higher carbon levels compared to the community forest, it did not differ significantly from grasslands wit soil carbon stock of 208.9 t ha-1 (766.6 CO2eq ha-1). Although the soil carbon stocks in the community forest was higher than BAU, it is much lower at 145.4 t ha-1 (533.6 t CO2eq ha-1), compared to other land uses. This is due to the fact that the area was highly degraded until restoration started in 2004.

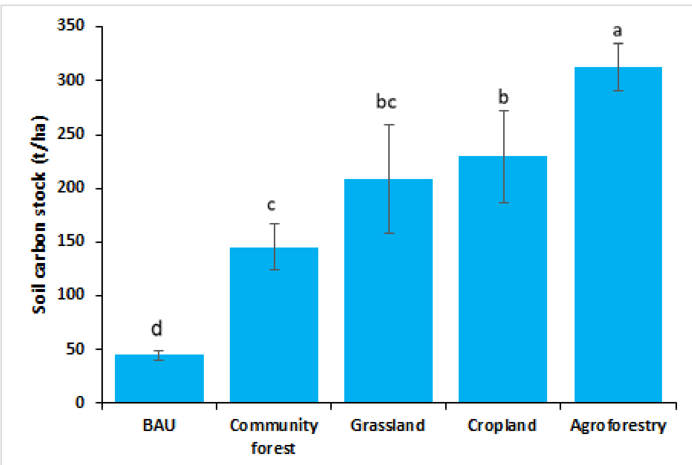


Figure 16. Soil carbon stock variations within 1m depth of the different land management systems in Tula-Jana landscape

With CSA practices, soil profile carbon stock buildup continued with time and was statistically higher than BAU (Fig. 17). The highest soil carbon stock was observed following 10 years of practicing CSA (229.4 t ha-1) compared to 3 years but did not differ significantly within the time series.

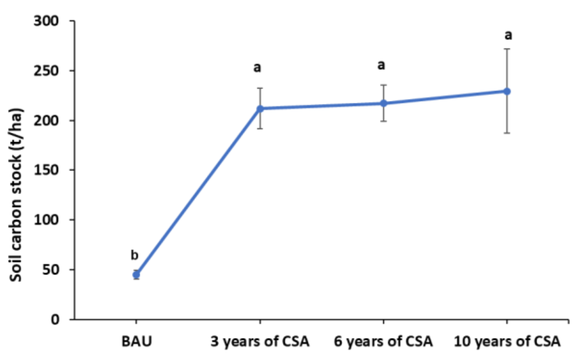


Figure 17. Soil carbon stocks within 1m depth in relation to period (years under practice) of CSA implementation in croplands in Tula-Jana landscape

To assess GHG emission, the CCAFS-MOT was used to estimate the net emissions for wheat. Result shows there is a considerable GHG emissions reduction with practicing CSA. There is GHG emissions reduction from 438 kg CO2 eq ha-1 for BAU to an average of 425 kg CO2 eq ha-1 with practicing CSA (Fig. 18). The tool also estimated that in addition to the existing CSA practices, the introduction of cover crops will further offset an average of 4723 kg Co_2 eq per hectare per year. CCAFS-MOT indicated that soil management practices including crop residue management contributed to reducing GHG emissions.

Figure 18. Comparison of net GHG emissions per area of the different treatment groups

5.2. *Evidence generation for learning and scaling*

In addition to these assessments, we also analyzed the impacts of restoration efforts on soil carbon sequestration at broader scale. We present two cases where we analyzed the impacts of land management options across different sites. The aim of this study was to understand impacts of intervention across sites for learning and scaling. Some of the sites are managed by the sustainable land management program of the Ministry of Agriculture.

5.2.1. Soil carbon sequestration associated with landscape restoration

In this exercise we aimed to understand the status of pristine-managed-degraded landscapes in terms of soil health through conducting detailed assessment of soil organic carbon (SOC) stocks in different reference sites. Taking soils under native forests as an appropriate ecological reference, we studied changes in SOC stocks along eight land-use types in the highlands of Ethiopia (Fig. 19). We then analyzed the dynamics of SOC stock following chrono-sequence land-use/cover systems in the highlands of Ethiopia. Eleven sub-areas were considered from the highlands. A total of 241 auger composite samples were collected and analyzed from the topsoil (0 – 20 cm).

