

Review of Lessons Learned in Changing Agricultural Landscapes in Ethiopia: What Worked Well and What Didn't Work so Well?

^{1*}Amare Hailelassie, ²Wolde Mekuria, ³Petra Schmitter, ⁴Stefan Uhlenbrook and ⁵Eva Ludi

¹International Water Management Institute, East Africa and Nile Basin Office, C/o ILRI-Ethiopia campus, Woreda 17, Kebele 21, Addis Ababa, Ethiopia. Email: a.hailelassie@cgiar.org

²International Water Management Institute, East Africa and Nile Basin Office, C/o ILRI-Ethiopia campus, Woreda 17, Kebele 21, Addis Ababa, Ethiopia. Email: w.bori@cgiar.org

³International Water Management Institute C/o Irrigation Head Office Yangon Compound Thitsar Road, Yankin P.O. 11081 Yangon, Myanmar. Email: p.schmitter@cgiar.org

⁴International Water Management Institute - Colombo 127, Sunil Mawatha, Battaramulla, Colombo, Sri Lanka. Email: s.uhlenbrook@cgiar.org

⁵International Water Management Institute, East Africa and Nile Basin Office, C/o ILRI-Ethiopia campus, Woreda 17, Kebele 21, Addis Ababa, Ethiopia. Email: e.ludi@cgiar.org

Abstract

Ethiopia has decades of experience in implementing land and water management interventions. Nonetheless, there remains persisting challenges to follow an adaptive management (AM) approach in efforts of restoring and transforming agricultural landscapes. This review was carried out to synthesize evidences on the impact on agricultural landscapes following the implementation of land and water management practices and to evaluate the use of AM approaches. We explored how elements of the structures and functions of landscapes have been transformed, and how the components of AM, such as structured decision-making and learning processes, have been applied. Despite numerous environmental and economic benefits of land and water management interventions in Ethiopia, this review revealed gaps in AM approaches. These include: (i) insufficient efforts in relation to evidence based contextualization of interventions, (ii) insufficient efforts in monitoring of bio-physical and socio-economic processes and changes post implementation, (iii) lack of trade-off analyses, and (iv) inadequacy of local community engagement and provision of feedback. Given the many uncertainties we must deal with, efforts to restore and transform agricultural landscapes cannot follow a business-as-usual approach. Future investment, in AM approach, tailored to the needs and context would help to achieve the goals of sustainable agricultural landscape transformation. The success depends on three interdependent pillars of action: the ability to make a robust, co-developed plan of interventions, the ability to continuously monitor changes based on key variables, and to learn from the knowledge generated and apply the learning as implementation evolves.

Key words: landscape, land and water management, restoration of ecosystem services, AM, Ethiopia

1. Introduction

Geological weathering and erosion are constructive natural processes that maintain the functioning of agricultural landscapes and ecosystem services [1-3]. Anthropogenic drivers often accelerate some of these natural processes and can negatively affect the structure and functions of agricultural landscapes and ecosystem services [4,1,3].

A recent study by Nkonya et al. [5], demonstrated that about 30 percent of the global land area, home to about three billion people, suffers from land degradation. This is translated to an annual cost of about US\$ 300 billion. Land degradation is particularly severe in sub-Saharan Africa, which accounts for about 22% of the total global cost of land degradation. Like in other sub-Saharan African countries, land degradation is significant in Ethiopia and causing considerable negative environmental and economic impacts [6-9]. For example, the direct cost of the loss of soil and essential nutrients due to unsustainable land management was estimated in 1994 to 3% of the country's agricultural GDP, or US\$ 106 million [11]. Gebreselassie et al. [12], estimated the net cost of land degradation in Ethiopia due to land use and land cover changes to about US\$ 4.3 billion annually and this value is 44 times higher than the 1994 estimate.

The challenges of land degradation in Ethiopia entail the need to transform and restore agricultural landscape by addressing the drivers of land degradation while maintaining or increasing ecosystem services. According to the World Bank [13], this would play an important role in reducing poverty. It was estimated that every 1% growth in Gross Domestic Product (GDP) would result in 0.15% reduction in poverty. Economic growth in the agricultural sector plays even a more important role: for every 1% increase in agricultural output, poverty would decrease by 0.9%.

In relation to the management of agricultural landscapes in Ethiopia, Haregeweyn et al. [14] showed that indigenous soil and water conservation (SWC) measures have been applied for centuries but improved SWC measures only came into practice following the recurrent drought-triggered famines of the 1970s and 1980s. The implementation of indigenous and improved SWC measures can support addressing new challenges such as climate change impacts and can be considered as a socio-

political opportunity for better livelihood outcomes [14]. In context of the current study, indigenous SWC measures refer to locally developed and practiced land and water management technologies (e.g. konso stonewalled terrace), whilst improved SWC measures are newly introduced or when the design and implementation of indigenous SWC measures have been improved through science.

In this regard, Sayer et al. [15] demonstrated the need to adopt knowledge-intensive and site specific sustainable agricultural landscape management options including the use of indigenous and improved SWC practices. Regardless of its type, SWC measure could add new structure to or change existing structure of landscape and thereby influence the landscape functions and the overall processes of landscape transformation. Birge et al. [16] argued that managing agricultural landscapes through land and water management practices (e.g. SWC measures) can take unpredictable trajectories and trigger unintended results (e.g. environmental pollution, land use conflicts); therefore, it must consider temporal and spatial process variability and be aligned with the socio-political context. This entails mechanisms to operationalize adaptive management (AM) approaches. Adaptive management is an approach to natural resource management for people who must act despite uncertainty about what they are managing and the impacts of their actions [15-17]. The adaptive process is often represented as a cycle of plan, do, monitor, and learn.

This review focuses on agricultural land and water management practices in Ethiopia. It explores the changes in landscape functions and structures following the implementation of land and water management practices. It assesses how lack or application of key elements of AM such as structured decision-making and learning processes are impeding or promoting landscapes transformation efforts. Further, the review documents what has worked well and what did not work so well in Ethiopia's agricultural land and water management efforts and identifies entry points for future investments. The review employed generic AM cycles as proposed by Birge et al. [16].

