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SPATIAL AND TEMPORAL ANALYSIS OF MANAGEMENT IMPACTS ON ECOSYSTEM SERVICES – SCENARIO MODELING IN A HIGHLAND WATERSHED OF NORTHWEST ETHIOPIA

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Declaration

I, the undersigned, hereby declare to the University of Natural Resources and Life Sciences, Vienna that this is original research work and all sources of materials used are accordingly acknowledged. This work has not been submitted to any other educational institutions for achieving any academic degree awards.

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Place and date: Vienna, January 2015

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Impossible is possible by GOD. It always seems impossible until it is done (Nelson Mandela). Zukunft ist Vergangenheit (Future is past). To expect the unexpected shows a thoroughly modern intellect (Oscar Wilde, 1854-1900).

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Abstract

The highland ecosystems of Ethiopia produce and deliver numerous fundamental and useful benefits that are basis for survival. However, human pressures have caused negative changes of the ecosystem and have made it poorly suited to provide products in a sustainable way. Strategic development options to satisfy the demands of the present society without compromising the benefits of the future are required. The objective of the study was to find ecosystem-service-based development options to improve the living conditions of the people in the highlands of northwest Ethiopia. A set of tools was applied to a demonstration watershed “Tara Gedam”. Participatory resource assessment focusing on ecosystem services was conducted by using interviews, focus group discussions, reviews, field surveys and informal meetings with beneficiaries and stakeholders. The dynamics of the landscape from 1957 to 2013 was analyzed using aerial photographs and satellite images. The method used for ecosystem-services-scenario-modeling was the Drivers-Pressures-States-Impacts-Responses (DPSIR) framework. The dynamics and pathways of scenarios were evaluated by a combination of qualitative and quantitative analyses of LCUTs and ESs. Subsistence, cultural or religious, and environmental services were the major ESs found in Tara Gedam. The benefits obtained by the population, ownership, administration and policy were the main factors of the investigations. The analysis of remote sensing data showed an overall increase of cropland and a decrease of other LCUTs over 56 years. Land use conversion predominantly occurred from forestland and/or shrubland to cropland. The population growth has a positive correlation with the expansion of farmland. It was shown that improved crop varieties and improved management can increase the yield 2-3 fold compared to the present management system. The increased productivity would offer sufficient time and land area for fallowing, exclosures, rehabilitation and restoration. From the trend analysis of the landscape dynamics, field experimentation and participatory resource assessment, the scenarios of Business as Usual (BAU), Transition Agriculture (TAG), Intensive Agriculture (INA) and Optimized Ecosystem Services (OPE) were defined as development options suiting the highland watershed using the DPSIR framework. TAG could be chosen as a rapid response of a low economy community. INA emphasizes food security, whereas OPE pays due attention to food security and environment protection simultaneously. OPE provides a potential synergy of environment protection and agriculture development. The result suggests that the application of either INA or OPE will improve the living condition of subsistence farming. OPE better ensures the provision of diversified and economically valuable ES so that it represents the best development option. Population growth, policy and technology are presumed to be the major ESs stressors affecting the state of the watershed. Future ES development requires integrated approaches to minimize degradation and to ultimately contribute to improved food security.

Key words: DPSIR, Ecosystem services, Intensified agriculture, Optimized ecosystem services, Remote sensing, Scenario modeling, Tara Gedam, Teff

Zusammenfassung

Die Hochland-Ökosysteme Äthiopiens erbringen zahlreiche Leistungen, die die Lebensgrundlage der Bewohner darstellen. Vom Menschen verursachte Belastungen brachten jedoch negative Veränderungen des Ökosystems und beeinträchtigen seine Fähigkeit zur nachhaltigen Lieferung von Gütern. Strategische Entwicklungsoptionen werden gebraucht, um die Bedürfnisse der gegenwärtigen Gesellschaft zu befriedigen, ohne die zukünftigen Leistungen zu gefährden. Das Ziel der Studie war es, Entwicklungsoptionen für die Ökosystemleistungen zu finden, um die Lebensbedingungen der Menschen im Hochland im Nordwesten Äthiopiens zu verbessern. Ein entsprechendes Instrumentarium wurde im Einzugsgebiet "Tara Gedam" exemplarisch angewendet. Mit Interviews, Gruppendiskussionen, Überprüfungen, Geländeerhebungen und informellen Treffen mit Nutzungsberechtigten und Interessensgruppen wurde in einem partizipativen Prozess eine Bestandsaufnahme der Ökosystemleistungen durchgeführt. Die Entwicklung der Landschaft von 1957 bis 2013 wurde mit Luftbildern und Satellitenbildern analysiert. Für die Modellierung der Ökosystemleistungen in Szenariotechnik wurde die DPSIR(Drivers-Pressures-States-Impacts-Responses)-Struktur verwendet. Die Dynamik der Szenarien und die Szenarienwege wurden durch eine Kombination von qualitativen und quantitativen Analysen von Landbedeckungs/Landnutzungstypen und Ökosystemleistungen ausgearbeitet. Bereitstellende (subsistence), kulturelle/religiöse (cultural or religious), und umweltbezogene regulierende (environmental) Dienstleistungen waren die wichtigsten in Tara Gedam vorgefundenen Ökosystemleistungen. Hauptfaktoren der Untersuchungen waren der Nutzen für die Bevölkerung, Eigentumsverhältnisse, Verwaltung und Politik. Die Auswertung der Fernerkundungsdaten zeigte für den Zeitraum der 56 Jahre eine generelle Zunahme des Ackerlandes und eine Abnahme der anderen Nutzungsarten. Es wurden vor allem Waldflächen und Buschwald/Strauchlandschaft in Ackerland umgewandelt. Die Bevölkerungszahl korreliert positiv mit der landwirtschaftlichen Nutzfläche. Es wurde gezeigt, dass verbesserte Pflanzensorten und verbesserte Bewirtschaftungspraktiken den Ertrag 2- bis 3-fach erhöhen können. Die erhöhte Produktivität würde genügend Zeit und Fläche für Brachlegungen, Ausschlussflächen, Rehabilitation und Restauration bieten. Ausgehend von der Trendanalyse der Landschaftsdynamik, den Feldversuchen und der partizipatorischen Bestandsaufnahme wurden die Szenarien "Business as Usual" (BAU), "Transition Agriculture" (TAG), "Intensive Agriculture" (INA) und "Optimized Ecosystem Services" (OPE) als Entwicklungsoptionen für das Hochland-Einzugsgebiet definiert. TAG könnte zur raschen Krisenbewältigung einer Gemeinschaft mit geringer wirtschaftlicher Leistungsfähigkeit gewählt werden. INA betont die Nahrungsmittelsicherheit, während OPE Nahrungsmittelsicherheit und Umweltschutz gleichzeitig beachtet. OPE stellt eine mögliche Synergie zwischen Umweltschutz und landwirtschaftlicher Entwicklung her. Das Ergebnis zeigt an, dass die

Anwendung von INA oder OPE die Lebensbedingungen in der Subsistenzlandwirtschaft verbessert. OPE sichert diversifizierte und ökonomische wertvolle Ökosystemleistungen in höherem Maße, stellt also die beste Entwicklungsoption dar. Bevölkerungswachstum, Politik und Technologie können als Haupt-Stressfaktoren für die Ökosystemleistungen angenommen werden. Die zukünftige Entwicklung der Ökosystemleistungen erfordert eine integrierte Herangehensweise, um Schädigungen zu minimieren und letztlich zu einer Verbesserung der Ernährungssituation beizutragen.

Stichwörter: DPSIR, Ökosystemleistungen, Intensivlandwirtschaft, Fernerkundung, Szenariotechnik, Tara Gedam, Teff

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1. INTRODUCTION

1.1 Background

Ecosystems produce and deliver numerous fundamental and useful benefits for life-sustenance. They are the basis for human welfare and economic development. These benefits are called ‘ecosystem services’ (Costanza et al., 1998; Nelson et al., 2009; Khaiter and Erechtchoukova, 2010). ESs provide vast economic value to the society, which is considered as a key element for its development. Ecosystem services (ESs) are tangible or intangible deliverables from ecosystems in the form of direct or indirect benefits to sustain, govern and/or support human livelihood (Millennium Ecosystem Assessment [MEA], 2005). Food availability for humans and other life forms is dependent on the flow of ecosystem services (Poppy et al., 2014). There are tight relationships between ESs, food security and environmental management.

ESs are aggregated and categorized into provision, regulation, cultural and supporting services for conceptualization and common understanding (de Groot et al., 2002; MEA, 2005; Rodríguez et al., 2006; Khaiter and Erechtchoukova, 2010). Food, fodder, fresh water, wood products, genetic resources and medicine are some of the examples for provision (production) services. Regulation services comprise flood protection, climate regulation, disease protection, pollination, protection against storm, and biodiversity. Cultural services are mostly related to human intangible benefits such as spiritual, aesthetic, educational and recreational values. Supporting services are the central accelerator and the basis for functioning and safeguarding of the essential components of ecosystems (Sileshi et al., 2007). They include primary production, nutrient cycling, soil formation and energy transformation.

Nowadays, all benefits derived from natural ecosystems are under huge pressures and conversions because of anthropogenic interference (MEA, 2005; Koniak et al., 2010). Human encroachments have modified the structure, processes and functions of natural ecosystems. The changes are the results of interaction and interrelationship between anthropogenic actions and the response of nature. The most influencing factors are population growth and the resulting demands, socioeconomic developments, technology variations, natural catastrophes and climate change. Over the past 50 years, ecosystems have been changed drastically by the growing demand of human basic needs and energy consumption (MEA, 2005; Bakker et al., 2011).

The ongoing intensive and extensive utilization of the natural resources, their management and in general the interaction of humans with nature have resulted in either positive or negative consequences. Several studies have reported that a prevalent significant decline, unsustainable use and irreversible change of ESs have occurred across the world (MEA, 2005; Egoh et al., 2008). MEA (2005) reported that globally 15 of the 24 ESs are declining, which has a negative consequence on the welfare of future generations. In the case of developing countries, natural resources are under heavy pressure because of overexploitation, mismanagement and misuse. The rapid development of society and economy causes negative impacts on ecosystems and poses serious threats to our living environment (Shao et al., 2013).

The study presented here deals with the highland farming system of northwest Ethiopia. This system is characterized by crop-dominated agriculture and free-grazing-based livestock production, with scattered trees deliberately grown or retained on farmland. It comprises a mosaic of dynamic land uses, which are the outcomes of anthropogenic activities since time immemorial. The farming system in the highlands is a complex arrangement of biological, physical and human components. Highland watersheds are sources of important ESs such as water, food, fodder and forage.

In recent time, changes of the ecosystem and, as a consequence, of ecosystem services in the highlands are accelerating. Previously forested areas have been transformed into crop dominated farming system. The major causes for these changes are demand-driven human activities. Dynamics of land use accompanied by poor land management and increasing of population take the biggest share as a cause of environmental degradation (Zeleke and Hurni, 2001; Hurni et al., 2005).

In order to improve the living conditions of the resident population, the ecological components that provide services and functions have to be managed more carefully. This has to be done without compromising the demands of future generations (Egoh et al., 2008). The occurrences of ESs need to be understood and synthesized for future development strategies and to support decisions. In this sense, careful strategic approaches and alternatives are required for the management of the resources in the highlands of Ethiopia to satisfy the demands of the present generation and to ensure sustainability for the benefits of the future generations.

1.2 Problem statement

The development options considered for the highland agriculture ecosystem are usually of conventional type, with minor, incoherent and unsystematic modifications of the present situation. These alternatives for the development of the agricultural landscape are hardly suited to provide sustainable food for humans and to secure environmental protection. Moreover, the progress of landscape development is slow, as it is strongly linked with cultural and social bondages. Hence, there are urgent needs to present efficient options for unconventional landscape management and development. This study is expected to provide useful landscape development plans to contribute to food security and to prevent environmental degradation.

The conceptual and methodical tools of ecosystem services, scenario modeling and the Drivers-Pressures-States-Impacts-Responses (DPSIR) framework are considered to provide a promising starting point of this study.

Research and development on ESs recently draw the attention of different disciplines (Geneletti, 2012). However, up to now little use has been made of the concept ‘ecosystem service’ in the development plans and decision making processes in the highland watershed of northwest Ethiopia. The presence of limited scenario modeling regarding ESs and land productivity in general (Cumming et al., 2005) prompted us to search for alternative strategies other than the existing management system in northwest Ethiopia. Regarding the present study, the spatial and temporal ES scenario modeling is chosen as an approach to visualize the future trend, provide development options or strategies as described by Duinker and Greig, (2007) and Mahmoud et al. (2011), design proactive measures (Bryan et al., 2011; Sohl et al., 2012) and complement decision-making processes.