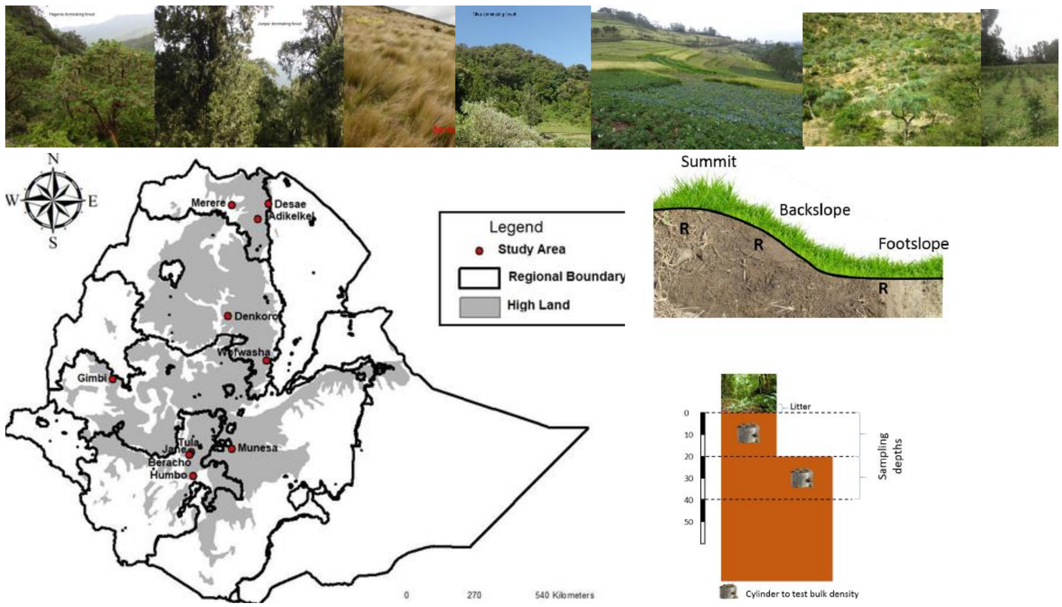


Figure 19. The distribution of the sampling sites for SOC stock analysis in the highlands of Ethiopia (light-dark-shaded area), and sampling areas (red-shaded small-circular area)

The study results revealed that there were statistically significant variations ($P < 0.05$) across the land-use types with the mean stocks ranging from 31.4 Mg SOC ha^{-1} in soils of intensively grazed lands to 145.0 Mg SOC ha^{-1} in soils of guasa grasslands (Fig. 20). Soils of natural/pristine vegetation and protected guasa grasslands contain the highest amount of SOC stock. Therefore, there should be more aggressive efforts towards an effective protection of these ecosystems. Soils under intensively used croplands and intensively grazed lands lost, respectively, 64.95% and 78.16%, SOC stocks originally accumulated in the top surface layers of the pristine forests. This points to the need to adopt locally feasible land management practices that lead to increased SOC stock and simultaneously reduced CO2 and greenhouse gas emissions from croplands and intensively grazed lands of the highlands of Ethiopia. Compared to stocks of SOC of intensively grazed lands (31.44 Mg SOC ha − 1), the annual stock gains in soils of controlled grazing lands (4.60 Mg ha − 1) were > gains in soils of enclosures (3.17 Mg ha − 1) > gains in soils of afforestation (2.35 Mg SOC ha − 1), which signifies that converting degraded lands to either controlled grazing lands, enclosures, or afforestation would be a promising practice for an enhanced carbon sequestration across the highlands of Ethiopia. This practice is in line with the United Nations' Sustainable Development Goals. The estimated regional partial stock balance revealed that the loss and gain ratio was 35.1 in 1991, and it declined to 15.4 in 2001, 2.2 in 2011 and 1.8 in 2015. These decreasing ratios indicate the possibility of closing the gap between the losses and the gains in the near future, and eventually shifting to higher rates of gains than losses. It is also important to note that determined efforts towards the effective protection of natural forests and the creation of enclosures and reforestation areas by local communities for enhanced carbon sequestration will benefit them from payments of carbon emission reduction (CER) credits.

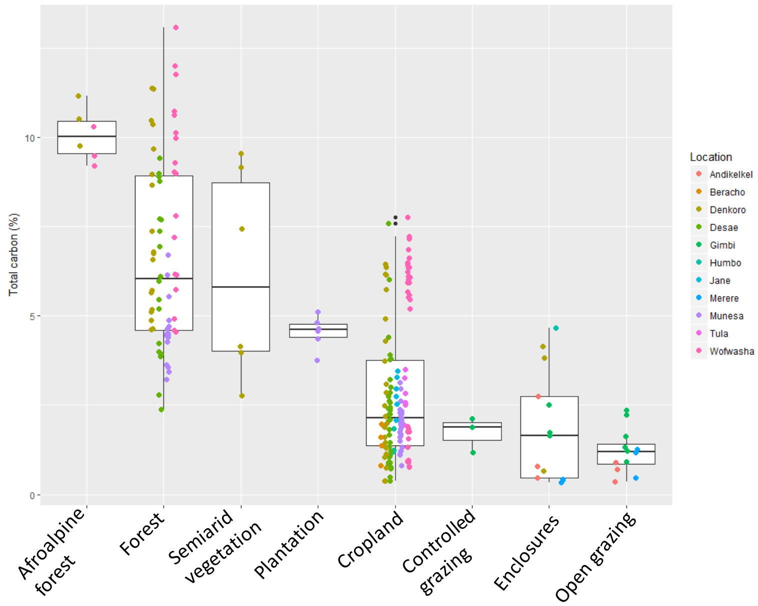


Figure 20. Gradient of soil carbon across different land cover types and locations in the highlands of Ethiopia.