2. Analytical Framework and the Context of Transforming Agricultural Landscapes in Ethiopia

2.1. Context of transforming landscape in Ethiopia

A landscape is perceived as a system of natural, bio-physical, and socio-cultural components that undergoes continuous transformation due to both natural and anthropogenic drivers [18,19]. The natural processes (Fig. 1C) involve, for example, the pedogenic process influenced by compounded effects of the lithosphere, hydrosphere, and biosphere as well as climate. The second, human-induced process (Fig. 1A), is triggered by socio-economic, cultural, and political interests [1]. Human social systems and landscape ecosystems are complex adaptive systems [20]: complex because ecosystems and human social systems have many elements and non-linear and dynamic connections between those elements (Fig. 1); adaptive because they require feedback mechanism with adaptive decisions/actions to a constantly changing environment [19].

In the context of this review, Ethiopias agricultural landscapes are cosnidered as a mosaic of farmers' fields, infrastructures (e.g. terraces, micro dams) and occasional natural habitats, and they are the result of interactions between farming activities and the natural and socio-economic settings in an area [19, 21].

The ongoing implementation of land and water management practices and the resulting transformation of agricultural landscapes in Ethiopia is attributed to both natural and anthropogenic drivers [22,14]. People modify the landscape by changing its structures (e.g. by installing SWC measures, planting or cutting trees, building micro dams, extracting groundwater, changing land use, etc.) to attain improved landscape functions and support their livelihood [19]. In many cases, the focus of human-induced processes is on increasing provisioning ecosystem services (e.g. food production). Such a focus on a single ecosystem service can have negative feedback (Fig. 1) on transforming landscapes and maintaining diverse ecosystem services which multi-functional landscapes can provide. Following the objectives of this review, we focused on human-induced landscape transformations. We focused on transformation within agricultural landscape and therefore changes from agriculture to urban or *vice versa* were not considered. The analytical framework and key indicators used are illustrated in the next section.

2.2. Analytical framework: landscape structures and focus indicators

Landscapes have three user-defined components [20]:

- (i) **Structure**—a spatial pattern of landscape units, i.e., the spread of plants and animals, arrangement of landscape elements, land use and land cover (LULC), artificial structure etc.; Fig. 1B).
- (ii) **Function**—the interactions between the landscape units, i.e., water, nutrient and energy fluxes, migration of organisms (Fig. 1B) and usually used synonymously to ecosystem function and
- (iii) **Changeability**—transformation of landscape structure and functioning over temporal scales.

Human-induced and natural processes act continually on the first two components while the third, changeability, is an integral part that is resultant of these actions and reactions (and thus not represented separately in Fig. 1).

Helming et al. [23] indicates a three-layered hierarchy of landscape structures (Fig. 1B) that are introduced here regarding human-induced transformations:

- (i) **Primary landscape structure** (Fig. 1B1): This is the original and permanent basis for the other structures. Although it is least influenced by human activities, the primary landscape structure shapes the type and magnitude of interventions and its outcome under secondary and tertiary landscape structures. Hence it is considered as intrinsic to interventions and not discussed in further detail in this review [18].
- (ii) **Secondary landscape structure** (Fig. 1B2): According to Skokanová and Eremiášová [24], this layer involves, for example, the current LULC or the geographical elements created to improve productivity, such as a dam or SWC measures. Given their multiple ecosystem functions and their pervasiveness in landscape transformation, LULC changes, SWC, and water harvesting-related indicators were key focus areas of this review [25]. We will use both quantitative and qualitative information to illustrate changes in ecosystem functions and services (e.g. biodiversity, soil erosion, agricultural productivity, carbon sequestration etc..) due to changes in secondary landscape structure.

(iii) **Tertiary landscape structure** (Fig. 1B3): This layer comprises mainly of elements of the socioeconomic sphere such as (in)tangible interests, expressions of and effects on society in the landscape [23]. Here we focus on examples illustrating livelihood transformation in relation to secondary landscape structural changes such as income from agricultural activities (irrigation from micro dams, income from afforestation, rainfed farming intensification) and how different SWC measures have transformed positively or negatively livelihoods in the community.

In this analytical framework, the landscape structure that relates to agricultural landscape transformation and land and water management practices belongs to the secondary layer (Fig. 1B2). Some examples include expansion of cultivated land, exclosures for landscape restoration, physical SWC measures and water harvesting structures. These are typical activities undertaken to manage agricultural landscape in Ethiopia [23,14,26]. Tertiary landscape structures (Fig. 1B3) are linked landscape structure 2 (B2) and how it transforms livelihood. Recent evidence related to how landscape structures B2 transform lives and livelihoods [27] is an important point of discussion, particularly in view of providing incentives to guide behavioural change and to support local communities in adopting certain land and water management interventions.

The functional component (Fig. 1B4) of a landscape consists of the processes influenced by its structure and processes driven by the human and natural system. This component is synonymous with ecosystem function and controls the provision of ecosystem services (Fig. 1D). In the introduced analytical framework, changes in the landscape function are driven by the changes in structure. For example, we consider how changes in the landscape structure such as LULC changes have influenced carbon sequestration, biodiversity, and erosion [28], or how SWC measures have influenced the restoration of degraded landscapes and agricultural production.