The reasons to focus on ESs scenario modeling are:

(1) the concept of ESs is not yet well-understood by different stakeholders and has not yet been incorporated in decision making processes in the highlands;

(2) in particular, no site-specific ES-based scenarios at fine and detailed scale have been developed up to now to mitigate the ongoing problems;

(3) there is a need of participatory and experiment-based, evidence-based modeling and analysis based on field data (socioeconomic and biophysical) and remote sensing in order to provide convincing results; and

(4) alternatives for the future development have to be designed which provide or suggest proactive measures (before the problems arise e.g. erosion prevention) instead of reactive measures (after the problem occurred e.g. gully treatment).

In general terms, reviews showed that most of the scenario studies follow top-down approaches. The studies are suited for developed countries, are less participatory approaches, have limitations on spatial information, are coarse in scale, exclude small landholding farmers, and mostly focus on theoretical models (Pfister et al., 2005; Rounsevell et al., 2005; Rounsevell et al., 2006; Busch, 2006). Busch (2006) reviewed 25 scenario studies and pointed out that all except 8% of the methods followed a top-down approach, are coarse in scale and use less participation of the local people. Environment (ecosystem)-targeted scenario modeling has been conducted by different institutions and authors, and at different spatial and temporal scales, see, for example, Special Report on Emissions Scenarios (SRES) about future greenhouse emissions (IPCC, 2000), climate change scenario (Moss et al., 2010), land use scenario for different environmental issues (Rounsevell et al., 2005; Busch, 2006; Rounsevell et al., 2006; Lin et al, 2007; Alcamo et al., 2011) and policy based scenarios of ESs in mountains (Hirschi et al., 2013). These scenarios are coarse in scale, have less emphasis in developing highlands and are not targeted to small landholding farmers.

The availability of ecosystem products depends heavily on the location and characteristics of the users (Limburg et al., 2002; Hein et al., 2006). Therefore, site-specific information for conservation and management is required due to variations of the ecologic and socioeconomic situations (Plummer, 2009).

The Tara Gedam watershed located in the highlands in northwest Ethiopia is chosen for this study. This area of approximately 900 ha size is small enough to perform fine-scale analyses with active participation of the small landholding farmers. The watershed is used in exemplary manner (pilot or model watershed). It should be possible to transfer the findings (if necessary with certain modifications) to other highland areas.

1.3 Concept framework

Scenario modeling is one of the methodological approaches analyzing alternatives of future development and showing the effects of measures changing the current situation through trend analyses. Conceptually, scenario analysis is the process of evaluating alternative future states with plausible pathways (Mahmoud et al., 2011), a process for forward-looking analysis

(Ahmed et al., 2010), or the development of alternative visions (Duinker and Greig, 2007; Price et al., 2012).

In this study, scenarios were chosen as methodological approaches to present options for improved livelihoods. The scenarios were developed based on the ecosystem-services point of view following the Drivers–Pressures–State–Impact–Response (DPSIR) framework (European Environment Agency [EEA], 2001).

DPSIR is a systems-based approach to understand the relationships between humans and the environment for structuring and communicating environment-based development and policy to solve environmental problems (EEA, 2001). It was chosen for this study because of its flexibility in decision-making and suitability for application at different scales, from global to watershed levels (Carr et al., 2007; Hou et al., 2014). The generic DPSIR model is illustrated in Figure 1. The framework has five components that influence each other. It provides comprehensive information about the driving forces of change, pressures on the ecosystem, states of the environment, consequent impacts on humans, and possible and necessary responses (Kristensen, 2004).

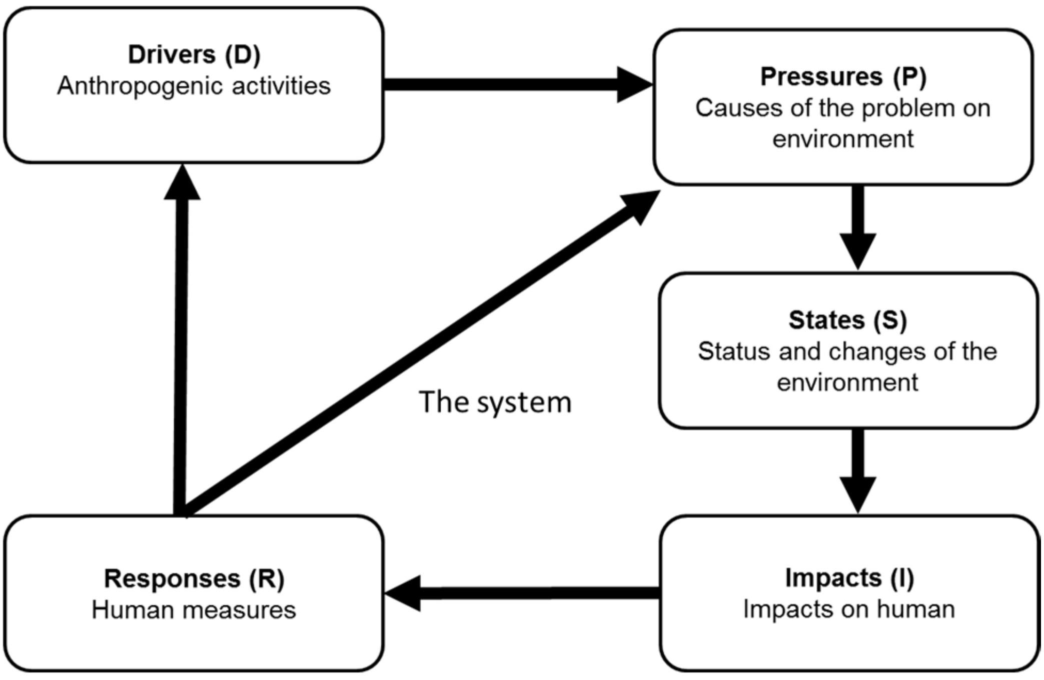


Figure 1. A generic DPSIR model (Adapted and modified from: Gregory et al., 2013)

The drivers of change are the growing populations with their growing demands on ecosystem services. As a consequence, pressures are exerted on the environment, changing its status and capacity to deliver the required ecosystem services. This in turn has negative effects (impacts) for the population. Remedies in the form of responses are sought to influence the driving forces and relieve the pressures on the environment, which again should have a positive effect on the social and economic impacts, etc.

It is essential to note that in the model of the system of these five components, only the relationships indicated as influencing pathways (arrows) between the components are considered. There are of course indirect influences between all components. For example, the responses ultimately should have effects in the environment (states), but this is described in the model framework by the direct causal links from responses to drivers (and partly also directly to pressures), from drivers to pressures and from pressures to states.

This framework was to be adapted for scenario modeling of ecosystem services in the highlands of northwest Ethiopia. The different scenarios to be considered are introduced into the DPSIR framework in the form of different responses. Each group of responses will result via the framework pathways in different states and impacts, which then together represent a certain scenario.

1.4 Objective

The general objective of the study was to find methods to improve the living conditions of the people in the highlands of Northwest Ethiopia in an ecologically compatible and sustainable way. This is to be attempted by ecosystem-services-scenario-modeling in a watershed in an exemplary manner, providing strategic development and management options for decision makers as a basis to bring sustainable development of natural resources and thus contribute to minimize land degradation and improve food security.

The specific objectives of the study were to:

- assess, classify and obtain qualitative information about the ecosystem services;
- model the dynamics of landscape transformation and population development using remote sensing data;
- investigate the highland ecosystem services at a fine spatial scale, and
- use the DPSIR model in ecosystem service based scenario modeling analyses with the aim to improve the current status of the watershed.

The study addressed the following research questions:

- Is it possible to improve the current situation (characterized by land degradation and food insecurity) using different options (scenarios)?
- How can the use of scenarios complement the decision-making processes in resource management?
- Does ESs scenario modeling using the DPSIR framework work for small landholdings?
- Which land use pattern would optimize ESs under the likely scenarios?

2. STUDY AREA

2.1 Location and topography

Tara Gedam watershed is located approximately at 12°8’30” - 12°10’30”N and 37°43’35” - 37°46’05”E. The watershed covers an area of 886 ha and is situated North of Addis Ababa (capital city of Ethiopia) in the Tara Kebele, South Gondar Administrative Zone, Amhara National Regional State, Northwest Ethiopia (Figure 2). The area is characterized by rugged topography with an altitudinal range of 2000 - 2600 m.

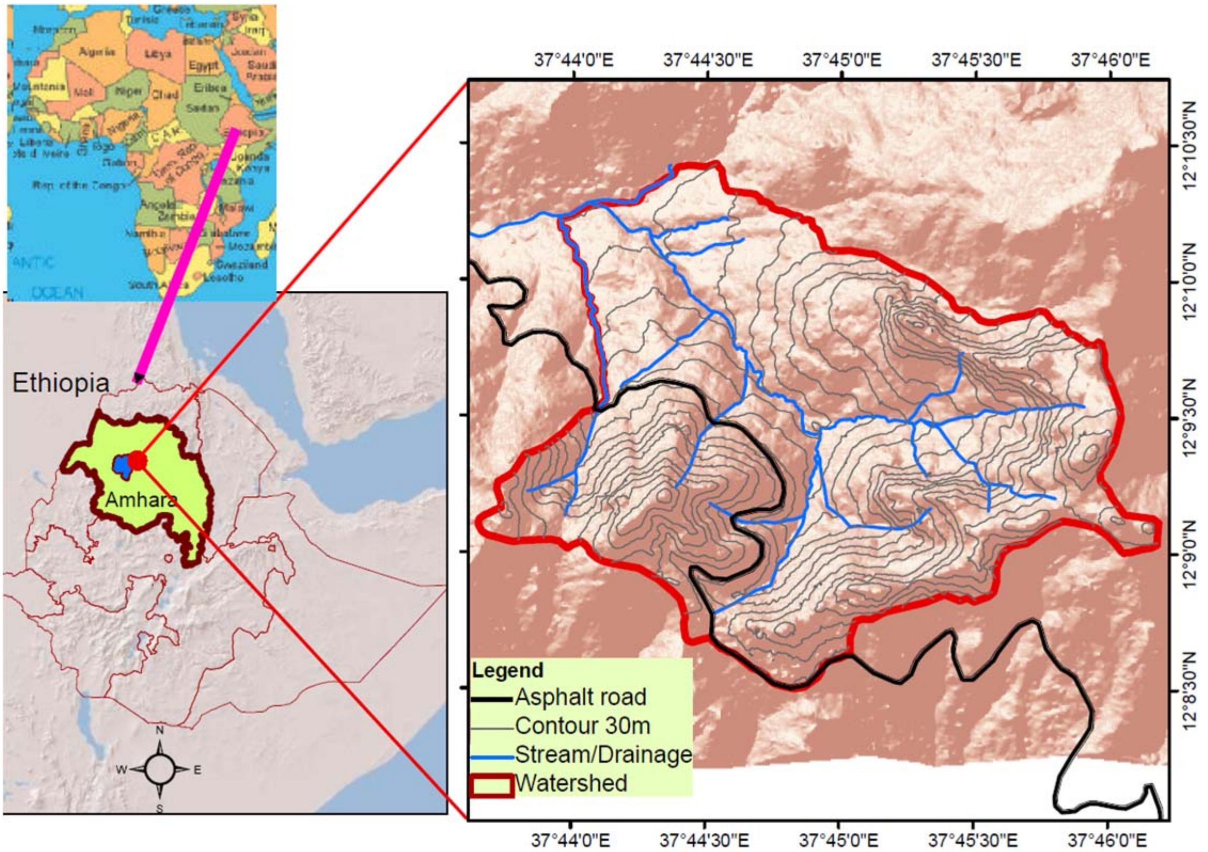


Figure 2. Map showing location of the study area

2.2 Climate, soil and water resources

The average annual rainfall is 1175 mm with peak rainfall season between June and August and dry season between December and April. The mean monthly temperatures range from 18 – 34 °C (Abiyu, 2012; Feyisa, 2012). The soils are of volcanic origin dominated by Nitisols, Cambisols, Leptosols and Luvisols (Abiyu, 2012; Feyisa, 2012). The watershed is drained by a stream called ‘Aguat Mefesesha’, which is a tributary of the ‘Arno’ River. Seasonal and intermittent streams, which originate from the watershed, are used by the local communities for irrigation and as a supply of drinking water.

2.3 Land cover/use types in the watershed

The watershed comprises different land cover/use types (LCUTs), mainly cropland, forestland, pastureland and shrubland. This is the result of a crop-livestock-tree based farming system in the study area. The dominant land cover is cropland. Crops cultivated in the study area comprise cereals, legumes and vegetables. Pastureland consists of different grass species. Shrubland is the mix of young tree species, thickets and bushes accompanied by grasses. Church-owned forests are found in and around the Ethiopian Orthodox Tewahedo Churches (EOTC). Government-owned forests are administered by the Regional State for the purpose of conservation. Church- and government-owned forests are dominated by indigenous species, including *Albizia gummifera* (J.F. Gmel.) C.A. Sm., *Calpurina aurea* (Ait.) Benth., *Dodonaea angustifolia* L.*f*., *Dombiya torrida* (J.F. Gmel.) Bamps, *Olea europaea* L. subsp. *cuspidata* (Wall. ex G. Don) Cif, and *Schefflera abyssinica* (Hochst. ex A. Rich.) Harms. *Acacia* spp., *Combretum molle* R. Br. ex G. Don, *Cordia africana* Lam. and *Croton macrostachyus* Del., are retained in the farmlands for different uses (Zegeye et al., 2011). The predominant exotic tree species introduced and grown for different household purposes include species of *Eucalyptus* and *Cupressus*.