5.2.2. *Assessment of the impacts of land restoration efforts on multiple ecosystem services*

Despite few and sporadic signals, there is generally a lack of quantitative evidence about the performances of landscape restoration interventions in improving livelihoods and enhance ecosystem services across scale (example see this review this review). Because of this, there is no clear information about what a truly restored landscape could offer. Lack of such information can undermine the value of restoration efforts (because gains in terms of complete ecosystem services are not quantified). It can also camouflage the real cost of land degradation (because we do not know how much we have lost in terms of different functions and services). Thus, it is necessary to understand what can be achieved by promoting climate-smart multifunctional landscapes that can support both ecological, as well as economic and socio-cultural benefits. Acquiring such data can support planning and informed decision making as well as convince policy makers, farmers, carbon traders, private sectors and others to invest in landscape restoration with the aim of getting multiple benefits in a sustainable manner.

Smart land use planning is about doing the right thing in the right place at the right scale: a multifunctional landscape approach advocates for more rational land use allocations that lead to greater resource use efficiency and the reduction of waste (see summary here). Knowing the comprehensive impacts of such interventions that can be ideal to plan knowledge-based scaling strategies and also facilitate national reporting, enhance negotiate potential for benefits such as carbon credit and payment for ecosystem services). Understanding what a multifunctional landscapes looks like and what benefits can be generated is essential to make informed decision with regards to SLM and land use planning. We thus reviewed literature and discussed with partners/stakeholders to identify site(s) in Ethiopia where relatively good restoration is achieved but at the same time for which quantitative data, of as many components as possible, are available. The ideas was to understand what truly restored multifunctional landscapes can offer by focusing on successfully restored sites and for which evidence is available. Both measured biophysical data and simulation analysis were used to understand the value of SLM options to create multifunctional landscapes. For situation where data was not available, the impacts of SLM interventions on ecosystem services were estimated by producing scenarios for before, after, and optimal intervention cases. The ultimate aim is to define what a multifunctional landscape looks like, what can it offer in terms of diverse ecosystem services under what management practices. The types of ecosystem services assessed depended on the availability of field, remote sensing, and simulation data.

In this report, we present assessment results for four watersheds (Fig. 21): Aba Gerima, Debre Mewi, Anjeni, and Gudo Beret. For the Debre Mewi watershed, where field data on crop yield, sediment retention, baseflow and biomass production was available, crop yield productivity, biomass change, and sediment retention were exclusively estimated. Habitat quality, carbon sequestration, and crop pollination were estimated for the other three watersheds using land use/cover maps of the past, current, and optimal scenarios as bases. The Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) tool was used to assess the changes in terms of different ecosystem services.

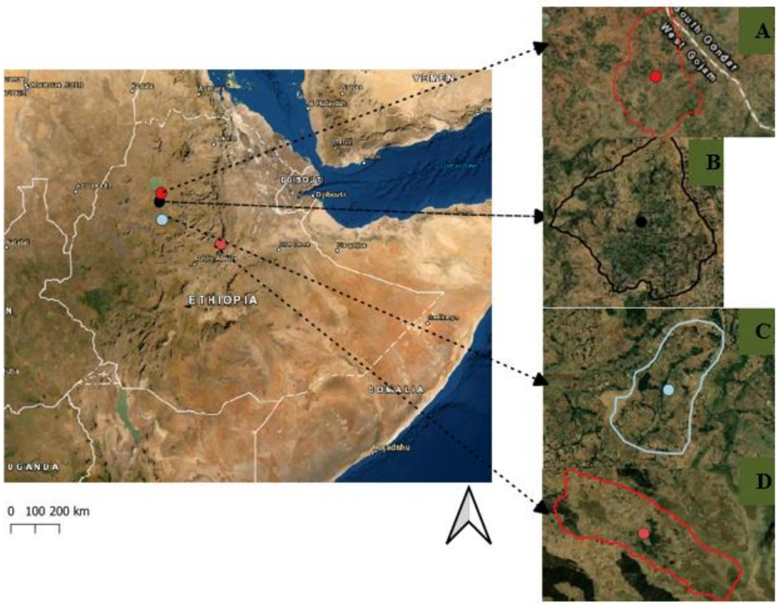


Figure 21. Location of the study watersheds, in the Amhara National Regional State, North-western Ethiopia. A) Aba Gerima, B) Debre Mewi, C) Anjeni, D) Gudo Beret

The results of the analysis for the different watersheds are shown in Figs. 12 - Fig. 25). Comparing the baseline productivity data of Debre Mewi with yield of four major crops (i.e. maize, wheat, teff, and finger millet), an increase in yield has been observed following integrated land and water management interventions. The increase in yield varies from crop to crop, the highest being for maize (120%) while the lowest is for wheat (9%). The canopy cover of the watershed increased from 8% to 20%, between 2010 and 2017 (Fig. 22). This indicates greening of the landscape related to land management interventions including grasses in bunds. The highest change is observed at valleys and lowland areas of the watershed. During the dry season, the area of canopy cover increased from 41 ha to 128 ha between 2010 and 2018. Evidence also shows that about 13,142 tonnes of sediment has been accumulated along bunds of different types. Since the bunds and terraces were constructed mostly at the upper and hillside of the watershed, higher soil sediment retention was observed in those areas. In addition, the impacts of the integrated watershed interventions have shown positive impact on water resources. Here, we have observed that streams which were dry and empty in 2010, have revived after the watershed interventions.