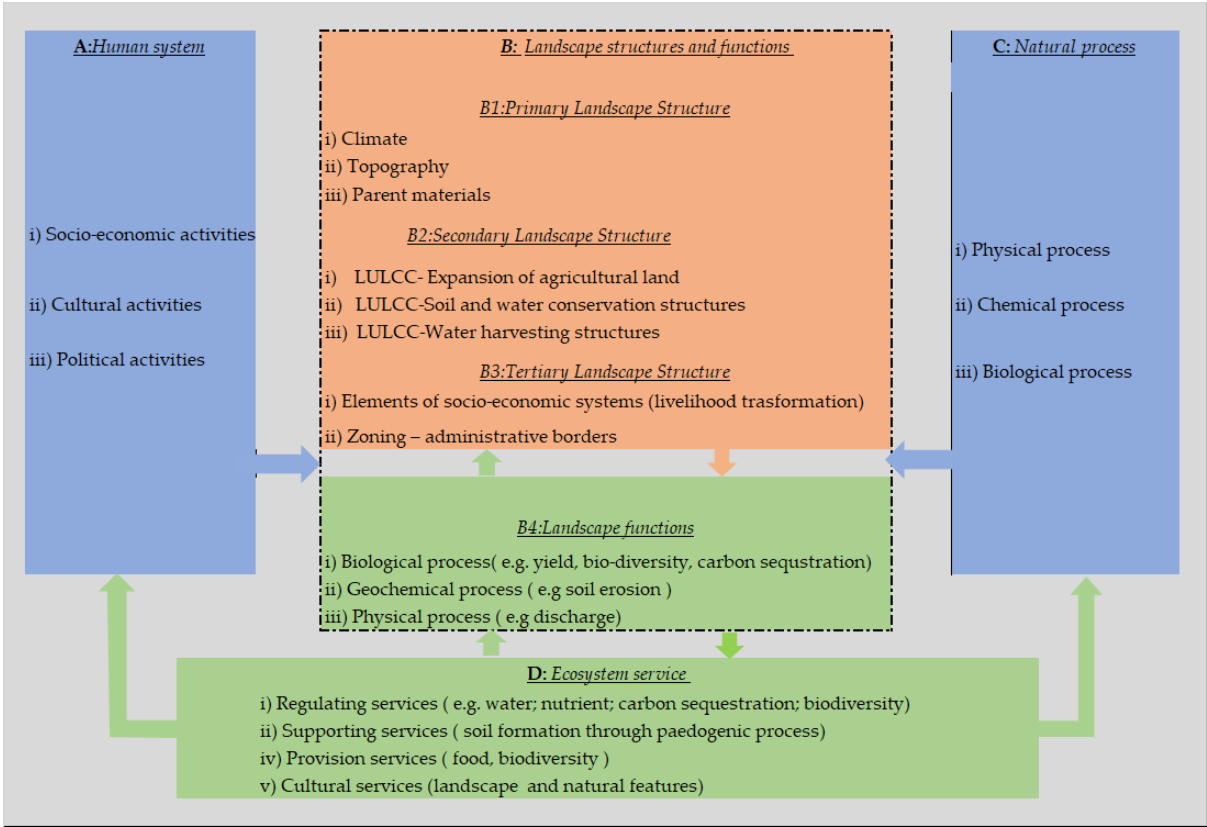


Figure 1. Framework of target indicators for a review of evidences of transformed landscapes and ecosystem services. [authors synthesise based on Helming et al. [23] and Hermann et al. [19]. LULCC stands for land use and land cover changes.

Landscape structure and functions are highly interconnected. To gain an in-depth understanding of these, selection of the right scale is important considering that the spatial and temporal scales of the processes and observations need to be aligned. However, availability of quality data, both spatial and temporal, is often limiting. This work considers evidence generated at different scales (farm plots, watersheds, landscapes, and basins) and consolidates the implications at the national scale. Likewise, temporal scale information is fragmented too. However, assessment of interventions in terms of their long-term impact on the performance of a landscape in delivering a broad range of benefits including transformation of livelihoods and ecosystem services is very scarce in Ethiopia as in many developing countries. Therefore, establishing empirical evidences of temporal trend for the target indicators—is beyond the scope of this review.

2.3. Adaptive management in relation to landscape transformation

Adaptive management and the theory of change for landscape approaches [15,16] are comprehensive and complementary frameworks related to landscape interventions and restoration of ecosystem services. According to Sayer et al. [15], a theory of change traces the links between an intervention and an ultimate impact and makes the assumptions underpinning prediction of the result explicit. The theory of change demonstrates the causal pathway and feedback loops driving progress towards improved landscape performance. Furthermore, the studies noted that metrics are needed at multiple stages throughout the process to understand progress and to inform policy and decision-making.

The concept of AM has evolved in numerous directions, but all are centred around iterative learning about a system and making management decisions based on that learning [17, 29]. The learning components focus on science (e.g. monitor, evaluate and adjust) while the other focus more on structured decision making by defining the problem, identifying objectives, formulating evaluation criteria, estimating outcome, evaluating trade off and deciding [16]. The adaptive process is often represented as a cycle of plan, do, monitor, and learn and can guide informed decision making while implementing activities related to landscape structural changes and also helps to address post implementation tradeoffs (Fig. 1) . We used elements representing both structured decisions making and the learning components to better understand the drivers and outcomes in the entire landscape (Table 1). In this line, Stirzaker et al. [29] argue that using real-life management of the system as a whole and turn it into an experiment by asking the right questions, implementing decisions, collecting the right data, and learning from the experience is crucial to understand landscape transformations.

The attributes of AM, which make it distinct from the traditional trial and error approach, is that it involves exploring alternative ways to meet management objectives. It forecasts the outcomes of alternatives based on the current state of scientific knowledge and it implements one or more of these alternatives. Adaptive management monitors impacts of management actions, updates knowledge and adjust management decision.

In this review we argue that the principles of AM can be applied to the concept of landscape transformation because of agricultural landscape intensification. We argue that the identification and monitoring of relevant indicators representing key landscape structures and functions support adaptive learning and decision making in sustainable agricultural intensification. We apply the developed framework in the context of degraded landscapes and the implementation of physical and biological SWC measures. Table 1 matches the framework of target indicators (B2 and B3 in Fig. 1) with key elements of the AM approach [16]. For each of the selected indicators, we explored if the literature reviewed attributed the failure or success of the interventions to one or more elements of the AM approach in Ethiopia [16].

The contribution of this review includes: i) the proposed analytical framework and demonstrating its applicability to target indicators and understand landscape transformation for specific areas which can be applied elsewhere., ii) presentation of structure and function of landscape transformation interactively and relating each of them with the learning and decision making elements of adaptive management in Ethiopia context.

2.2. *Data sources*

Data were collected from three major sources: peer-reviewed articles included in the Scopus and ISI Web of Science databases, grey literature, and expert knowledge following discussions in the agricultural water management platform in Ethiopia. The terms used to search for literature separately and in combination included 'landscape', 'landscape transformation', 'ecosystem services', 'sustainability', 'conservation and development', 'land use change', 'exclosure', 'soil erosion and sedimentation', and 'carbon sequestration'. Where relevant, we specified Ethiopia in these searches. From 71 articles identified 26 were on the general scientific background of agricultural landscapes and their transformations and 45 were specific to Ethiopian agricultural landscapes.