2.4 Socioeconomic situation

The study watershed has 392 households. The total population living in the watershed is 1889 people. The field survey showed that about 11% and 89% of the households are female- and male-headed, respectively. The average family size is about five per household. Regarding education, 82% of the household heads are illiterate. About 16% of the people are dependent on food aid by the government, and the remaining 84% are based on small-scale agriculture economy. The average number of cattle and oxen were about two and one per family, respectively. The minimum and maximum landholding sizes were 0.05 and 3.53 ha, respectively. The average size of crop landholding per individual household was about 1.1 ha while the average number of parcels (plots) was 4.5 per household.

The livelihood of local communities is based on agricultural activities. The dominant practice is mixed farming, which integrates crop with livestock production (Feyisa, 2012). Crops are grown for both household consumption and income generation. Livestock provides draft power, loading and transportation services as well as income. The increase of human and livestock population accompanied by poor cultivation resulted in shortages of agricultural products (food, wood, feed etc.) and hence, food insecurity. Seasonal migration to nearby towns and agriculture investment areas is common to generate additional income by selling labor.

3. DATA AND METHODS

3.1 Assessment, typology identification and description of ecosystem services

The data for the study were obtained from field surveys, focus group discussions (FGDs) and secondary sources to identify and classify ecosystem services in the highland watershed.

3.1.1 Field data collection

The field data collection was conducted between June and October 2012. Participatory research (resource assessment and description) was performed by involving local farmers and experts. This was mainly aimed at identifying their common priority demands (preferences). Representative local farmers were selected through the help of development experts. Focus groups were formed according to the geographical location of residences or, in the case of landless farmers, the work location.

Six focus groups were created for the purpose of discussions. Four of them were farmers who have landholding right in the watershed; one group was composed of farmers who are landless; and one group was formed by the team of development experts. These development experts represent the three disciplines of crop production, livestock development and natural resource management. In total, the focus groups comprised 37 interviewees (33 farmers and 4 experts), including five female participants. The number of persons in the FGD ranged from 4 to 8.

In addition to the FGD meetings, individual farmers were met informally on their farmland. Walking-and-discussing (transect walk) in the farmland and describing the farm plots were among the methods used in the field. In total, seven meetings were carried out including two preparatory meetings. The purposes of the first two preparatory meetings were to make introductions and to brainstorm on the objectives of the discussions and the interviews. The FGDs were carried out five times between June and October 2012 to generate the required information. Influential or economically elite farmers were not included at the first and second preparatory meetings deliberately, in order to have free and unreserved discussions among the remaining group members during the initial stage, and to avoid bias as a result of anticipated dominance by the elite farmers. During the first meetings, the discussions were less interactive. The respondents were encouraged to talk freely about the subject. When the contacts became closer at a later stage, the participants became more communicative. Gradually, participants discussed without reservations and revealed their experiences.

The discussions were targeted at exploring the concepts of ES, ES categories and decision processes with reference to ecosystem benefits and their management. The discussion characteristics of each group were explored by facilitators and the researcher, using visual inspection and by switching between the groups. The minutes were prepared by moderators. The results of each FGD were aggregated by bringing all groups together. In each meeting, the moderators requested the focus group participants to prioritize ESs (e.g. food, feed and water) based on their importance. The general questions asked were: what are the benefits/demands from the watershed and what are the participants' top priorities? How are the farmers' livelihoods linked to these ecosystem deliverables? In what kind of intervention are the farmers' interested, to improve their livelihoods?

A final workshop was conducted in which members of the focus groups, development experts, district policy makers and researchers participated (Figure 3).

Figure 3. Focus group discussion and workshop meetings

The objective of the workshop was to aggregate the results obtained from the different FGDs. It was helpful to investigate the differences and similarities of the knowledge of the ecosystem/ ESs among stakeholders and have a common understanding.

3.1.2 Typology of ecosystem services

Typology, in the context of this study, refers to a method of classifying ESs using the knowledge and experience of beneficiaries and stakeholders. One purpose of the FGDs was to set up the basis for a typology of the ESs adapted to the situation in the mountainous highlands. The specification of a typology was beyond the scope of the focus groups interests and, hence, the strategy was to obtain key words from the focus groups, which could be aggregated into a common framework at a later stage. The key words noted varied slightly from farmer to farmer depending on their needs, exposures (training and experience sharing) and level of understanding. From these keywords, the typology was developed taking into account in which context these keywords were used, which connotations might be associated with them, and paying attention to the classification scheme of the Millennium Ecosystem Assessment (MEA) (MEA, 2005). Therefore, classification of ESs was done using a “contextual method” (interpreting different verbal expressions and opinions) based on the narrative summary of the discussions and interviews. Development experts were also consulted for final documentation.

3.1.3 Data analyses

Information obtained in the FGDs was captured qualitatively in three-stages. The first stage comprised the assessment of raw information from the discussions. The second step included processing the raw data for identification, definition, typology and description of the benefits. The final step was interpretation, elaboration and display of the information. Each benefit was defined and classified in connection to LCUTs. Classification was carried out using a contextual method and supported by descriptions provided by MEA (MEA, 2005).

3.2 Modeling the dynamics of landscape transformations using remote sensing data

3.2.1 Data types and preparation

The term ‘hybrid remote sensing data’ refers to the use of datasets of different sources, types as well as spatial and temporal resolution to generate the descriptive landscape transformation model. The remotely sensed data used were aerial photographs and satellite images from Landsat, IKONOS and World-view 2. The pixel sizes of Landsat, IKONOS and World-view 2 are 30m, 4m and 2m, respectively. The images were projected to the UTM zone 37 coordinate system. In addition, extensive field work was conducted. The boundary of each parcel of land in the watershed was mapped using GPS data, and its land cover was recorded. A topographic map was obtained from the Ethiopian Mapping Authority (EMA).

In total, nine datasets of different dates were used. These dates and datasets were aerial photographs (1957 and 1980), Landsat data (1986, 1995, 2003 and 2011), IKONOS (2001), Worldview-2 (2011) and field data with parcel boundaries recorded with GPS (2013) (see Table 1).

3.2.1.1 Aerial photographs

The 1957 and 1980 aerial photographs (scale 1:50,000) were obtained from the EMA in hard- and soft-copy. The black and white 9×9 inches (23cm×23cm) images were scanned with 1016 dots per inch (dpi). The pixel size thus was 25 µm in the image or 1.25 m (25 µm × 50,000) on the ground. These image data were processed using photogrammetric procedures to produce black and white orthophotos using the Leica Photogrammetry Suite (LPS) software. A detailed Digital Terrain Model (DTM) was also obtained in this procedure from the 1980 aerial photographs.

Camera calibration was done using the information obtained from the hard copy of the aerial photographs. The camera used was UAG II 3119. Exterior orientation was obtained with nine Ground Control Points (GCPs) identified on Google Earth and from GPS data. The GCPs selected were permanent features which were expected not to have changed over the past 50 years, for example landscape features (cliffs and valleys), churches, and road junctions. Three tie points were selected manually in the overlapping regions of the stereo pairs, and 168 additional tie points were generated automatically using the LPS software. The parameters of the exterior orientations of the images were then determined by bundle adjustment, using both GCPs and tie points. The residuals of GCPs after exterior orientation were $rX = 2.1$ m, $rY = 1.6$ m and $rZ = 7.5$ m. A digital terrain model was created from the 1980 aerial photographs. Orthophotos were produced from the photos of both dates (1957 and 1980).

3.2.1.2 Satellite images

The sources, dates and spatial resolution of the images are indicated in Table 1 below. Landsat images were acquired from the source http://glovis.usgs.gov for free (accessed on 21/03/2014). The high resolution images IKONOS and Worldview-2 were purchased and acquired from the commercial company Mapmart (http://www.mapmart.com) in geo-referenced form (georeferenced with a coarse DTM). Data preparation of these multispectral images such as layer stacking, enhancement, geometric corrections and radiometric-topographic normalisation were done using ERDAS Imagine including ATCOR software (ATCOR, 2013).

Table 1. List of remote sensing data collected for the study area

Data type	Date: Year (Month)	Scale, pixel size	Source	Remark
aerial photographs	1957 (11)	1:50000	EMA	Hard copy scanned 1016 dpi
	1980 (02)			
Landsat	1986 (11)	30m	http://glovis.usgs.gov	free access
	1995 (01)	30 m	http://glovis.usgs.gov	free access
	2003 (01)	30 m	http://glovis.usgs.gov	free access
	2011 (01)	30 m	http://glovis.usgs.gov	free access
IKONOS	2001 (03)	4m	http://www.mapmart.com	purchased
World-view 2	2011 (04,05)	2m	http://www.mapmart.com	purchased
field data with GPS localization	2013	(parcel boundaries)	field survey	shape files

A total of 9 different datasets was used to model the dynamics of landscape transformation of the watershed from 1957 to 2013.

3.2.2 Geometric correction

Geometric correction was not considered necessary for the Landsat images, due to the near-nadir viewing characteristics of Landsat. There were, however, problems with the oblique-view images of IKONOS and World View.

The images from IKONOS and World View 2 were available in a version geo-referenced with a coarse DTM. The resulting congruence with the orthophotos and with the map produced from fieldwork with GPS measurements was not satisfying. Therefore, a polynomial transformation was used to correct or at least to decrease these displacements with the aid of ground control points (GCPs) from the reference images (orthophotos). The polygons prepared from the GPS data were superimposed on the orthophoto of 1980 and used as a reference for collecting the GCPs. First-, second- and third-order polynomial transformations have been tried out in order to make a choice. The second-order polynomial was found best to transform the images. The root mean square value of the residuals was 4.1 m. Nearest neighbour resampling was used for the polynomial transformation.

3.2.3 Radiometric-topographic normalization

Radiometric-topographic normalization, on the other hand, seemed necessary for the Landsat images taken at a relatively low solar elevation, but not for IKONOS and World View-2 taken at higher solar altitudes.

The Landsat images were processed with the ATCOR software package (ATCOR, 2013). Haze reduction was not considered necessary. The detailed DTM obtained from the photogrammetric processing of the aerial photographs was used. Aerosol type and atmospheric model were determined by trial and error to obtain the most reasonable and credible result. Visibility was set to the values suggested by the software.

3.2.4 Land cover mapping and population data

The LCUTs listed in Table 2 were defined. The first four classes (cropland, forestland, grassland, shrubland) were used for preparing maps by interpretation of aerial photographs and by digital classification of multispectral satellite images. In addition, the other two (agroforestry and marginal/wasteland), which could not be detected in the remotely sensed images, were used in scenario modelling.

Table 2. Land cover/use classes

Land cover/use class	Characterization features
Cropland	Land used for cultivation of annual crops or fallowed for one year
Forestland	Land dominated by trees, covered with natural or plantation forest
Grassland	Land under permanent pasture/grass used for grazing
Shrubland	Shrubs, bushes and young trees, managed for grazing, browsing and collecting wood for household use
Agroforestry	Parcel of land used for annual crops integrated with trees or fruit species (e.g. Maize with *Carica papaya* or *Psidium guajava or Rhamnus prinoides*)
Marginal/underutilized	Land not used for production due to degradation or unused space between two or more parcel boundaries

3.2.4.1 Land cover/use type from field work

The GPS data comprise the coordinates of the boundaries of 1869 polygons and of a corresponding number of inner points. A consumer-type GPS receiver was used, providing an accuracy of approximately five meters. For each inner point, land cover, for agricultural parcels also crop type, ownership and other data were available from the field survey. These point data attributes were attached to the polygons. Area and perimeter of each parcel were determined. Parcels were aggregated into the respective land cover class for overall mapping. Field verifications were undertaken to re-evaluate, check and re-adjust the mapping.

3.2.4.2 Land cover/use type interpretation from aerial photographs

LCUTs were interpreted on the aerial photographs (orthophotos) using characteristics such as tone, texture, pattern and association. Interpretation keys as illustrated in Figure 4 were set up and used as the basis of the interpretation.