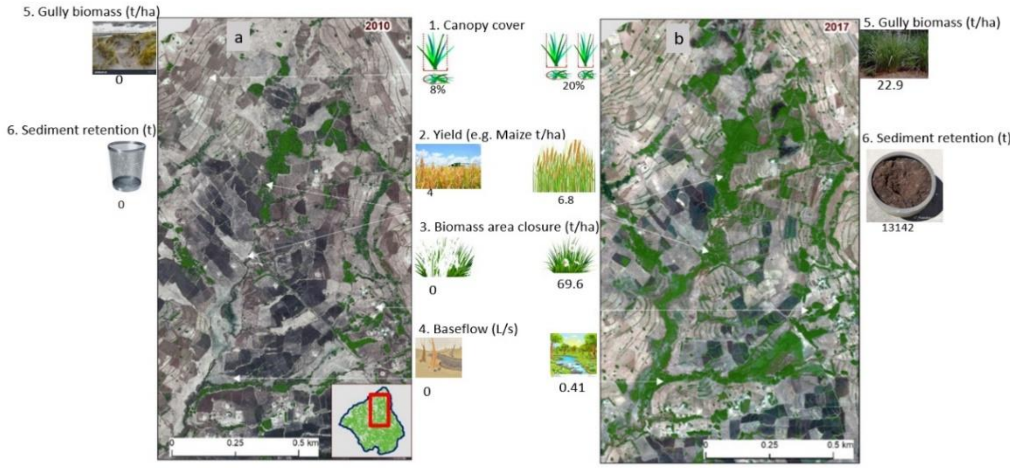


Figure 22. The benefits of employing integrated watershed management options at the landscape scale: the case of Debre Mewi watershed

The canopy cover change of the Anjeni watershed has also shown an increase in association to the SWC practices. The land management options that contributed to the resulting increase in canopy cover were area closure, terracing, gully rehabilitation, and farmland plantation. Following such interventions, the canopy cover of Anjeni watershed has increased from 100ha in 2010 to 140 ha in 2017 (Fig. 23).

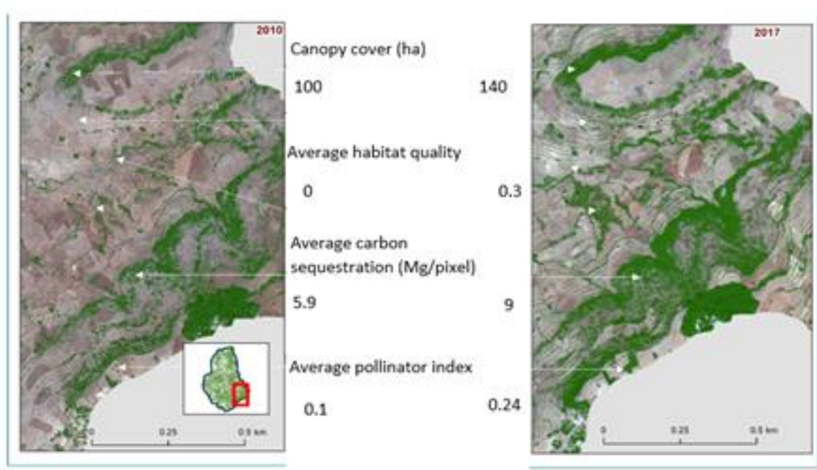


Figure 23. Assessment of the multifunctional benefits of integrated land and water management practices in the Anjeni watershed

Habitat quality was modelled based on the LULC map of the watersheds and in consideration of the suitability of LU classes, and the threat/weight of other LU classes on suitable habitats. The habitat suitability index ranges between 0 and 1. The results show that the average habitat quality improved for all watersheds going from before to optimal SWC intervention cases. Similarly, an increase has been recorded in the overall and average carbon stored in Mg per pixel for all watersheds following interventions. For Aba Gerima watershed, the average habitat quality and average carbon storage has increased to 0.4, and 1.3 Mg per pixel respectively (Fig. 24).

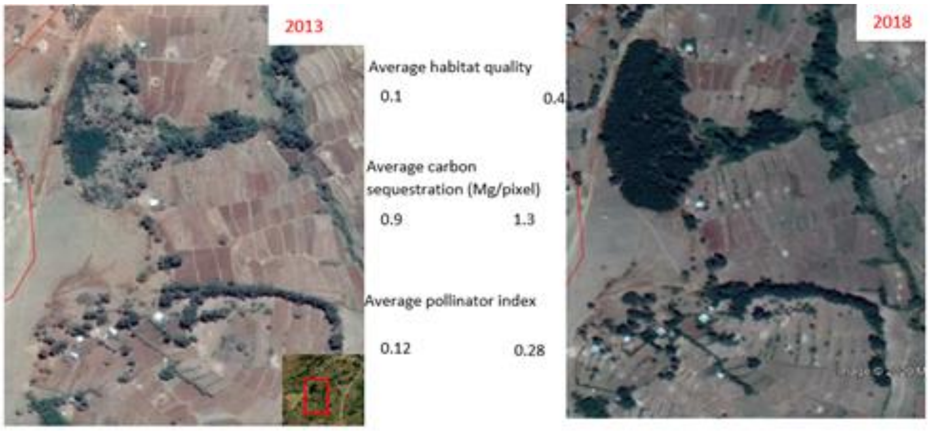


Figure 24. Assessment of the multifunctional benefits of integrated land and water management practices in the Aba-Gerima watershed