Table 2 indicates how often elements of AM were mentioned in the selected literature sources, either as recommendation or as gap for sustainable landscape transformation. It also provides the

number of cases that AM elements were mentioned (directly or implicitly) for each of the target indicators (as in Fig. 1, B2 and B3). We observed that different elements of AM were mentioned 142 times, and more than 80% of these were for indicators under the structural landscape component.

Many articles note gaps in one or more elements of the AM approach for respective agricultural landscape transformation interventions. Some scholars connected structures and functions (Table 1) of landscapes in a cause and effect relationship. Therefore, many articles were assigned to multiple indicators.

Table 1. Matrix matching the framework of target indicators of landscape structures B2 and B3 (figure 1) and key elements of the adaptive management approach Birge et a., [16].

Indicators for transformed landscapes (as in B2 and B3)	Target landscape component (as in B2 and B3)	Key elements of adaptive management								
		Structured decision making						Learning		
		Define/contextualize the problem	Identify the objective	Formulate evaluation criteria	Estimate outcome	Explicit evidence for trade-off	Intervention and resource allocation	Monitor	Evaluate	Adjust/negotiation and feedback
Land use and land cover change	Structural	X	X	X	X	X	X	X	X	X
Water harvesting		X	X	X	X	X	X	X	X	X
Soil and water conservation structures and practices		X	X	X	X	X	X	X	X	X
Discharge, sediment yield	Functional	*	*	X	X	*	*	X	X	X
Carbon sequestration, biodiversity		*	*	X	X	X	*	X	X	X
Livelihood transformation		*	*	X	X	*	*	X	X	X

X stands for cases where reviewed literature indicated application or lack of AM triggered bad or good performances of the focus indicators. Indicators under functional elements do not follow the whole AM approach as they are the result of changes in the structure and of external drivers and therefore marked by *

Table 2. Total number of incidents adaptive management (AM) elements were mentioned for each of the target indicators in identified literature suggesting gaps in key ingredients of AM in landscape transformation interventions.

Example of indicators for transformed landscape	Target landscape component	Number of incidents AM elements were mentioned *									Total number of incidents AM elements mentioned for each of the target indicators
		Structured decision						Learning			
		Define/contextualize the problem	Identify the objective	Formulate evaluation criteria	Estimate outcome	Explicit evidence for trade-off	Intervention and resource allocation	Monitor	Evaluate	Adjust/negotiation and feedback	
LULC change and related agricultural practices	Structural	8	4	2	4	8	3	3	5	4	41
Water harvesting		8		17	1	4	4	2	2	4	42
SWC structures		10	3		2	6	3	2	3	5	34
Discharge, sediment yield,	Functional	1				3			1	1	6
Carbon sequestration, biodiversity		1				3		2	2	2	10
Livelihood transformation		1	1		1		1	1	1	3	9
Total number of incidents each element of AM was mentioned		29	8	19	8	24	11	10	14	19	142

*The numbers refer only to literature published on Ethiopian agricultural landscapes in context of the targeted indicators (Table 1 and Figure 1)

3. Managing Agricultural landscapes in Ethiopia: What Worked Well and What Didn't Work so Well

3.1. *Structural indicators of transforming landscapes*

3.1.1. Land-use and land-cover changes: Expansion of cultivated land

Changes in LULC globally are driven by multiple factors including population increase, poverty, economic activities, and other socio-economic factors [30]. Land-use and land-cover changes are so pervasive that when aggregated globally, they significantly affect key aspects of the landscape structure [28].

Several studies by Kindu et al. [31], Gashaw et al. [32] and Deribew and Dalacho [33] documented changes in LULC and ecosystem services across time in Ethiopia. Many of them, however, did not enumerate comprehensive nationwide evidence. Available information at the micro scale (e.g. farm fields, watersheds) and meso scale (river basins, regions) show, however, that the magnitude of change is enormous, and that the direction of change varies across regions and scale of studies. For example, from a 145-year analysis of the situation in the northern highlands of Ethiopia, Nyssen et al. [22] concluded that the landscape is greener now. The findings of Gebremichael et al. [34] from their work in the Blue Nile basin concluded that erosion and sedimentation increased by 81% due to increased land conversion to crop land. The only recent national-scale land-use change study involving agricultural land expansion (2000-2010) was done by United Nation Convention to Combat Desertification (UNCCD) [35]; it showed only a 0.38% decline in forest cover with a proportionate increase in crop land and shrub, grasslands and sparsely vegetated areas.

Despite the small change from natural land cover to cultivated land as illustrated by the national-scale work [35], contrasting values available from meso- and micro-scale studies imply that there are hotspot areas of LULC change where ecosystem functions and services are degrading rapidly [36]. As summarized in Table 2, the total number of incidents AM elements mentioned as recommendation or gap in current LULC practice was 42. Of this, more than 70% related to the element of structured decision while the rest goes to learning components of adaptive management.

Overall, from an agricultural land perspective, three major causes of LULC changes can be recognized: (i) expansion of agricultural land due to individual farms encroaching into other land-use types; (ii) foreign direct investment (FDI) in agriculture; and (iii) restoration of degraded lands through physical soil conservation measures integrated with tree planting and biological soil conservation measures through, for example, exclosures.

(i) *Expansion of agricultural land due to activities by local farm investments*

Studies indicated that agricultural lands have been increasing in different parts of the country at the expense of forested land, grassland and shrublands. For example, a study conducted in the central highlands of Ethiopia [37] demonstrated a 62% increase in cropland between 1975 and 2014, which has mainly occurred at the expense of grasslands. Similarly, Derebew and Dalacho [33] showed that over the course of 60 years (1957-2017), agricultural land and forest land showed a comparably equal extent of net change (+ 36.7% and - 37.8%, respectively), but in opposite directions. Such changes in agricultural lands had resulted in an increase in total crop production over the past decade [38].