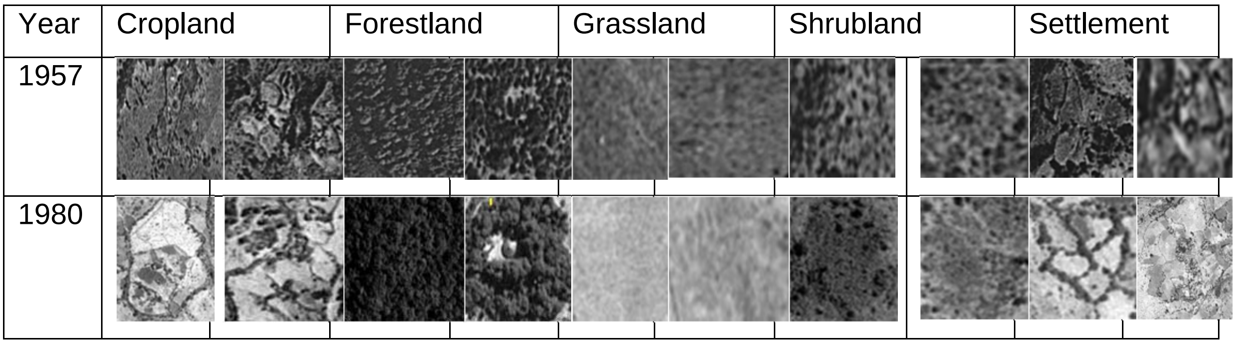


Figure 4. Sample keys used for interpretation

The polygons of each parcel of cropland, forestland, grassland and shrubland describing the 2013 land cover situation were superimposed on the stereo images of 1957 and 1980. The LCUTs of every polygon were determined by visual interpretation in stereo, using a workstation with liquid crystal shutter glasses and LPS software. As a single polygon from 2013 may comprise different LCUTs in 1957 and/or in 1980, the proportion of each LCUT was estimated and up to 3 LCUTs together with their proportions were recorded in the attribute table. Thus the total area of each LCUT in the years 1957 and 1980 could be determined. Detailed maps with LCUT delineations inside the 2013 polygons, however, could not be deduced from this dataset. For final visualization of a thematic map, the dominant LCUT was displayed for each polygon.

3.2.4.3 Land cover/use type classification from satellite images

Multispectral supervised classification was undertaken with the ERDAS Imagine software. The maximum likelihood algorithm was employed for mapping land cover from Landsat, IKONOS and World View-2 images. The spectral signatures were collected as training sites for each class. The number of training samples slightly varied from year to year and from image to image. The training samples were approximately evenly distributed on the images. They were collected from areas that can be considered as reasonably homogeneous so as to avoid too many mixed pixels, and for which the LCUT can be visually interpreted with reliability taking into account expert knowledge on spectral signatures and on the historical development.

3.2.4.4 Population data

Settlements (numbers of houses) were used as indicators for population dynamics. The data of the past were obtained from the remotely sensed images by counting houses on aerial photographs, Google Earth images and on the WorldView-2 image. Direct census data were obtained from field work conducted between May 2013 and January 2014.

Houses were interpreted on the 1957 and 1980 aerial photographs in stereo by first searching the patterns in the areas of cropland plots. Grass-thatched huts appear as round dots. The count of houses for 2001 was obtained from Google Earth by setting this date on the timeline. For 2011, the number of houses was determined from the multispectral WorldView-2 image where the houses were clearly visible. The houses were marked as point features on the images, and their positions were exported using ArcGIS software. The house counts for 2013 were directly obtained from the field census conducted between May 2013 and January 2014. Here, the positions of houses were determined by GPS. In this field survey, the number of persons living in each house could also be collected. However, this information is not available for the earlier investigation dates because of absence of documentation.

3.2.5 Change description

The land cover/use data obtained from the remotely sensed images were not detailed and homogeneous enough for producing complete “from-to” change matrices of the transitions between each class at two dates. Therefore, only the proportions of the areas of LUCTs in different years were considered and interpreted.

The rate of change per year, (C), of a quantity X (which can be the area of a LCUT, or a house count) between two dates is calculated according to equation (1) (Puyravaud, 2003):

$$C = \left({}^{X_e}/_{X_s} \right)^{1/(e-s)} - 1 \qquad (1)$$

where X_s is the value of the quantity (e.g. area of a LCUT) in the first year, s (start), of the period considered, and Xe is the value of the quantity in the last year, e (end), of the period considered. A constant change rate between the two dates (years) is assumed.

Correlation analyses were performed between the rates of change of different quantities for a considered period of time, e.g. between population (described by number of houses) and cropland area.

The temporal development of a quantity X for the whole time interval considered (1957 to 2013) was modeled by fitting curves under the assumptions of exponential growth and of logistic growth (Smith, 1977; Murray, 2002), again with the assumption of the growth constant r (and, for logistic growth, carrying capacity K) being constant for the whole time interval. For exponential growth, the model is described by the equation

$$X(t) = X_0 \cdot e^{rt} \quad \text{..............................} \ (2)$$

where X_0 is the quantity X at time t=0. The connection with equation (1) is given by

$$e^r - 1 = C \quad \text{..............................} \ (3)$$

For logistic growth, the model is described by

$$X(t) = \frac{KX_0}{X_0 + (K - X_0)e^{-rKt}} \quad \text{..................} \ (4)$$

The models were fitted to the data by least-squares estimation with the function nls() in the R “stats” package of the programming language R (R Archive Network, 2014).

3.3 Improved technologies and management practices

3.3.1 Improved crops experimental setting

A field trial with improved varieties of teff and wheat with recommended management intervention was conducted in the 2012 and 2013 cropping seasons. Three improved varieties of teff and three of wheat were obtained from the Plant Breeding Research Directorate of Adet Agriculture Research Center, Ethiopia. These improved varieties (Table 3) are currently providing higher yield than other varieties in agroecological situations similar to Tara Gedam Watershed. Local varieties grown by farmers were included as a reference to compare with the newly introduced varieties.

Table 3. Crop varieties for demonstration

No.	Teff variety	Wheat variety	Remark
1	Local	Local	Obtained from farmers
2	Kuncho	Gassay	From research center
3	Etsub	Tay	
4	Dukem	Picaflore	

Sites were selected in collaboration with development agents in order to test the performance of varieties under different site conditions within the watershed. In order to cover different climatic situations, the experiment was repeated in 2013.

The varieties of teff and wheat were planted and demonstrated on 23 and 24 sample farmers' fields, respectively, in two years (2012 and 2013). All the recommended packages (improved seeds, fertilizer, weeding, etc) of each crop were applied to treatments (varieties). Seed rate of wheat was 160 kg/ha. Currently, Diammonium phosphate (DAP) and Urea are the only inorganic fertilizers available to be used by small landholding farmers (Kiros et al., 2014). The recommended fertilizer rate for wheat was 260 kg ha^{-1} of Urea and 100 kg ha^{-1} of DAP. 100 kg ha^{-1} of DAP and 100 kg ha^{-1} of Urea were applied during sowing. 160 kg ha^{-1} of Urea were applied as a split 32-40 days after sowing. The application was conducted after weeding. Planting was done in rows at a spacing of 20 cm. Seed density of teff was 27 kg ha^{-1}. Teff was sown by broadcasting. The fertilizer rates recommended for teff were 100 kg ha^{-1} Urea and 100 kg ha^{-1} DAP. 100 kg ha^{-1} of DAP were applied at sowing and 100 kg ha^{-1} Urea were applied 30-35 days after sowing. For teff, there was no urea application during sowing, according to recommendations. Spatial distribution of experimental plots and the field layout are presented in Figure 5 below.

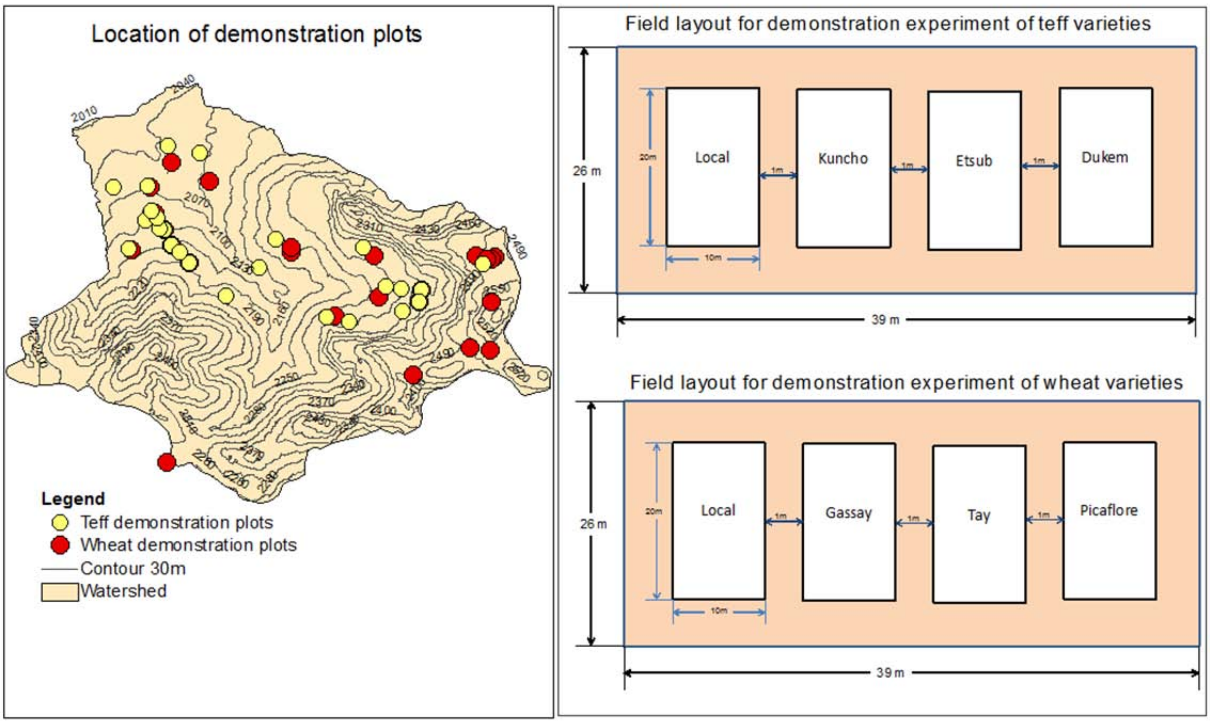


Figure 5. Spatial distribution and field layout of improved variety experimental plots

The size of one plot was 200 m^2. Since four treatments (varieties) were used in each replicate, the total plot size approximated 1100 m^2 including space between plots and boarder. Four of the selected crop varieties (treatments) were planted per sample farmer`s field. The plot of an individual farmer was considered as a replication. Weeding and other agronomic practices were uniform to all treatments (varieties under test). Sampling of plants for yield measurement was carried out in a 1mX1m ($1m^2$) sub-plot per treatment. The plant samples were taken from the center of the larger plot. The plant samples were sun dried and threshed to obtain the grain, which was then weighed using a sensitive balance. The unit for grain yield was quintal ha^{-1}. One quintal is equal to 100 kilograms.

3.3.2 Provision of seedling for agroforestry and forage management

Seedlings of *R. prinoides*, *Mangifera indica L.*, *P. guajava*, as well as species of *Tephrosia and Moringa* were provided for establishing agroforestry practices (Figure 6). These species were selected according to the discussions in the participatory process. Area exclosures of degraded lands were established by fencing and guarding. Forage lupine was provided for farmers as a preliminary test for its adaptability and forage suitability. This was done to understand the farmers' tree/shrub planting preferences and to demonstrate the appropriate land management activities to improve ESs in the watershed.

Rhamnus prinoides for agroforestry

Tephrosia spp for soil fertility management

Grass obtained from exclosure

Forage lupine

Figure 6. Provision of different inputs used for land management

3.3.3 Data analyses

The grain yield data were subjected to analysis of variance (ANOVA) using Univariate General Linear Model (GLM) in SPSS. GLM was used to estimate the main and interaction effects of categorical explanatory variables (topo-sequence, variety and year effect) on the response variable (grain yield). In the analyses, topo-sequence, variety and year were used as fixed factors. A comparison of means was conducted using posthoc Scheffe method.

3.4 Scenario modeling of ecosystem services

3.4.1 Basic information on biophysical situation and land productivity

Remote sensing, field work and interviews with farmers and experts were used to obtain information on the biophysical situation in the watershed of Tara Gedam, together with the acquisition of acquisition of yield data from field experiments including improved and high yielding wheat and teff varieties. These methods form the bases and starting point for the scenario development.

3.4.2 Socioeconomic information

Socioeconomic data are needed for qualitative and quantitative descriptions of scenarios. The methods for collecting socioeconomic data were interviews, workshops, FGDs and feedback information as suggested by Swetnam et al. (2011). The required information was collected from beneficiaries and stakeholders in a “bottom-up” and participatory way. FGDs and individual dialogues served to identify and categorize ESs, define the connections between LCUTs and ESs, and understand the most demanding ESs. Workshops were conducted to obtain for feedback information and suggestions for development plans. The data were collected separately for both upstream and downstream villages and then aggregated at the watershed level.

The socioeconomic data types obtained were population count, population structure (age), educational level, wealth (income source), livestock count, settlement pattern and related issues. This assessment was carried out to understand the drivers of change and set goals prior to commencing scenario formulation.

3.4.3 Conceptual design of scenarios

Scenarios for the future development of the watershed were set up by considering the following elements:

- Land cover/use: An essential starting point for the potential development of land cover/use is the historical development derived from remotely sensed data.
- Ecosystem services: This is the central concept for describing the connection between the ecosystem and the human living conditions.
- Population development: Different alternatives of population projection are considered.
- Socioeconomic situation: Potential lines of future development in relationship to the food supply in regional subsistence farming and to other economic options are examined, in particular considering the
- Demands and gaps of products needed for the livelihood of the population.
- Agricultural technology and development options and their acceptance: They are the key to improved living conditions in the watershed.
- Policy framework: This can trigger and support sustainable development.