Finally, crop pollination was modelled based on the LULC change in the watersheds and in consideration of the presence of pollinator bee species, their relative abundance, availability of nesting grounds, and availability of floral resources. The values used here were mainly based on general literature and default values from the model builder were also adopted. Therefore, it is advised that the model is customized with watershed specific values for more accurate estimations. The results in Fig. 25 show that both the average pollinator index estimated for the Gudo beret watershed has resulted in an increase (0.26) compared to the base year (0.1).

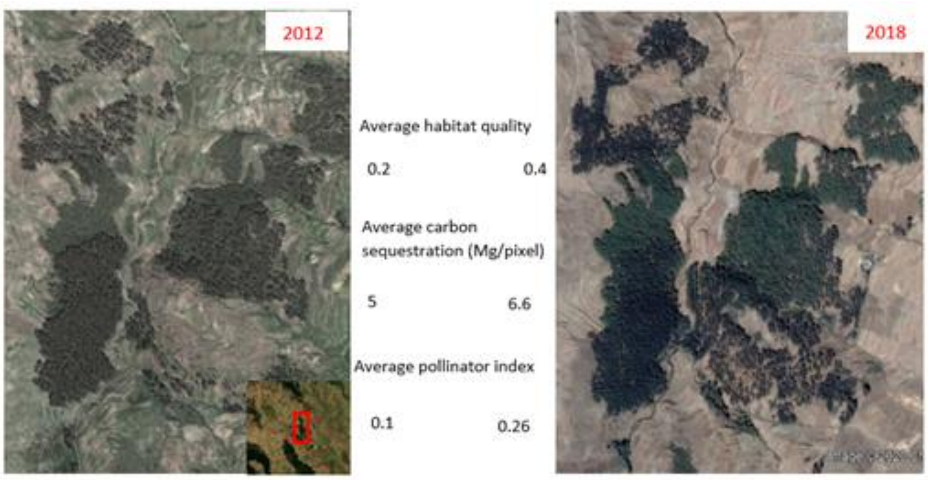


Figure 25. Assessment of the multifunctional benefits of integrated land and water management practices in the Gudo beret watershed

The results reveal that while individual land and water management options can have their own benefits, integrated SLM interventions can bring multitude of ecosystem services whereby the coupled interventions of physical, biological, and income generating activities would have benefits more than the sum of individual ecosystem benefits. This quick analysis opened our eyes to the need for comprehensive quantitative information regarding the performances of integrated watershed management interventions, in order to gain a clear picture about the 'real' benefits of truly restored landscapes. This can facilitate planning and decision making - for example- governments and policy makers can have an idea of what to expect in their landscape restoration investments. Such information can provide data about the cost of investments made for land restoration in relation to the benefits gained. This can be achieved if we are able to analyze the multifunctional benefits that can be enjoyed from well restored and managed sites. It is thus essential to conduct a thorough study on selected sites to have a clear picture of the ecosystem functions that can be rendered as a result to sustainable land management efforts, which can form the basis for scaling and PES as well as carbon payment negotiations.

6. Development of framework to guide targeting and scaling of CSA options

Natural resources management technologies through watershed/landscape approach have often been implemented using Community Based Participatory Watershed Development (CBPWD) guideline. This guideline was broadly designed on the basis of agro-ecology, slope gradient and land use as criteria for technology targeting. This was built on local experiences without being complemented by research and multi-disciplinary experts' views. Practical experiences and case studies have proven a lack of appropriate selection and placement of SLM technologies in a given farm or landscape. Selection and placement as well as the scaling up of NRM technologies and strategies have been constrained with inadequate knowledge about the detailed characteristics of local agro-ecological and climatic factors (rainfall), topographic conditions (slope gradient, landform and landscape topographic index/transmissivity), soil characteristics (soil texture, soil depth, soil drainage). At the same time, analysis and characterization of specific technology requirements and their functions was given inadequate emphasis. These led to inappropriate technology targeting, which then undermined effectiveness and efficiency of interventions.

To make an efficient use of SLM technologies and effective landscape management options, practitioners and planners should have the capacity to understand and analyze the landscape/watershed characteristics so that they can be able to identify and select the required technologies that fit the area under consideration. However, mismatch between the conditions/attributes of watersheds and the requirements and functions of technologies was identified as one of the major problems for the 'limited successes of many watershed management interventions. In addition, there is lack of integrated technology implementation on the topo-sequence such that they are complementary and promote synergy. On the other hand, the various SLM technologies might have multiple functions when applied under different conditions. However, whenever a specific technology is not implemented at the right condition, it can lead to undesirable impact causing low adoption due to the negative perception by the land users.