However, studies by the World Bank [13] and Bachewe et al. [39] showed that the relative contribution of agricultural land expansion to increases in agricultural production was decreasing in the period 2005-2015, which can be explained by the gain in yield due to increased use of fertilizers, herbicides, improved seeds and irrigation. This finding was supported by Franks et al. [38] who found that there has been a tendency of production gains accruing from higher land productivity rather than an expansion of cultivated land. Similarly, the World Bank [13] reported that the agricultural sector of Ethiopia recorded a remarkably rapid growth in the past decade, and that this was the result of strong yield growth as well as an increase in cultivated area, which rose by 7% and 2.7% per year, respectively, during the period 2004–2014. Kibret et al. [40], from their LULC change study in south and central Ethiopia, concluded that land conversion to agriculture in that part of the country may have reached a cut-off point beyond which it would have ecological consequences. Headey et al. [41] also argued that with little suitable land still available for expansion of crop cultivation, especially in the highlands, future cereal production growth would have to come from yield improvement.

Despite the presence of some areas where production still depends on expansion of cultivated land, many of the evidences above [13, 39,40, 41] suggested that future direction of agricultural productivity increase in Ethiopia could be intensification. For intensification, likewise for extensification, to be sustainable tools such as AM can be useful. It guides the process to assess the underlying trade-offs and seek options for optimal management choices under conditions of uncertainty.

(ii) *Foreign direct investment in agriculture*

Despite the few studies that explore the nature and benefits of FDI in Ethiopia, Mulue et al. [42] reported that between 1992 and 2017 an investment in 122 projects [8.8 ETB (about 2.6 billion USD)] was recorded: the third largest areas of FDI following manufacturing and contracting. Bossio et al. [43] indicated FDI in agriculture with close to 2 million ha of disclosed contracts for lease of land. Many of these land areas were in Gambela, Beni-Shangul Gumz and in Oromia regional states.

The aim of such investments was to increase provisioning ecosystem services (food production), technology transfer, job creation and flow of capital into the country [42]. Although only a smaller portion of the 2 million ha of land has been put in practice, scholars argue that the environmental sustainability in agricultural production is a major issue in the context of large-scale FDI in agricultural land [42]. Intensive agricultural production has negative impacts on biodiversity, forest, land, soil, and water resources. In this regard Teklu et al. [44] reported emerging threat of pesticide pollution of water resources in the Rift Valley: areas where flower farms and intensive irrigated agriculture are practiced partly through FDI. Overall, limited empirical evidences have been gathered on the opportunity costs (e.g environmental impacts, human health) of such land-use change.

Bossio et al. [43], who examined the impacts of FDI on water resources, indicated a potential increase in the consumptive use of freshwater resources, thus straining the already scarce freshwater resources although the investment may indeed enhance land and water productivity. Here there can be multiple suggestions in relation to AM to mitigate the negative impacts of such landscape transformation measures: (i) identify areas with the least opportunity cost; and (ii) systematically

monitor the emerging changes in landscape structure and functions in order to contribute to evidences supporting the AM cycle and application of the knowledge in future development endeavours [42].

(iii) *Restoration of degraded landscapes through physical and biological soil conservation measures*

Since the 1970s and 80s, several national programs, including the Sustainable Land Management (SLM) program (phases I and II) and the Productive Safety Net Program (PSNP), supported the implementation of SWC measures in the country. For example, during the period 2010-2015, more than 15 million people contributed unpaid labour (equivalent to USD 750 million each year) to the SLM programme [45]. During this same period, SWC measures have been introduced in more than 3,000 watersheds and more than 12 million hectares of land have been rehabilitated by implementing physical (such as stone bunds, soil bunds, trenches, fanya juu and check dams) and biological (exclosures, afforestation and reforestation) conservation measures [46, 45].

Studies demonstrated that the implemented physical SWC measures played an important role in rehabilitating degraded landscapes and improving ecosystem services (47-49, 27). For example, the transformation of these landscapes through SWC measures resulting increases in water retention and ground water recharge. This provides opportunities to support supplementary or full irrigation in rainfed or dry season agriculture, respectively [50]. Shallow ground water with less than 20m depth incurs less cost and easier to extract, thus can be an incentive to invest in SWC. Estimate shows that shallow ground water can irrigate as much as 8% of total irrigable land in Ethiopia [51]. Gowing et al. [50] argue that increased groundwater recharge and availability of shallow groundwater is an opportunity for intensification of agriculture and ecosystem services. Sustainable exploitation of this opportunity, however, needs careful monitoring of impacts of water abstraction, use and impacts on water quality which implicitly linked to application of AM approach.

Of the biological soil conservation measures, establishment of exclosures on degraded landscapes has been given more emphasis due to its multiple benefits [52-55]. Exclosures are areas protected from the interference of humans and livestock to promote natural regeneration of secondary vegetation. Recent estimates indicated that more than 4.2 million hectares of land in the country are

covered by exclosures [27]. Ethiopia recently pledged to rehabilitate 15 million ha of degraded land by 2030 [45] and, according to the government's plan, about 50% of the land – over 7 million ha - will be rehabilitated by establishing exclosures [45].

However, local communities raise concerns about the long-term soil conservation approaches and technologies discussed above, as the measures are not effective in generating short-term economic benefits [27]. The critical questions, therefore, are: (i) how would these land and water management, specifically SWC measures work for poor rural communities? (ii) how well are farmers organized and enabled for taking collective action? and (iii) what are the incentives and requirements to support local communities to adopt long-term conservation approaches? A recent work by Mekuria et al. [27] proposed a business model scenario to explore the feasibility of exclosures and address the complex challenges related to implementation. These business models identified short-term revenue streams such as beekeeping, harvesting fodder for livestock fattening, and cultivating high-value plant species, including fruit trees and herbs. These are feasible, sustainable economic activities that could allow for the restoration of ecosystem services over the long term if anchored to the principles of AM.

The other challenge is that the implementation of SWC measures in agricultural landscapes lacks monitoring, stakeholder's engagement, and longer-term impact assessment and that the approach in general lacks the learning ingredients of the AM cycle (16, 56, 17). The fact that impacts of SWC measures are a function of time requiring context-specific intervention, development of a matrix of evaluation criteria and involvement of the local community, as illustrated in the AM cycle and theory of change, is crucial [16,17]. As summarized in Table 2, the total number of incidents AM elements were mentioned as recommendation or gap in current SWC practice were 34. Of this, 71% of the count was under the element of structured decision while the rest related to learning components of AM. Recent initiatives by the World Bank to include hydro-meteorological monitoring system, as part of the SLM (phase III) in Ethiopia, might in part be a response to such criticism. Some of the key gaps such as the lack of evaluation, contextualization of interventions, assessment of outcomes of SWC measures in relation to livelihood improvement are summarized in Table 3.