The scenarios were formulated within the DPSIR framework. The development of the watershed is seen and described in the loop of the DPSIR components (Figure 1):

- Drivers: demands and sources of demands are considered as drivers of ecosystem change. They are determinants and accelerators of the livelihoods and economy of the community. Elements that directly or indirectly impact food security and environmental conditions are identified to start the scenario storylines. At the initial stage, drivers were freely listed to obtain a broad scope of choices. After obtaining multiple sets of drivers, their numbers were limited to a manageable quantity of key drivers to facilitate analysis and for consistency of the storylines.
- Pressures: Pressures are revealed as the next component of DPSIR. They are the results of the demands of individual farmers, the community, government policy and church doctrines. These pressures are substantiated using images (LCUTs), field survey (farm characterization and yield quantification) and socioeconomic data (census data).
- States: then, the pressures cause the overall environmental situation (state) of the watershed and its change. Pressures exerted from driving forces are consequently responsible for the state of the ecosystem, the landscape structure and its functioning. The states describe the physical phenomena in quality and quantity. The ESs were perceived in connection with LCUTs. The states description may also include instabilities, e.g. due to erosion.
- Impacts: the state of the ecosystem and its change has rigorous consequences (potentially positive and/or negative) for the livelihoods of the population. Negative impacts are to be responded through human measures.
- Responses: the responses chosen to counteract negative impacts are the starting points to trigger different scenarios. The components of responses may include agricultural technology, improved management, development plans, family planning and policy changes.

Presuming different responses, different scenarios resulted in the causal loop of the DPSIR framework. Each DPSIR component was the input of the next component in the loop. Defining responses varying over the timeline, the DPSIR loop may be passed through several times. Each scenario can then be seen as a development cycle of the set of DPSIR components.

Indicators were defined for the different elements of the components. These indicators should enable quantitative modeling of the DPSIR loop processes.

Four different scenarios were defined and elaborated. In particular, the issues of food security, policy, socioeconomic demand, rehabilitation programs, conservation activities and available knowledge bases were paid attention to. The time horizon of modeling the scenarios was 25 years, i.e. from 2016-2040. The year 2015 is considered as a preparatory year.

The scenarios were defined both by qualitative descriptions and by quantitative methods. The qualitative descriptions produced storylines and pathways of each scenario in narrative form. The quantitative method was used to test the assumptions using numerical calculations and results.

3.4.4 Quantitative scenario modelling

The main subjects in need of quantitative modelling are population development, LCUT transitions and crop production.

For scenario modeling, population projections were made assuming exponential growth (Smith, 1977; Murray, 2002), using the formula:

$$N = N_0 e^{rt} \qquad (5)$$

where N is the total population, N_0 is the population at t=0, e is Euler´s constant, r is the growth rate and t is the time in years.

The development of LCUT areas has to pay attention to constraints of available land area and to the suitability of the land for providing ESs. For agricultural land in particular the crop area has to be seen in relation to expected crop yield and the food requirements. Similarly, grazing land has to be seen in relation to forage requirements for the type of farming assumed in the respective scenarios.

Various software tools exist for quantitative scenario modeling according to these ideas (e.g. Sohl et al., 2012). However, the use of such elaborate tools was considered as beyond the scope of this work, in particular in view of the limited and consequently also “manually” manageable size of the watershed. In order to be able to pay particular attention to land suitability, two more LCUTs (agroforestry and marginal/wasteland) were introduced in addition to the LCUTs interpreted and classified from the remotely sensed images.

The development of LCUT areas therefore is quantitatively treated in constant time-steps of five years by spreadsheet calculations. The shift of areas from one LCUT to another one is decided based on expert knowledge on the various influencing factors according to the respective scenario assumptions. In particular, the suitability of land for different uses is mainly rated according to the slope which is known from the digital elevation model.

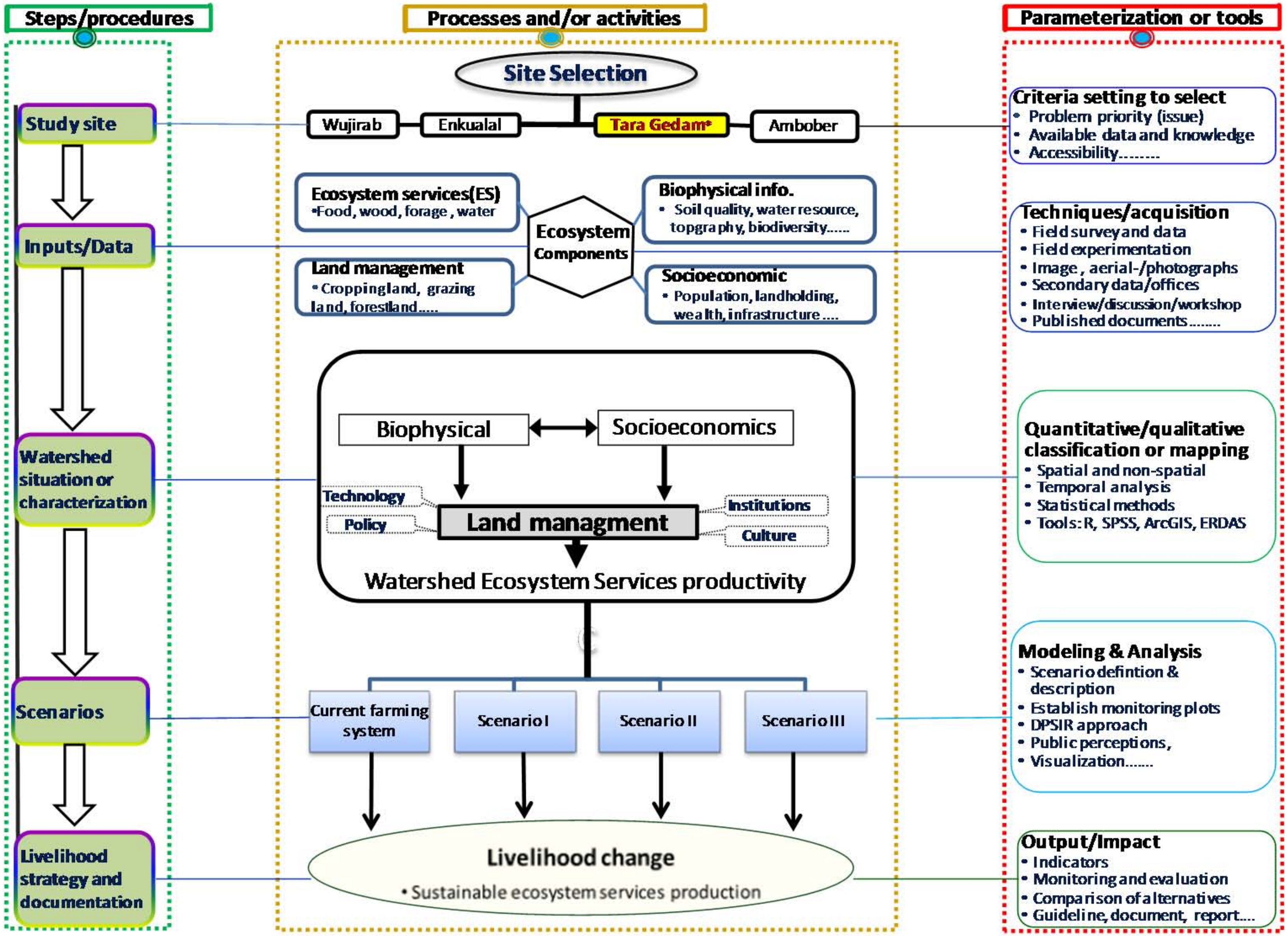
In this way each scenario can be presented in a spatially explicit way by LCUT maps prepared for each time-step. The last time-step produces the final situation in the year 2040 for each scenario. The temporal perspectives are given by diagrams showing the temporal development of each LCUT.

Crop production was modeled for evaluating the relationship between food production and food demand of the population. Wheat was chosen for modeling productivity. Yield data (quintal ha^{-1}) obtained from field experimentation and land allocated for crop and agroforestry were used to calculate the overall amount of production and the surplus/gap of food for the population in the watershed.

3.5 Overview of method

The overview of the methodological approach is presented in Figure 7 below. The diagram includes three pillars, namely steps of the scenario modeling, the major activities conducted in the respective steps and the techniques or tools to perform each activity. The conceptual framework shows data flow diagrams that included site selection, land management analysis, scenario development and livelihood change description. Each step of the scenario analysis is composed of a continuous chain of activities and parameterization techniques.

Figure 7. Methodological approach for analysis of ecosystem services scenario



4. RESULTS

4.1 Participatory assessment, typology and description of ecosystem services

4.1.1 Description and classification of ecosystem services

The detailed description of ESs in the highland watershed of Tara Gedam requires the objective assignment of LCUTs to desirable tangible products, benefits, priority demands and priority interests by the local people, the Ethiopian Orthodox Tewahedo Church (EOTC) and the Government. Ecosystem services were categorized into classes based on predominant tangible outputs and direct benefits obtained from the watershed by beneficiaries.

The purposes of different land uses and ecosystem products are described here for subsequent synthesis. Food production here refers to annual crops only, whereas forage production refers to any type of feed for livestock utilized in the form of hay, fresh cut grass, grazing and browsing. The EOTC owned forests provide cultural and religious services. These forests are accustomed to keep the spiritual values and beauty of the church compound. State-protected forests are owned by the Government and the management is aimed at flood protection, biodiversity conservation, erosion prevention (of steep terrain), climate regulation and headwater protection. Government and EOTC administered forests can be natural, planted or a mixture of both.

From the point of view (as found out from the discussions) of farmers, the ESs can be divided into two classes, namely those providing products for subsistence (food, forage, wood and water), and those providing cultural or religious services (deliverables from forests in and around churches) (Figure 8). On the other hand, Government administered forests are not considered very important since they are not useful for the immediate benefit of the farmers. They are, therefore, not included in their discussions and classification. However, farmers trained for guarding state forests proposed the conservation value of forests, indicating that exposure (training and experience sharing) has implications on the categorization of ESs. However, this information was not included in the classification scheme.

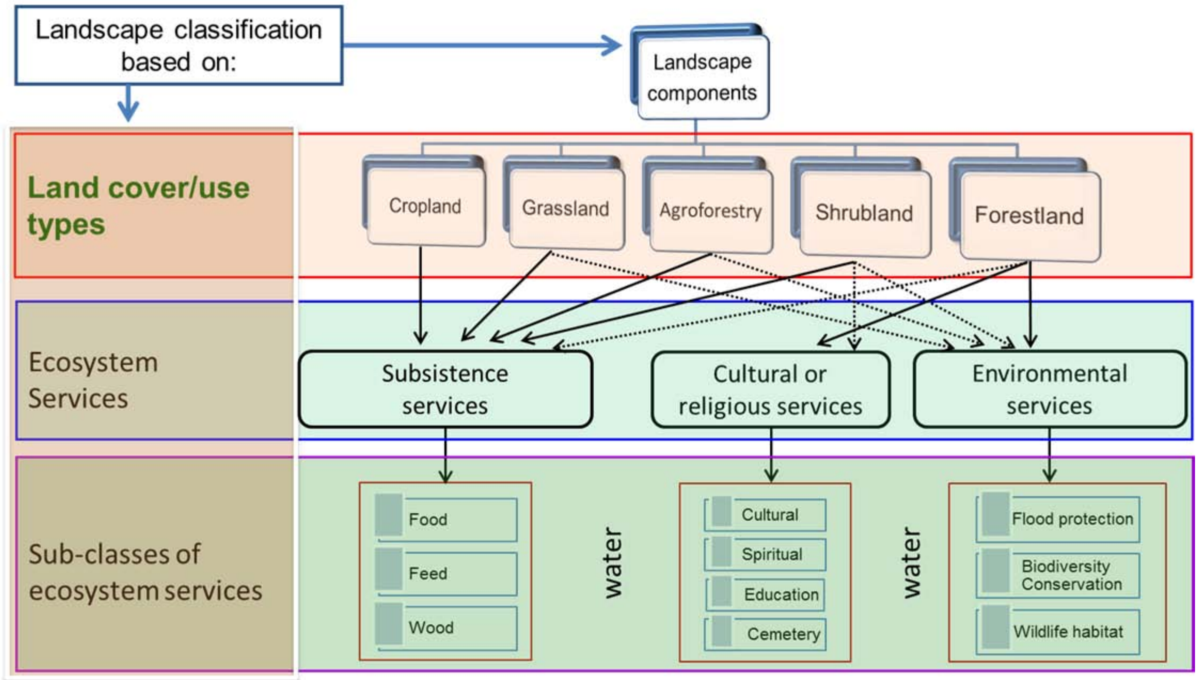


Figure 8. Contextual aggregated typologies of Ecosystem Services

Based on the perspectives of the other stakeholders (experts, researchers, decision makers), the ESs are divided into three, namely *basic-need/subsistence* (individual farmer/community demand), *religious/education* (church and monastery demand) and *environmental services* (Government demand) (Figure 8). Food, wood, feed and water are categorized under day-to-day demand called *subsistence service*, whereas flood protection, biodiversity and/or wildlife conservation are classified as *environmental* and/or *regulation service*. ESs that originate from EOTC forests are classified as *cultural* or *religious services*. Church forests are also used as shade for the livestock and as a location for cemeteries. Priests and monks explained that the forests are used for grazing during the dry season when there is a shortage of feed. Forests host different types of birds and wild animals, which contribute to the beauty of nature. All forests are currently used for research, development and education purposes.