SLM comprises measures and practices adapted to biophysical and socio-economic conditions aimed at the protection, conservation and sustainable use of resources (soil, water and vegetation) and the restoration of degraded natural resources and their ecosystem functions. However, for a certain set of biophysical/environmental and socio-economic conditions, the practical challenge is to select and place appropriate/optimum technologies that can fit to specific context.

To tackle the above challenges, it will be essential to develop a conceptual 'framework' that can guide placement of complementary technologies across the landscape. The framework can guide matching options with context - where specific technologies should be placed across the landscape. In addition, it will be important to develop tool/dashboard that can facilitate problem identification (where are the hotspots), technology choice and matching with site conditions and generating evidences related to performances of interventions.

As part of the 'creating multifunctional landscapes' project, we compiled our experiences within Ethiopia and beyond to develop a decision support tool/guideline that can match landscape conditions with the appropriate technology options (measure) and making sure that landscape condition will satisfy technology functions and/or requirements, identify catalogue of

SLM options, match the options with the landscape condition and generate evidences related to the performances of watersheds (Fig. 26). Professionals, planners and decision-makers can use the tool to identify the most suitable SLM practices and technologies for targeted areas and communities and understand the optimal benefits that can be enjoyed from those practices.

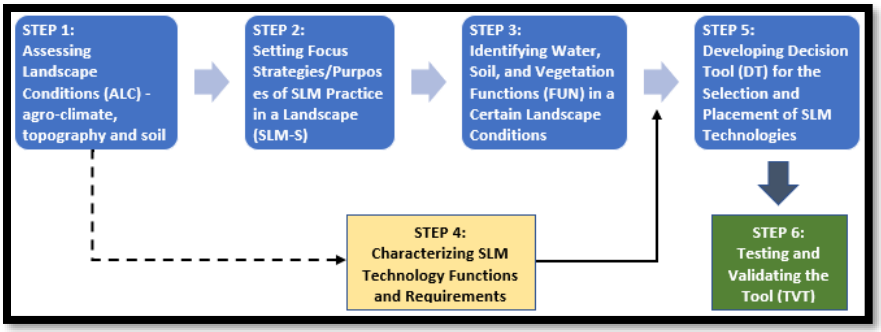


Figure 26. Key steps of landscape diagnosis to devise suitable land management options

A detailed assessment of each of the six steps (Fig. 26) was conducted to ultimately identify the key land degradation issues to resolve and the major functions of SLM options. Most of the assessment is done based on review of WOCAT technology questionnaire, the Community based Participatory Watershed Guideline of Ethiopia and other related literatures. A key consideration is that SLM measures need to be environmentally friendly, socially accepted, profitable and cost-efficient and achieve highest impact on productivity and other ecosystem services. To meet these criteria, detailed characterization of the functions and requirements of SLM technologies/measures is essential to help to guide practitioners and planners where to place them. Based on WOCAT classification, SLM technology options can be vegetative, mechanical/structural and agronomic measures. The specific technologies in each category which are commonly implemented and adapted in the Ethiopian context were identified from the info-techs in the Community Based Participatory Watershed Development Guideline. The technologies were characterized based on the functions and their landscape requirements (Table 1). In principle, at certain landscape conditions, the specific technology options have provided specific functions to prevent, control and manage the soil, water and vegetation resources. In addition, by considering these functions of the technology options, the agro-climate, topographic, soil and land use requirements needed to achieve these functions are described.

Once the landscape diagnosis and characterization of SLM options was undertaken, the next step will be to develop a tool that can guide implementation and mainly conduct ex-ante assessment of the potential impacts of various interventions. Developing such a tool that can be practically useful needs detailed dataset (especially related to the landscape conditions) so that the characterization can be as detailed as possible. However, such data are not available at the required scale, resolution and accuracy in Ethiopia. We will thus use relatively coarse resolution dataset with the aim of building a prototype tool. The tool will be designed to have four major components: landscape diagnosis, land scape restoration options, landscape impact assessment, and tradeoff analysis and optimization.

The landscape diagnosis tool will be useful to describe the overall characteristics of the landscape in terms of climatic, topographic, soil, vegetation variables, and indicate the hotspots and coldspots/stress and degradation. This is the first stage of investigation of the health of the area under consideration. Once this is described and the core problems and their spatial distributions are defined, the next step will be to identify a suit of climate-smart land and water management options that can enable tackle the observed problems (defined during the diagnosis stage). This will be based on the requirements of the respective options (to know whether those can fit the hotspots identified, site-specific options). The tool will then match the 'options' with the context of the landscape and guides implementation. This will be done based on expert knowledge, literature and different optimization tools. The third step helps asses the impacts of those innervations in terms of different ecosystem services. This step is deigned to evaluate the impacts of the technologies in addressing the 'diagnosed' problems. This can be based on ex-ante analysis as well as earth observation and ground-based data analysis. The final step will assess the tradeoffs and/or complementarities of the various interventions considering different ecosystem services. This is an important step to fine tune the implementations of technologies to optimize benefits. The steps reflect that tool follows a synonymous approach of treating a patient.