2 Table 3: Examples of recent agricultural LULC studies in Ethiopia and the key gaps they discussed in relation to the adaptive management (AM) cycle

Authors	Focus issues	Spatial and temporal scale	Key conclusion	Examples of reflection on AM
Nyssen et al. [22]	Land-cover change	145 years; northern Ethiopian mountains by re-photographed 361 landscapes that appear on historical photographs (1868–1994)	The northern Ethiopian highlands are currently greener than at any time in the last 145 years.	Lack of explicit evidence on trade-off outcomes and contextualization of the problem - example eucalyptus dominated LULC.
Tadesse et al. [28]	Land-use land-cover change and erosion	2001-2015; watershed	Vegetative cover in the study watershed reduced by 91% during 2001-2010 and increased by 88% during 2010-2015.	Need for sustainable land management practices for sustainable livelihoods of local people.
Gebremichael et al. [34]	Erosion as influenced by land-use change	1973-2000; Upper Blue Nile Basin	Conversion of natural land use to agriculture and barren land has contributed to increasing sediment movement and runoff	Need for upstream-downstream consideration (trade-off).
Bossio et al. [43]	Foreign direct investment, land-use change, ecosystem services	2000-2012; national but not spatially explicit	Local food security without compromising local and downstream water availability.	Lack of trade-off analysis in enhancing foreign direct investment.
Tefera et al. [57]	Exclosed area management, land-use change, ecosystem services	Small catchment in Tekeze and Awash river basins; temporal scale not indicated	Lack of clear management guidelines for exclosure.	Need for monitoring and evaluation, contextualization of intervention, lack of outcomes in relation to livelihood improvement.
Kibret et al. [39]	Agricultural land expansion	1972-2013; south central Ethiopia	Agriculture has reached its maximum extension on suitable lands and is now expanding into marginal lands. Sustainable intensification trajectory is needed.	Current land-use change interventions need to consider elements of AM.
United Nation Convention to Combat Desertification UNCCD [35]	Land-use change, land degradation neutrality	2015 and projected; nationwide	Mainly descriptive.	Lack of monitoring, negotiation, evaluation, capacity of implementers

3.1.2. Small water harvesting structures

Expanding water harvesting structures is one of the adaptation mechanisms necessary for transforming landscape structures for better ecosystem service provision in the face of climate change. As concomitant benefits, water harvesting can reduce surface runoff and erosion and recharges ground water. Accordingly, many regional and national governments introduced the implementation of water harvesting structures to improve livelihoods and adapt to climate change since 2000s [58,59]. However, the impacts of implemented water harvesting structures (such as farm ponds and micro dams) on livelihoods is constrained by siltation, seepage losses, insufficient flows, structural damage, and spillway erosion [60].

For example, Gebremedhin et al. [60] showed that 61% of the water harvesting structures constructed in northern Ethiopia had siltation problems, 53% suffer from leakages, 22% had insufficient inflows, 25% were handicapped by structural damage, and 21% faced spillway erosion problems. Also, lack of benefit sharing mechanisms hampered improving equity, in most cases better-off farmers benefited more than poor farmers [61-63]. This suggests that the location, design to improve seepage losses, construction, and maintenance to combat siltation as well as governance of these structures need to be improved. This substantiate evidences summarized in Table 2 which illustrates the highest total number of AM elements mentioned as recommendation or gap in current water harvesting structure and practices (43). Of the total counts of the incident, 81% of the count was related to the element of structured decision making (Table 2).

Despite the huge potential, both in terms of available runoff and land resources, what has been achieved and recorded in this respect until now is limited and many interventions related to small water harvesting structure and practices did not meet the expectation of the farmers and there are several cases of dis-adoption. We argue that enabling AM and incorporating elements of the impact pathway, as suggested by Sayer et al. [17] and Birge et al. [16], would be a good starting point to overcome some of the bottlenecks. Adaptive management demands early community engagement, understanding trade-offs and monitoring of changes and impacts and learning and therefrom [64].

Therefore, it could mitigate the negative environmental, economic, and social consequences of small water harvesting interventions currently observed.

3.2 Livelihood transformation through natural resources management and agricultural activities

As indicated in Figure 1, the tertiary layer of agricultural landscape structure focuses on how agricultural and natural resource management-related activities are transforming livelihoods. We use Productive Safety Net Program (PSNP) where millions of farmers participated each year, as an example, to illustrate the key role AM approach could play in sustaining the impacts of natural resource management interventions on livelihood transformation. One of the major components in PSNP is public works program. Under this program eligible households with able-bodied adults are enrolled into the public works program which involves enhancing agricultural landscape structure (soil conservation structure). These public works activities occur for 6 months of each year, during which clients receive a salary based upon their household size. Public works clients are expected to graduate from the program when they gain sufficient assets

The PSNP clusters the key goals for smallholder livelihood activities into three classes and with variations within each of them: (i) For households with a wide gap between livelihood expectations and actual livelihood outcomes (far below the poverty line), the goal is to improve livelihood outcomes expressed in relative terms with reference to their current performance. (ii) The second cluster applies to households that are better off and also includes farm households that are just below the poverty line and striving to secure food and proper clothing and being able to send their children to school, depending on their priorities and ambitions. (iii) For the third cluster, transforming livelihood outcomes at the household level may involve these farm households exceeding minimum requirement and moving beyond the borderline of poverty. The PSNP uses these clusters to target smallholders to participate and to graduate from the program.

Relating this to AM would require us to answer the following questions: (i) is sufficient evidence available on how the implementation of different land and water management interventions

under PSNP transform the three livelihood clusters, (ii) what learning has been generated from the evidence and whether (iii) what learnings have been used to plan and design next phases of the programme. In the case of PSNP, many studies have focussed on the impact of payments made to program participants on wealth accumulation and local infrastructure development (e.g. roads, schools, etc.) rather than on the actual longer-term environmental and livelihood impacts of these interventions [63]. This clearly illustrates inadequate knowledge management efforts on how investments in agricultural landscapes are transforming livelihoods and the local economy. Several other land and water management programs also lack short-term and long-term evidences of impacts on small holder livelihoods. This is supported by the proportion of learning elements of AM (from the total number of counts of incidents mentioning AM elements) mentioned as a recommendation or gap in the current livelihood transformation related indicators (56%; figure not indicated in Table 2).