4.1.2 Land cover/use and ecosystem services

Four LCUTs were distinguished, namely cropland, grassland, forestland and shrubland. Each ES has corresponding LCUTs. The dominant products derived from croplands are food and feed. Forests are protected and conserved by the EOTC and the state for microclimate amelioration, flood protection, wildlife habitat as well as spiritual and aesthetic values. Shrubland owned by the community delivers feed and wood products. Wood products are extracted from trees/shrubs planted around settlements or from trees retained deliberately in farmlands. The benefits originating from environmental/regulatory services are not appreciated by farmers, and, hence, are not their priorities.

4.1.3 Choice of beneficiaries

Water was the top priority choice of participants in the focus group discussions, and it was repeatedly indicated as the most influential ecosystem product. Water was indicated as the most in demand and the most limited resource since it is least available during the dry season for drinking due to mismanagement and the topographic nature of the watershed. Following water, food, wood and feed were the top priority demands chosen by the focus group members as well as by the individual farmers.

4.1.4 Administration/ownership of ecosystem services

Individual farmers, communities, government and the EOTC manage different ESs for different purposes. The watershed farmers gave top priority for water, food, feed and wood related products. Food crops are produced to secure the food requirement of each household. Wood and related products are extracted from trees/shrubs that are planted around settlements or from deliberately retained trees in farmlands as traditional agroforestry practices. Grazing land is managed either communally or by individual farmers. Private grazing land is established close to the farmer's residence or farming areas by allocating a parcel of land varying approximately from 400 to 4,500 m^2. Grazing on individually managed grassland is controlled by allowing only a small number of cattle per unit area for a short time. Then, sufficient time for regrowth is allotted. This mechanism improves forage productivity and grazing land quality. Free grazing is the common practice at community-administered pastureland at the village level.

Community-managed pasturelands are used by farmers who are members of the respective village, disregarding the role of individual farmers and the numbers of cattle owned. The actions for enhancement and better forage production are arranged in accordance with community decisions, but no activities are conducted for improvement and sustainable use. The communal grazing land is exploited beyond its carrying capacity. The high stocking rate results in soil compaction, diminished biomass availability and environmental deterioration. Community-managed pasturelands are more vulnerable to degradation and overexploitation than individual-farmer-managed pastureland. Soil erosion and gully formation were observed in and near communal grazing lands (Figure 9).

Figure 9. Soil erosion (left) and gully (right) in grazing lands

The Government manages environmental or regulatory services originating from the protected forests and grasslands (the latter are small in area). The assessment showed that forest and forestland protected and conserved by the state target microclimate amelioration, biodiversity conservation, flood protection and serving as a habitat for wildlife. Forests under the management of the EOTC provide spiritual, cultural/religious, aesthetic values, shade and improved microclimate services. Other LCUTs not considered as providing ecosystem services (paths, roads, underutilized land) are nevertheless important for accessibility and thus, eventually, for environmental diversity.

4.1.5 Qualitative description

In order to describe the ESs, the type of products, the purposes and the problems were under consideration. Different ESs have different roles and purposes as described below.

Food

Food from the ecosystem provides the highest contribution to household supplies. The major food source is intensively cultivated cropland of low productivity, which represents a less diversified ecosystem over time. It is located all over the watershed, from upstream to downstream. Sorghum [*Sorghum bicolor* (L.) Moench], finger millet (*Eleusine coracana* Gaertn.), maize (*Zea mays* L.), teff [*Eragrostis tef* (Zucc.) Trotter], wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), some pulses (*Pisum sativum* L. and *Phaseolus vulgaris* L.), and some oil crops [*Guizotia abyssinica* (L.*f*.) Cass. and *Linum usitatissimum* L.] are the common rain-fed crops grown in the area. Among these, teff and wheat are the two top cash crops.

The most dominantly grown crops are finger millet, maize, sorghum, teff and wheat depending on the onset of rain and crop rotation patterns. Crop rotation is governed by household demand, market demand, accessibility of technology, and land quality. The most commonly used crops for household consumption are sorghum, maize and finger millet. Very recently, triticale was introduced for cultivation as source of food. Very little food is provided from forests. Elder farmers stated that about 20-30 years ago wild edible fruits such as *Carissa spinarium* L. *Cordia africana* Lam., *Rosa abyssinica* Lindley *Rubus* spp., *Syzygium guineense* (Willd.) DC., and *Ximenia americana* L. were collected. Wild mushrooms (locally called 'Enguday') were collected in the forest for consumption. Medicinal plants collected in the forest have also an important role in the health care of the local people.

Feed and forage

Grassland, shrubland and open forest provide grazing, browsing or other forage production services. Parcels of land distributed in 'pocket areas' (small parcel of lands less than 400 m^2) owned by individual farmers are used for feed production. These lands are dynamic and liable to change to other land uses. On the other hand, communal grazing lands are assigned at permanent locations and are less liable to be converted into other forms of land use. Shrub-dominated steep terrain is also used for free grazing and as source of wood. Wood collectors pick up dried and fallen wood for free in government forests and communal shrublands. Individual farmers cut old trees on their land for fuelwood.

Religious/spiritual functions

Religious/spiritual functions obtained from forests are found upstream as well as near and around churches. Local people highly respect these sacred areas and no other products are obtained than spiritual values. However, the monks and priests residing in it practice forest grazing. They also collect fallen and dead wood from the forests.

Protected forests

State protected forests are situated on steep terrain, dominantly on north facing slopes aimed at flood protection, headwater regulation, climate regulation, biodiversity conservation and wildlife protection. The state recruits guards for the protection of the forests in order to avoid cutting of trees by residents.

Traditional agroforestry

Although most of the farmers are reluctant to plant trees because of their long rotation periods and fragmentation of land, some farmers retain trees as a traditional agroforestry practice for different uses. These trees are managed through pruning and pollarding to produce wood for the purpose of fuelwood, construction, making household utensils and farm implements, and they are also used for fodder and shade.

Of the 1,351 plots used to produce crops and forage, only 383 contained trees. From all the surveyed parcels, more than 70% contained no trees. Traditional agroforestry and home gardening are practiced around the residence areas. Wood products made predominantly of *Eucalptus spp.* are found around settlements. Partly dried and fallen fuelwood is collected from the natural forests. *Croton macrostachyus, C. africana* and *Acacia* spp. are the dominant species integrated with crops as an agroforestry practice.

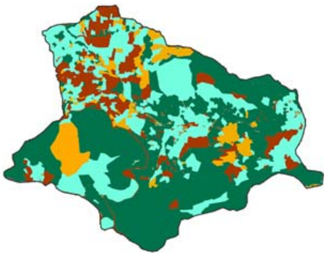
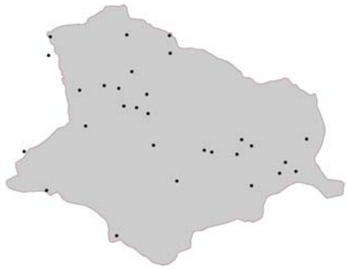
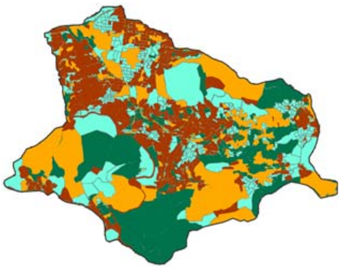
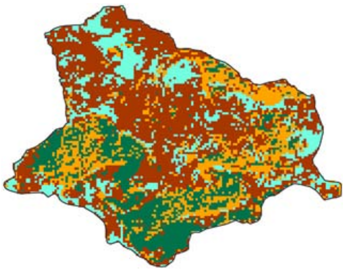
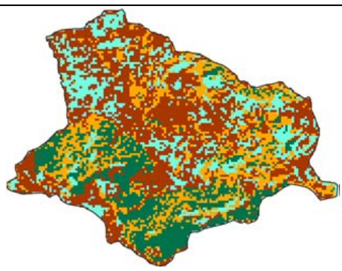
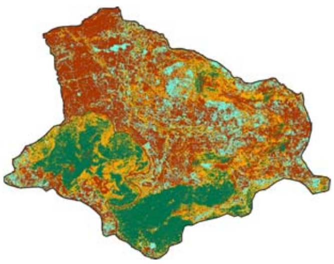
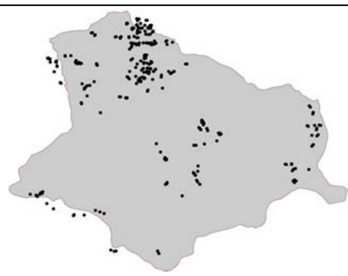
Water resources

Two surface water sources (“Aguat Mefesesha” and “Arno”), two hand-dug wells, one government-built hand pump and one developed spring are used as sources of water for domestic consumption. Limited irrigation is practiced using intermittent streams to produce vegetable and fruits. Recently, farmers adapted rain or runoff harvesting technologies for supplemental irrigation during the dry season. Five to six farmers exhibited experience of runoff harvesting around their homestead using earthen sunk and/or geo-membranes (plastic sheet) to irrigate their homegardens. The volume of water ranges from 36 - 80 m^3. Farmers explained that water availability has undergone significant decline during the past two to three decades. Serious drinking water shortage for humans and livestock occurs between February and mid-June.

4.2 Modeling the dynamics of landscape transformation

4.2.1 Land cover/use mapping

The land cover maps for the different dates from 1957 to 2013 obtained by interpretation of aerial photographs, by classification of Landsat and of high-resolution satellite images and from field work are compiled in Figure 10. Land cover and house distribution maps from 1957 to 2013. Also included in this figure are maps of the spatial distribution of houses.

	land cover	houses
1957	 from aerial photograph	 from aerial photograph
1980	 from aerial photograph	 from aerial photograph
1986	 from Landsat	
1995	 from Landsat	
2001	 from IKONOS	 from Google Earth

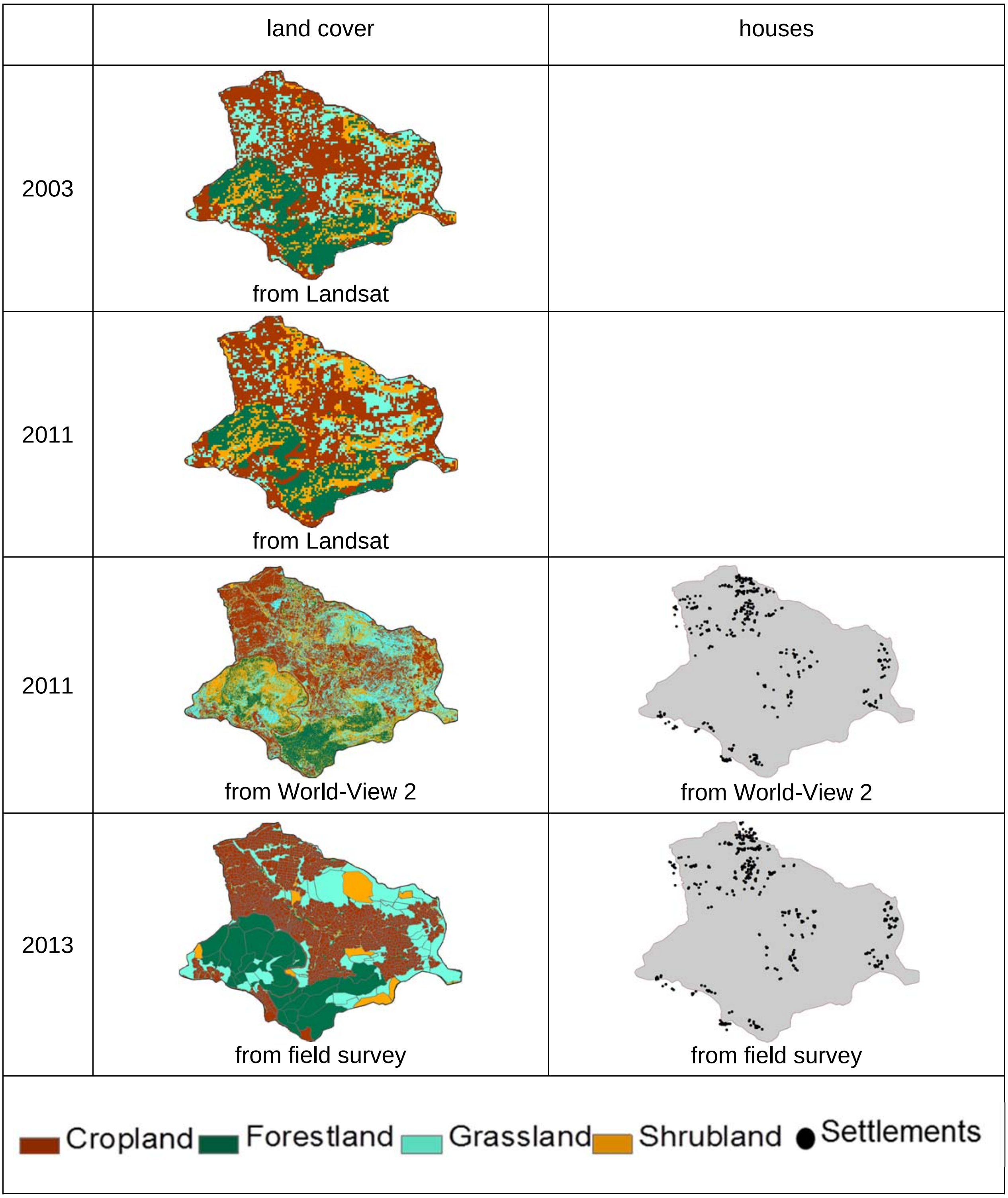


Figure 10. Land cover and house distribution maps from 1957 to 2013

Areas of land cover types (hectares), settlement data (number of houses) and derived crop landholding size (hectares) are presented in Table 4 below.