When finalized, the tool will use combination of datasets from the cloud, integrates information from crowdsourced citizen science to diagnose the conditions of landscapes and prescribe suitable options as well as evaluate impacts in near real-time (Fig. 27).

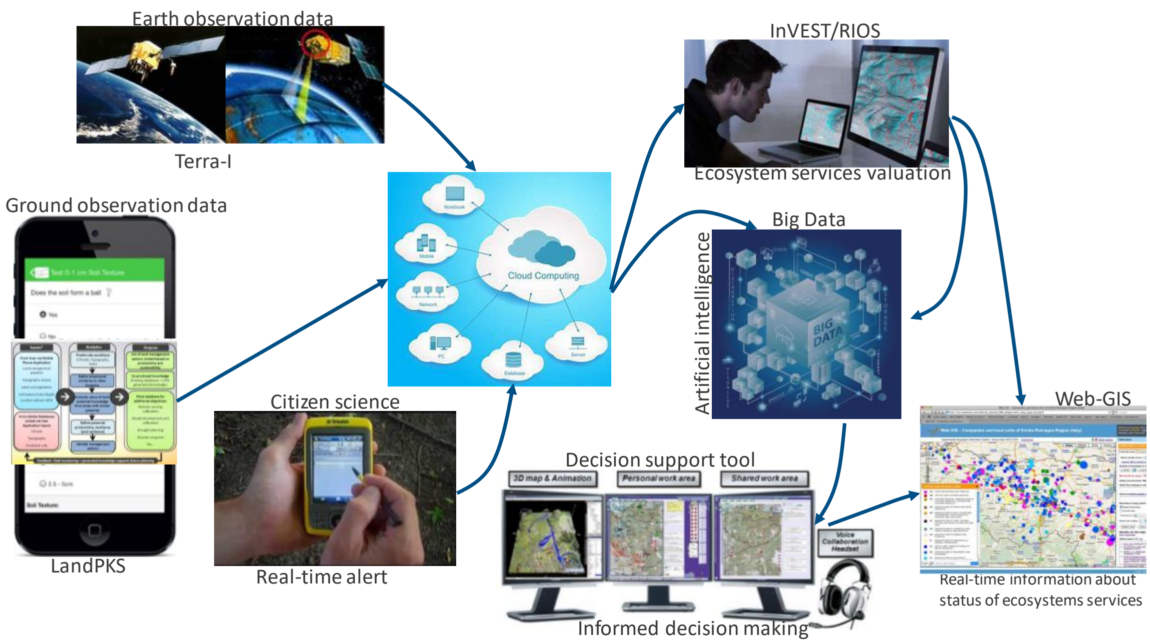


Figure 27. Data sources and means to develop decision support tool that can help target technologies to specific sites and generate evidences of impacts in near real-time.