The only available comprehensive information, on how agricultural activities improves livelihood and level of poverty, is reported by World Bank [13]. Using the international poverty line [US\$ 1.90 per day at 2011 purchasing power parity (PPP)] as a yardstick, poverty is reported to have fallen from 55.3% in 2000 to 33.5% in 2011. A decomposition of yield increase reveals the importance of increased input use (e.g. improved seeds and agrochemicals) as well as total factor productivity growth [ratio of aggregate output (e.g., GDP) to aggregate inputs (2.3% per year)]. A doubling of the adoption of improved seeds and fertilizer played a major role in sustaining higher yields. Ethiopia's real GDP has tripled since 2004, although it remains well below regional and low-income countries levels. Recent work by Sheahan and Barrett [63] revealed that less than 4% of farm households in Ethiopia use integrated inputs consisting of inorganic fertilizer, irrigation and improved seed varieties, which implies that there are untapped productivity gains to be made from coordinated modern input use by deploying governance mechanisms (and improved knowledge and skills, supply chains, business models etc) to promote its uptake. This supports the claim discussed earlier that future Ethiopian food production largely depends on intensification; it also implies the need for an integrated and evidence-based approach, supporting AM, to ensure a sustainable intensification pathway [16].

3.3. *Examples of transformed landscape functional indicators*

As stated earlier, the structural and functional components of a landscape are very interactive with strong feedback loops. What we presented here are examples of how changes in the landscape structures influence the ecosystem services embedded in the landscape functions. We present below selected indicators such as impacts on yield, sediment, and discharge as well as on carbon sequestration and biodiversity. Keeping in mind the interactions of structural and functional elements of a landscape, the selection of examples is based on two key factors: (i) examples that reflect what we demonstrated earlier under structural landscape components; and (ii) examples that can have long- and short-term impacts and include multiple ecosystem services.

3.3.1. Impacts of SWC measures on crop yield, discharge, and sediment yield

Adimassu et al. [10] summarized the impacts of SWC practices on the grain yield of crops. These same authors indicated that the impacts of SWC measures on grain yield are divergent and influenced by the type of SWC measure. The authors concluded that most of the physical SWC measures were less effective in enhancing grain yield of crops and attributed the reduced yield to the trade-off of increased area the SWC structures occupied [10]. In high rainfall areas there was higher likelihood of waterlogging, which contributed to the reduced yield implying lack of contextualizing interventions as suggested in AM [16]

Several other studies have demonstrated that the implemented SWC measures had positive impacts on reducing surface runoff and sediment load. For example, a study conducted in north western Ethiopia by Dagnew et al. [67] showed that SWC practices significantly reduced the daily, monthly, and annual runoff and sediment load compared to untreated lands. Zegeye et al. [68], reported that gully head treatment reduced surface runoff by up to 42% compared to the runoff generated from untreated gullies. Gebremichael et al. [34], who illustrated trends of the Blue Nile flow (1970-2009) and sediment load (1980-2009) at the outlet of the Upper Blue Nile basin at El Diem station, reported statistically significant increasing trends of annual stream flow, wet-season stream flow and

sediment load at 5 % confidence level. The dry-season flow showed a significant decrease. However, during the same period, annual rainfall over the basin showed no significant increase. The counter-intuitive finding is why larger basin wide impact assessment (e.g. Gebremichael et al. [34] showed increase in trends of sediment yield and runoff, while SWC measures are proven to be effective at smaller scales as suggested for example by Dagnew et al. [67]. This could be explained by the fact that the overall area where SWC measures were applied is still small and that the total basin runoff is controlled by the over-proportional increase of runoff which comes from none SWC areas.

One of the lessons in terms of application of the AM cycle is that most of the SWC measures lack proper geographic, plot-level and social targeting [10], thus the positive impact on the landscape ecosystem functions (runoff, sediment yield) is low. This is counter-intuitive given decades of experiences of SWC research and generation of many context specific technologies and guidelines in Ethiopia. We argue that while generating contextualized SWC technologies is a key step, presences of the right institutions is what enables the use of these technologies and adoption of AM practices. In Ethiopia, several gaps related to institution and policy which explain lack of contextualization of SWC measures can be enumerated. These involve, for example, organizational instability; inefficient organizational structure (due to understaffing, under equipping), lack of linkages and alliances between institutions; shortage of skilled manpower, inadequate office and workshop facilities, lack of integrated information management systems.

Sayer et al. [17] and Birge et al. [16], in relation to the AM cycle for landscape interventions, suggested a defined objective, site-specific intervention and trade-off analysis and community participation as important ingredients for sustainable landscape management. These gaps in real world case studies are reflected on number of incidences (Table 2) where these AM elements were mentioned in the reviewed literature as recommendation or gap though these are smaller compared to other indicators considered.

Hailelassie et al. [69] argued that farm systems are heterogeneous; each farm system is unique in terms of its livelihood assets (including both biophysical and socio-economic resources) and

agricultural practices and therefore unique in terms of sustainability. Considering this use of a single indicator such as crop yield or run off to evaluate the transformation of landscape functions is inappropriate. Conceptually heterogeneity applies also to scales of analysis. For example, a sediment yield assessment or runoff measurement at plot level will have different values and implication compared to watershed level derived estimates because of sediment redistribution pathways. Therefore, a conclusion about impacts of change of agricultural landscape structure on landscape functions using single scale and incomplete indicator is misleading. When it comes to landscape functional indicators, the challenge is to develop spatially explicit monitoring and learning techniques involving suggestions by Sayer et al. [17] and Birge et al. [16] to support management (Table 2).