Table 4. Areas of land cover types, settlement data and crop landholding size

Year	Source	Area (ha)				Number	Area (ha)
		Crop-land	Forest-land	Grass-land	Shrub-land	Houses	Cropland holding size
1957	B/W Photo	76.8	450.4	253.7	105.6	29	2.6
1980	B/W Photo	195.8	245.5	222.0	223.0	59	3.3
1986	Landsat	393.3	163.0	154.4	175.7	91 [1])	4.3 [1])
1995	Landsat	351.2	167.4	166.4	201.4	176 [1])	2.0 [1])
2001	Ikonos	358.2	196.3	136.7	195.2	273	1.3
2003	Landsat	386.3	197.6	199.1	103.4	287 [1])	1.3 [1])
2011	Landsat	386.5	175.0	151.6	173.4		
	WorldView 2	296.3	125.1	248.4	216.5		
	Mean value	341.4	150.0	200.0	195.0	351	1.0
2013	Fieldwork	439.7	219.6	184.6	42.5	395	1.1

[1]) The number of houses cannot be counted on Landsat images. Therefore, these numbers are interpolated according to equation (1).

The land cover maps prepared from different sources and the derived numerical values have different qualities, and care must be taken when drawing conclusions regarding land cover change. Two different figures for land cover areas were obtained for 2011, which show considerable discrepancies. These differences may be accounted partly to the different seasons of image acquisition and the related phenology of vegetation and partly to the influence of different spatial resolution of the images.

4.2.2 Population data

The maps showing the distribution of houses for the different dates of the high resolution images are included in Figure 10. It can be seen that clusters of houses are located mainly in or close to areas of cropland. Houses of inhabitants living outside the watershed close to the border, but cultivating agricultural plots inside the watershed, were included in the survey. The opposite case of people living in houses inside the watershed but cultivating plots outside was not observed.

According to the field census result of the year 2013, a total of 1889 settlers resided in 395 houses in the study area (including those outside close to the border). This represents a population density of 213 persons/km², which is above the average of 179 persons/km² for highlands as reported by the Bureau of Finance and Economic Development (BoFED) of ANRS, BoFED (2011). Houses were either grass thatched huts or covered with corrugated iron sheet. The number of family members in a household varied from 1 to 10; the average number was 4.8 members per household. The male and female population was 52.3% and 47.7%, respectively. 10% of the total households were female-headed families (farmers), and the others were male-headed families. 48% of the total population was below 18 years (i.e. the dependent group) due to a high fertility rate. About 16-25% of the population were dependent on aid by the government. The number of aid-dependent varies with the onset of the rain. A higher dependency occurs when there is late onset of rainfall.

It can be expected that livestock population correlates with human population. The data of the year 2013 showed a livestock of 822 cattle. Out of this cattle livestock, 415 are oxen. The number of sheep, goats and equines were not included in the census because of frequent change of their number. Large flocks of livestock are grazing and browsing on small areas of land. Most of the highlands accommodate livestock beyond their carrying capacity. Due to this fact soil erosion and gully formations are observed in and close to grasslands.

4.2.3 Land cover change and population growth

The general trends are the increase of agricultural area (cropland), the decrease of forest area, a certain stabilization of this land utilization in recent years, and a continuing population growth (Figure 11). Obviously, increased crop production is required to support the growing population. The farming system of Tara Gedam watershed depends predominantly on cereal cultivation.

Land use conversion predominantly occurred from forestland and/or shrubland to cropland. The conversion rate and the spatial distribution of land conversion depends on the population growth, on site characteristics and on policy interventions, as will be discussed below.

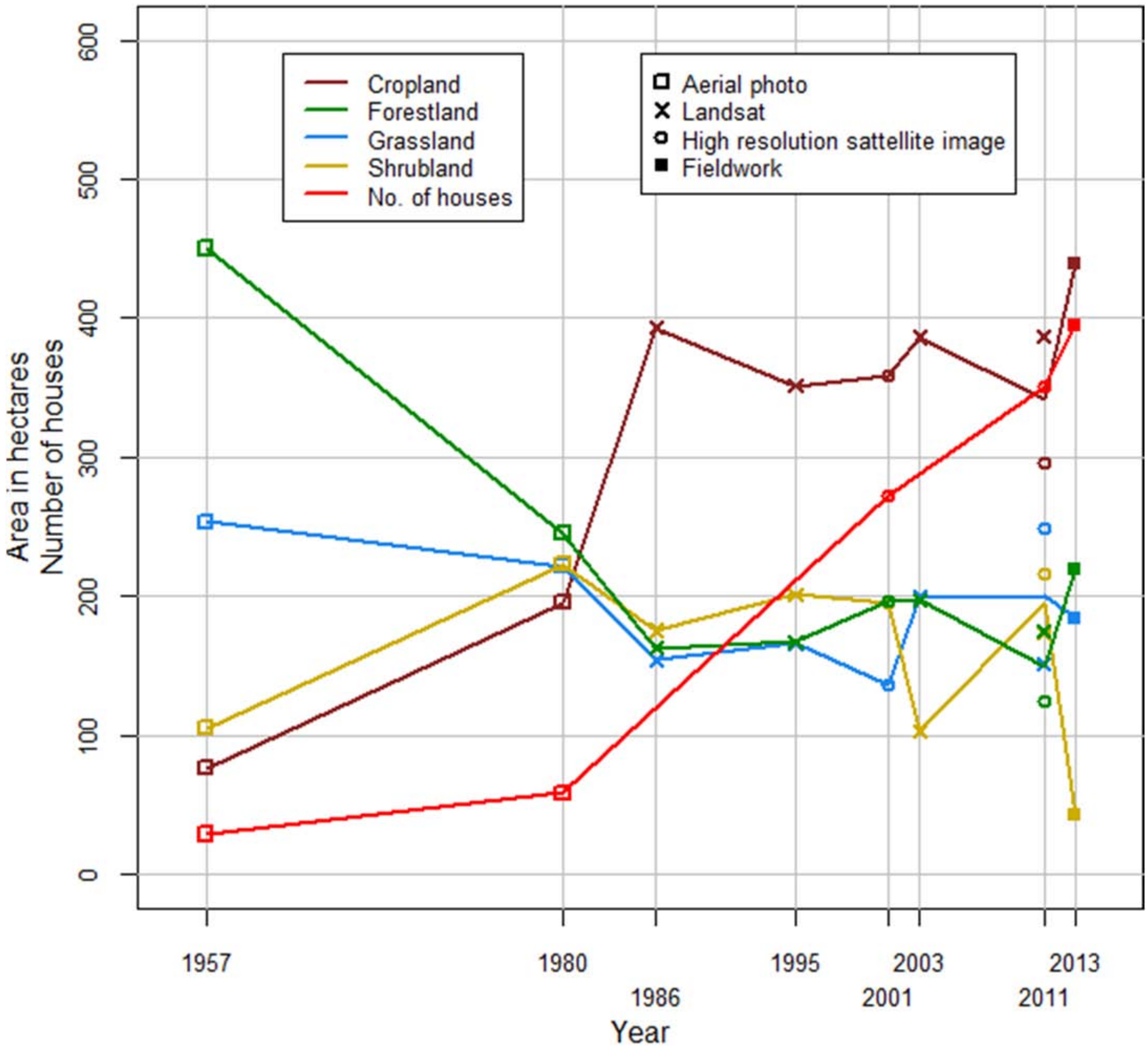


Figure 11. Land cover/use change and population change between 1957 and 2013

4.2.4 Modeling of land cover change and population growth

Calculating the rates of change between consecutive dates of data acquisition with equation (1), the values compiled in Table 5 were obtained. In the case of dates where there are land cover/use data only, but no data on the number of houses (which applies to the dates with Landsat images only), the change values of the number of houses were assumed to be constant, i.e. they were calculated from the numbers for the nearest dates. Short time intervals of 2 years were not considered. The reason for this is that, due to the obvious uncertainties of the data, small changes of results between acquisition dates at short time intervals may not faithfully describe the actual changes in the watershed. Only gross trends should be considered.

Table 5. Rate of change per year, calculated according to equation (1)

Period	Rate of change (percent per year)					
	Cropland	Forest	Grassland	Shrubland	Houses	Holding size
1957-1980	4.2	-2.6	-0.6	3.3	3.1	1.0
1980-1986	12.3	-6.6	-5.9	-3.9	7.6	4.4
1986-1995	-1.3	0.3	0.8	1.5	7.6	-8.2
1995-2001	0.3	2.7	-3.2	-0.5	7.6	-6.7
2001-2013	1.7	0.9	2.5	-11.9	3.1	-1.4
1957-2013	3.2	-1.3	-0.6	-1.6	4.8	-1.5

Correlation analysis was conducted to observe the statistical relationship between land conversions and settlement expansion (Table 6). The increase of population (measured by the number of houses) showed a statistically significant positive correlation only with cropland. In line with this result, the study of Minale (2013) in the highland of Gilgel Abay catchment pointed out that population trend has a positive correlation with the expansion of farmland and settlement. This is also strengthened by the study of Zeleke and Hurni (2001). Forestland and grassland showed negative relationship with settlement expansion. Shrubland showed least association with all the other variables.

Table 6. Pearson correlation coefficient between different variables

	Cropland	Forest	Grassland	Shrubland	Houses
Cropland		-0.84 *	-0.78 *	-0.15	0.95 *
Forest			0.75 *	-0.37	-0.75
Grassland				-0.26	-0.68
Shrubland					-0.27
Houses					

* Significant correlation ($p<0.05$).

Fitting the models of logistic growth to the cropland area and of exponential growth and logistic growth to the population data (number of houses) according to equations (2) and (4) gave the results as shown in Figure 12. Also included in this figure is the curve for “other land”, which is the sum of forest, grassland and shrubland, obtained as the difference of cropland to the total area of the watershed. The parameters of the logistic and exponential growth curves obtained by least-squares-estimation are: logistic growth for cropland: growth constant r=0.10, carrying capacity K=400, 84% of the variance are explained by the model; for logistic growth for the number of houses: growth constant r=0.10, carrying capacity K=479, 99% of the variance are explained by the model; and for exponential growth for the number of houses: growth constant r=0.04, 97% of the variance are explained by the model. It must be noted that (a) the assumptions of land cover/use trends and population changes with model parameters constant over the whole time span of almost 60 years are unrealistic, and (b) that the number of data points clearly is too low for reliable estimates of the parameters even of these simple models. Images from more acquisition dates and more detailed image analysis methods would be required to use more sophisticated models and to obtain more reliable estimates. The results are given here mainly to show the basic potential of historic remotely sensed data.