Table 1. Description of SLM technologies

SN	Technology	Description	Functions	Limiting/constraining factors
1	Grass strips	Consist of grass planted in strips along the contour lines and spaced at suitable intervals. It addresses surface erosion by water.	Retard runoff velocity Retain eroded sediment	Low rainfall/moisture stress Grazing management/free grazing
2	Agronomic conservation measures	Agronomic techniques combine crop residue, mulching, intercropping and strip-cropping in a suitable farming system and environmental conditions. It solves chemical and physical soil degradation and soil moisture stress.	Increase infiltration and thereby reducing surface runoff and soil erosion Reduce impact of raindrops through interception	Low cropping intensity/cover and steep slopes Competitive use of crop residues for feed and fuelwood
3	Contour ploughing	Soil is ploughed along the contour instead of up- and downward and used to reduce surface erosion.	Retard velocity of runoff and thus soil erosion by concentrating water in the downward furrows Retain soil moisture	High rainfall Shallow soil depth
4	Bench terrace	A series of level or nearly level strips built along the contour lines at suitable intervals supported by steep banks or risers. It controls soil erosion by water.	Modify slope gradient by reducing the degree and length of the slope and control erosion and retain sediment Increase infiltration of rain water	Shallow soils Non-workable soils
5	Stone walls	It the use of rocks and stones lying on the slope and build low stone walls to control soil erosion by water.	Control soil erosion and runoff velocity Reduce slope length	Unavailability of stones Steep slope
6	Hillside terrace	A hillside terrace is a physical barrier constructed on hills to conserve soil moisture. It is a built along the contour where a strip of land, about 1 meter wide, is levelled for tree planting. It controls soil erosion and enhances soil moisture.	Retard runoff velocity and intercept runoff Retain eroded sediment	Poor soil drainage
7	Semi-circular bunds	It involves building low embankments with compacted earth or stones in the form of a semi-circle with the opening perpendicular to the flow of water. It addresses soil moisture stress.	Intercept rain and runoff for crop, tree or grazing	Poor drainage and steep slope
8	Fanya Juu	Fanya juu terraces comprise embankments (bunds), which are constructed by digging ditches and heaping the soil on the upper sides to form the bunds. Constructed on the contour to hold rainfall where it falls. It addresses soil erosion by water.	Retard velocity of runoff and drain safely Retain eroded sediment	Steep slope High intensity of rainfall
9	Level soil bund	Impermeable structures constructed along the contour and across the slope. It controls soil erosion by water and improve soil moisture	Reduce velocity of runoff Retain eroded soil and conserve soil moisture	Poor drainage High rainfall
10	Stone bunds	Stone bunds increase the moisture retention capacity of the soil profile and water availability to plants, and increase the efficiency of fertilizer applications. It controls soil erosion by water and improve soil moisture	Reduce velocity of runoff Reduce soil erosion and retain sediments	Poor soil drainage and very steep slopes Unavailability of stones
11	Stone faced soil bunds	Stone faced soil bunds are applicable where need to reinforce one or both sides of the embankment with a stone wall or riser. It controls soil erosion by water and improve soil moisture.	Stone bund reduces the velocity of runoff Reduce soil erosion and retain sediments	Poor soil drainage
12	Hillside ditches	A series of shallow ditches built along the contour lines at appropriate intervals. It controls soil erosion by water and improve soil moisture.	Intercept and store surface runoff and recharge sub-surface water	Poor soil drainage
13	Trenches	Trenches are shallow to deep pits constructed along the contours. It controls soil erosion by water and improve soil moisture and sub-surface flow	Collect and store rain water to support the growth of trees, shrubs, cash crops and grass Recharge springs, wells and groundwater	High rainfall and rocky soils Poor soil drainage
14	Micro-basins	Micro-basins are small circular and stone faced (occasionally sodded) structures for tree planting. It controls soil erosion by water and improve soil moisture and sub-surface flow	Collect rain & runoff and conserve soil moisture Recharge springs, wells and groundwater	High rainfall and rocky soils Poor drainage
15	Tie-ridging	Tie ridges are small rectangular series of basins formed within the furrow of cultivated fields. The principle or purpose is to increase surface storage by first making ridges and furrows, then damming the furrows with small mounds, or ties. It addresses soil moisture stress.	Increase soil moisture storage Increase infiltration	Rainfall variability Poor soil drainage

7. Capacity building

Capacity development is a key component of the project. We have three PhD students (male) and one MSc student (female) working related to 'multifunctional landscapes'. One of the PhD students is assessing the impacts of changing land use, management and climate on hydrological characteristics while the other assesses the impacts of SLM interventions on overall ecosystem service provision. The third student is investigating the 'environmental and socio-economic challenges of rift-valley lakes in Ethiopia and developing management plans'. The MSc student is applying the ELMO tool to understand the perceptions of households' about land and water management options. In addition, we are supporting three PhDs (2 male, 1 female) in the Amhara region. These are mainly focusing on the Lake Tana and its basin to study the extents, drivers and impacts of water hyacinth. We are also hosting two PhD students that are supported by CLIFF-GRADS (Climate Food & Farming Graduates).

We have also provided various training to local experts through exchange visits and workshops in the two CSVs and beyond. Thu far over 500 participants have participated in trainings of various types. This was an important achievement as experts from different parts came together to gain experiences and practical exposure about successful sites. In collaboration with the regional Bureaus and Universities, further training related to 'integrated land and water management' were also provided to farmers and practitioners. In addition to the above, it is also worth mentioning that some of our sites have been visited by a large number of national and international partners. The participants have come from different countries to share experiences.

8. Summary and conclusions

The experiences gained at the learning watersheds of the project and other successful sites in the country provided good lesson to identify climate smart CSA practices that can be scaled to other areas. Because CSA options that involve SLM and SWC are expensive to implement and difficult to handle by research organizations, partnering with development organizations, government and NGOs is essential. The various partnerships established across the country can be instrumental to scale technologies. An important lesson is that landscape based CSA practices should be complemented with plot/farm level intensification options to facilitate adoption. Evidence generation is vital to make informed decisions and will be good to develop system that can enable assess impacts in near real-time. The framework developed in this project can help achieve that once fine-tuned to fit local situations.

Our experience show that the amount of evidences generated is by far small compared to the volume of SLM-related work implemented in the country. In cases where some studies are conducted the focuses are on few ecosystem services without considering the possible multitude of benefits. Because of this it is possible that the benefits of land restoration are hugely underestimated and undervalued mainly because the multifunctional services of parcels are not considered well. In addition, it is likely that the true cost of land degradation might have been underestimated because no detailed accounting of losses in terms of whole ecosystem services not conducted. It is thus vital that detailed assessments of the SWC/SLM/CSA intervention be made. This will specifically be important for Ethiopia where tremendous land restoration investment is being made by different actors. Considering the Green Legacy initiative by the Prime Minister of the country it will be essential and useful to develop an automated digital tool that can guide targeting and scaling of technologies in near real-time. With the current developments in data acquisition, storage and analytics, this should be a reachable target to aim at.

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