In sum, the implementation of SWC measures in the country (i) failed to match hotspot areas with technologies and farms [61-63, 70]; (ii) erosion processes intensified after the LULC changes in the central, western and southern part of Ethiopia which were covered with non-cultivated land during the initial “wake up” stage of the need for SWC measures [34,57]; (iii) lack of standard evaluation criteria and a comprehensive matrix addressing temporal, spatial and social dimensions of SWC [70]; (iv) failed to counterbalance the impacts of historical LULC changes; and (v) often failed to engage farmers and thus did not manage to increase adoption at larger scale [27]. The major challenges in relation to indicators of landscape functions (persisting erosion, increasing runoff and siltation of water harvesting structures and downstream water bodies and infrastructure) are related to these failures. The above summaries are also related to lack of structured decision making and learning processes in development interventions. Traditional trial-and-error approach, which is often a dominant practice in the current land and water management in Ethiopia, can accomplish learning by from what went wrong in the past, considering a feedback loop and adapting when necessary to avoid similar mistakes. Such an approach is not suitable for ecological systems for two reasons. First, slow feedbacks may mask long-term undesirable management outcomes. Second, ecosystems do not recalibrate to some predictable, stable state following failure. Instead, management mistakes can be persistent and costly [16], thus AM

which (unlike the traditional trial and error) emphasize learning while doing could be an appropriate [64].

3.3.2. Impacts on carbon sequestration and biodiversity

Studies demonstrated that the various land and water management measures implemented in the country (change in landscape structure) contributed to the restoration of both below- and above-ground carbon storage. For example, Woolf et al. [71] estimated the mean carbon benefit (both above- and below-ground carbon) across Productive Safety Net Programme (PSNP) sites to about 5.7 tonnes of CO₂e per ha per year. Extrapolating these results to the whole intervention area of the PSNP (600,000 ha) would imply that a total carbon benefit in the order of 3.4 million t CO₂e per year has already been achieved by PSNP.

Similarly, studies by Mekuria et al. [53,54] and Anwar et al. [72] demonstrated that land and water management practices (mainly enclosure) are effective in increasing ecosystem carbon stocks (ECS). For example, a study conducted by Mekuria et al. (53,54] in Tigray, most northern part of Ethiopia, showed that differences in ECS between enclosures and grazing lands varied between 29 (±4.9) and 61 (±6.7) C t ha⁻¹ and increased with enclosure duration. A study in north-western Ethiopia [56] showed considerable increases in aboveground carbon (ranged from 0.6 to 4.2 t C ha⁻¹) were observed following the establishment of enclosures. Anwar et al. [72] showed that over a period of six years, aboveground biomass increased by 56 t ha⁻¹ (or 81%) at the watershed scale because of the conversion of communal grazing land to enclosure.

SWC measures were also effective in improving biodiversity. For example, studies [53,71] detected higher plant species richness and diversity in enclosures compared to communal grazing lands. Furthermore, differences in plant species richness and diversity compared to adjacent communal grazing lands increased with age of the enclosure.

In AM approach, spatially explicit analyses and continuous monitoring are important to inform local authorities about the gains and losses of investments and continuously adapt the management approach, as necessary. For farm households contributing free labour, the establishment of enclosures

for carbon sequestration may not make sense. Smallholder farmers are often risk-averse and focused on short-term gains. The bottom-line, however, is how such community segments can be incentivized better in light of superior objectives, and how to understand and minimize all trade-offs arising from such interventions to enable wider adoption of the practice to support sustainable landscape transformation. For example, exclosures require land, labour, and water – but all these resources have opportunity costs. The point then is whether the benefits from carbon sequestration and restoration of biodiversity can exceed the opportunity costs of these inputs today and tomorrow and how can farmers who bear the costs (labour, land loss, etc.) be compensated - in real money – paid by polluters who pay for carbon emissions?

These are important issues that research and AM need to explore and make interventions context specific and sustainable. This is demonstrated by the proportion of highest learning elements of AM from the total number of incidents AM elements mentioned as recommendation or gaps in the carbon sequestration related indicators (60%, figure not indicated in Table 2).

4. Prospects for Transformed Agricultural Landscapes under the Premise of Sustainable Ecosystem Services

This review synthesized evidences of transformed structural (e.g. LULC, micro-water harvesting structures, exclosure, livelihood transformation) and functional (e.g. production, runoff, sediment, biodiversity and carbon sequestration) elements of the Ethiopian agricultural landscape, and identified gaps in the application of an AM cycle following implementation of SWC measures. Despite numerous environmental and economic benefits, the review identified several gaps in applying the principles of AM.

All the elements of AM cycles have emerged as important gaps, but with different magnitude. The most frequently mentioned elements of AM in the reviewed literature were contextualizing interventions (20%) followed by explicit trade-offs (17%) and negotiation and feedback (13%). Although elements of AM are not mutually exclusive, the above trends show where the future focus of investment

of land and water management should be. Overall, these gaps can be summarized as follow: (i) lack of evidence of trade-off analysis and implementation of management options, (ii) insufficient knowledge management efforts particularly in relation to evidence-based contextualization of interventions, continuous post intervention monitoring of bio-physical and socio-economic changes, (iii) inadequacy of local community engagement at the onset of interventions and provision of feedback mechanisms, and (iv) information gaps on outcome and impact estimation and how land and water management intervention transform local community livelihood across space and time.

These gaps suggest that the planning and implementation of interventions to transform agricultural landscape for improved ecosystem services need structured decision making and continuous learning and its application as the implementation evolves. Addressing the identified gaps will help to attain sustainability of these interventions and to ensure that the people's needs are met now and in the future. Given the many uncertainties we must deal with, land and water management intensification cannot follow a business-as-usual approach. This means that change in the mode of operation is not a matter of choice. For this to happen, Ethiopia needs to follow an AM approach in landscape transformation. The success depends on three interdependent pillars of action: the ability to make a robust, mutually agreed plan of interventions, the ability to continuously monitor changes of key variables, and to learn from the knowledge generated and apply the learning as implementation evolves [64].

Acknowledgments

The authors are grateful to the Coordinated Research Program Water, Land and Ecosystem (WLE) of the CGIAR for the financial support to this study. We would like thank Prof Jennie Barron who reviewed the draft manuscript and we recognize members of agricultural water management platform in Ethiopia for their constructive comments during the conceptualization of this review.

Conflict of interest:

The authors declare no conflict of interest.

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