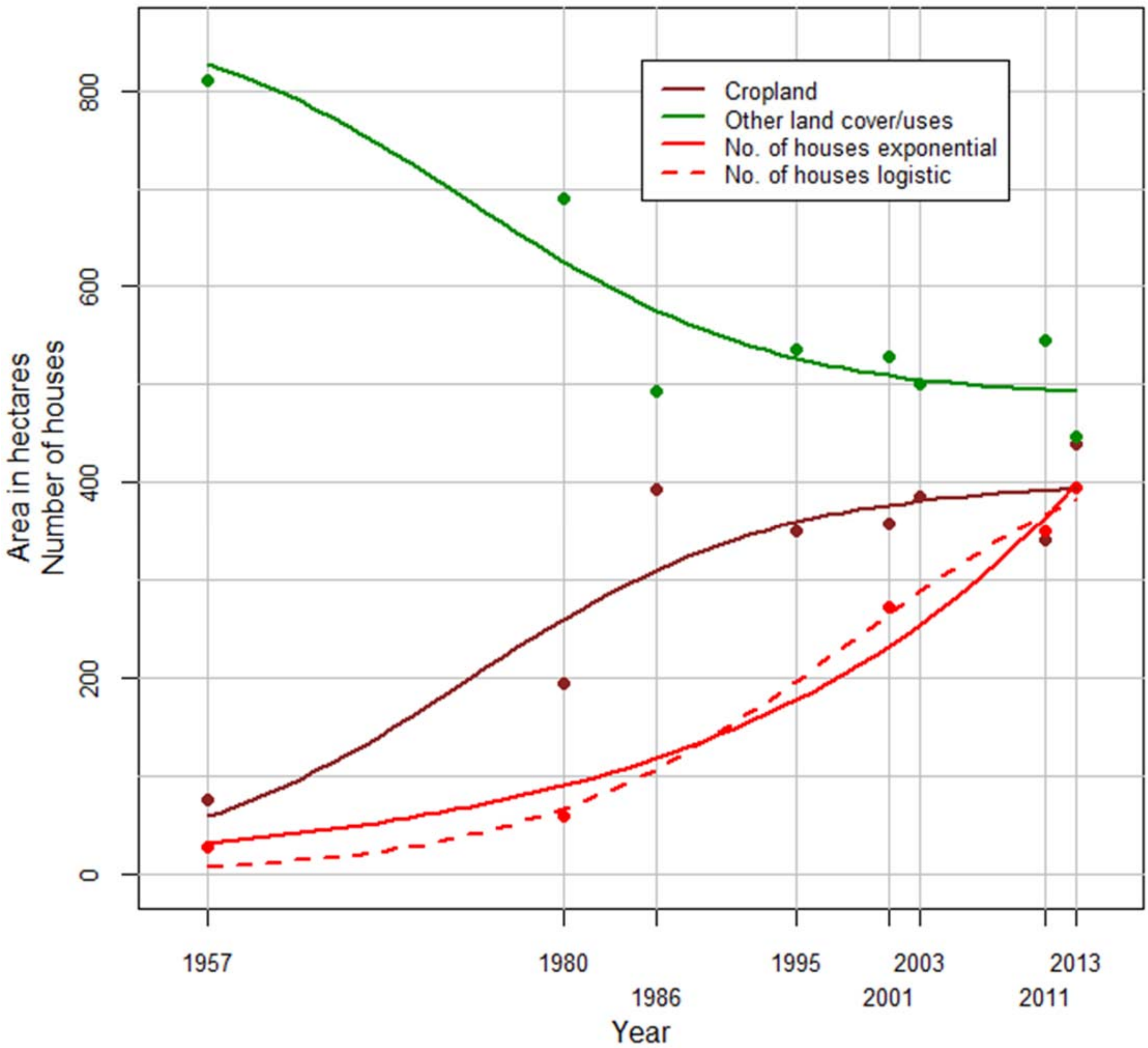


Figure 12. Models fitted to the cropland, other LCUTs and the population data

4.3 Estimation of land productivity based on improved field crops

4.3.1 Improved crop varieties

4.3.1.1 Teff grain yield

The analysis of variance (ANOVA) using GLM showed significant difference ($p<0.05$) for grain yield across toposequence, variety and year (Table 7).

Table 7. GLM ANOVA of teff grain yield

Source of variation	DF	Mean Square	F	Significance.
Corrected Model	15	244.0	38.3	*
Intercept	1	39625.3	6215.8	*
Variety	3	965.2	151.4	*
Year	1	274.0	43.0	*
Toposequence	1	150.2	23.6	*
Variety * Year	3	41.0	6.4	*
Variety * Toposequence	3	4.2	0.7	ns
Year * Toposequence	1	13.0	2.0	ns
Variety * Year * Toposequence	3	1.2	0.2	ns
Error	76	6.4		
Total	92			
Corrected Total	91			

*Significant difference ($p<0.05$), ns=non significant, DF=degree of freedom

The upper part of the watershed gave higher yield as compared to the lower part. The interaction of variety with year showed significant ($p<0.05$) effect on grain yield. All interactions except year with variety showed no significant effect on teff grain yield.

The data was split by year and toposequence, the mean comparison was conducted to observe whether there is difference in each year (Table 8). The 2012 result showed that the Local variety was significantly different ($p<0.05$) from improved varieties. However, there was no significant difference among improved varieties. In the 2013, Kuncho showed significant difference ($p<0.05$) in grain yield from Local and Dukem variety. Overall, Kuncho and Dukem showed significant difference ($p<0.05$) in grain yield over years.

Table 8. Mean+SEM grain yield of teff varieties

Year	Toposequence	Varieties of teff			
		Local	Kuncho	Etsub	Dukem
2012	Upper	11.8±0.8 ^{B}	25.0±1.6 ^{A}	23.4±1.6 ^{A}	22.3±1.8 ^{A}
	Lower	10.6±1.2 ^{B}	20.1±0.5 ^{A}	21.4±2.0 ^{A}	18.6±1.2 ^{A}
	Subtotal	11.3±0.7	**22.6±1.1**	23.0±1.3	**20.5±1.2**
2013	Upper	11.5±0.4 ^{c}	29.2±0.6 ^{A}	27.8±0.5 ^{AB}	25.7±0.9 ^{B}
	Lower	10.7±0.2 ^{B}	26.8±1.6 ^{A}	23.9±1.3 ^{A}	25.0±1.1 ^{A}
	Subtotal	11.2±0.3	**28.1±0.8**	25.5±0.9	**25.4±0.7**
2012 and 2013	Upper	11.7±0.4 ^{B}	27.1+1.0 ^{A}	25.4±1.1 ^{A}	24.3±1.0 ^{A}
	Lower	10.6±0.6 ^{B}	23.1+1.3 ^{A}	23.4±1.1 ^{A}	21.8±1.3 ^{A}
	Subtotal	11.2±0.4	25.2±0.9	24.5±0.8	23.2±0.8

Different upper case letters indicate significant difference in grain yield between varieties within slope position and year at p<0.05.

Numbers in bold indicate significant difference (T-test, p<0.05) in grain yield between years, within varieties.

Underlined numbers indicate significant differences (T-test, p<0.05) in grain yield between slope positions, within varieties.

The grain yield in test year and toposequence varied (Table 8). In 2012, the local variety gave yield of 10.2±1.2 quintal ha^{-1} at the lower positions of the watershed, whereas it provided 11.8±0.8 quintal ha^{-1} at the upper positions. The improved teff variety, Etsub, provided the highest yield (23.0±1.3) in 2012. In 2013, Local teff variety provided the lowest yield in upper and lower slope positions. Overall, in 2013 Kuncho teff variety provided the highest grain yield of 28.1±0.8 quintal ha^{-1}. The overall grain yield in year and toposeqeuence for teff variety of local, Dukem, Etsub and Kuncho was 11.2±0.4, 25.2±0.9, 24.5±0.8 and 23.2±0.8 quintal ha^{-1}, respectively. Overall, Kuncho provided the highest average grain yield and has a yield advantage of approximated to 14 quintal ha^{-1} over the farmers' variety. Kuncho provided the highest average grain yield. It has the highest plant density because of higher tillering capacity. Hence, it has the highest number of heads per unit area.

The interaction of variety with toposequence showed no significant difference in all teff varieties except Kuncho. It provided approximately 4 quintal ha^{-1} more on upper slope position than on lower positions.

The grain yield distribution (quintal ha^{-1}) is shown on Figure 13 using boxplot. This was the combined data of the year 2012 and 2013.

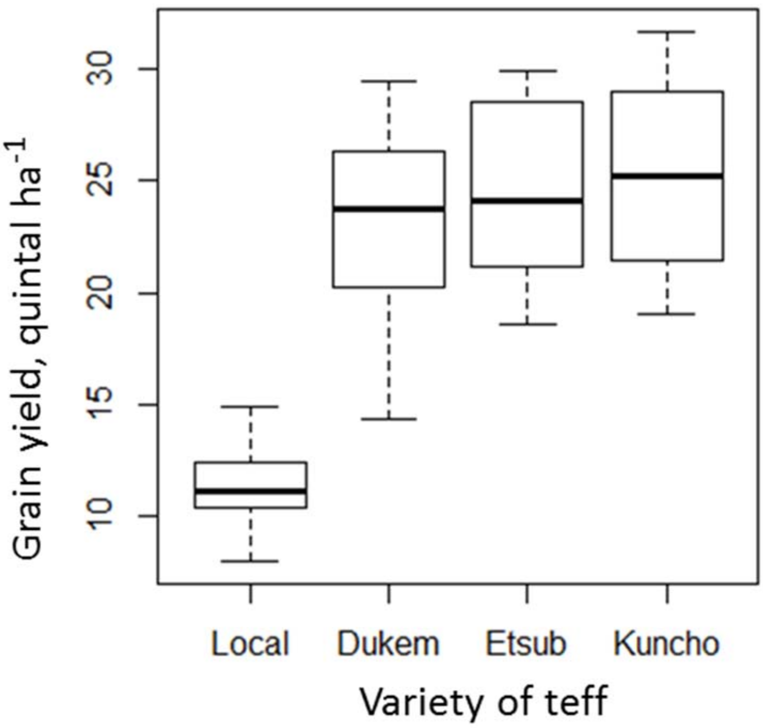


Figure 13. Boxplot showing the yield distribution of teff varieties

Etsub and Kuncho showed normal distribution, however, Dukem showed negatively skewed distribution. The local variety provided the lowest grain yield and showed normal distribution.

4.3.1.2 Wheat grain yield

The ANOVA result showed that there is significant difference among varieties, toposequence and year ($p<0.05$) as it is indicated in Table 9 below.

Table 9. GLM ANOVA of wheat grain yield

Source	DF	Mean Square	F	Significance
Corrected Model	15	1277.5	37.8	*
Intercept	1	91681.5	2711.8	*
Variety	3	3438.2	101.7	*
Year	1	1667.6	49.38	*
Toposequence	1	299.8	8.9	*
Variety * Year	3	130.5	3.9	*
Variety * Toposequence	3	52.4	1.59	ns
Year * Toposequence	1	239.8	7.1	*
Variety * Year * Toposequence	3	11.2	0.3	ns
Error	80	33.8		
Total	96			
Corrected Total	95			

*Significant difference ($p<0.05$), ns=non significant

The interaction of variety and year, and toposequence and year showed significant effect ($p<0.05$) on grain yield of wheat. However, variety and topoposequence and variety, year and toposequence showed no significant effect on grain yield. The overall result showed that Local wheat variety represented the lowest yield (14.7±0.5 quintal ha^{-1}) and Tay wheat variety gave the highest grain yield (45.9±2.1 quintal ha^{-1}) (Table 10).

Table 10. Mean+SEM grain yield of wheat varieties

		Variety			
Year	Toposequence	Local	Gassay	Tay	Picaflore
2012	Upper	12.6±1.2^{B}	36.2±1.6^{A}	39.6±3.0^{A}	32.1±0.1^{A}
	Lower	15.0±1.5 ^{B}	34.7±1.4 ^{A}	36.5±2.1 ^{A}	32.1±0.1 ^{A}
	Subtotal	**13.3±1.0^{C}**	**35.8±1.2^{AB}**	**38.6±2.1^{A}**	**32.1±0.1^{B}**
2013	Upper	16.0±0.5^{B}	53.3±2.4^{A}	53.9±2.7^{A}	49.2±2.5^{A}
	Lower	14.9±0.2^{B}	40.3±2.5^{A}	44.4±2.8^{A}	41.6±3.3^{A}
	Subtotal	**15.7±0.4^{B}**	**49.3±2.5^{A}**	**51.2±2.4^{A}**	**47.0±2.2^{A}**
2012 and 2013	Upper	14.6±0.7^{B}	45.2±2.6^{A}	48.0±2.6A	42.2±2.6^{A}
	Lower	15.0±0.6^{B}	37.9±1.8^{A}	41.0±2.3^{A}	37.5±2.6^{A}
	Subtotal	14.7±0.5^{B}	43.1±2.0^{A}	45.9±2.1^{A}	40.8±2.0^{A}

Different upper case letters indicate significant difference in grain yield between varieties within slope position and year at $p<0.05$. Numbers in bold indicate significant difference (T-test, $p<0.05$) in grain yield between years, within varieties.

The grain yield in test year along toposequence varied (Table 10). In 2012, the Local and Picaflore wheat varieties showed statistically significant difference from Tay wheat variety on grain yield. Local variety provided lowest grain yield (13.3±1.0 quintal ha^{-1}), whereas Tay provided the highest grain yield (38.6±2.1 quintal ha^{-1}). Similarly, in 2013 Local variety provided the lowest yield and Tay provided the highest grain yield in both toposequences (Table 10). The maximum difference was observed between mean grain yield values of Tay and the Local varieties, while the minimum difference was observed between Gassay and Picaflore varieties. The 2012 and 2013 combined grain yield of wheat (Figure 14)

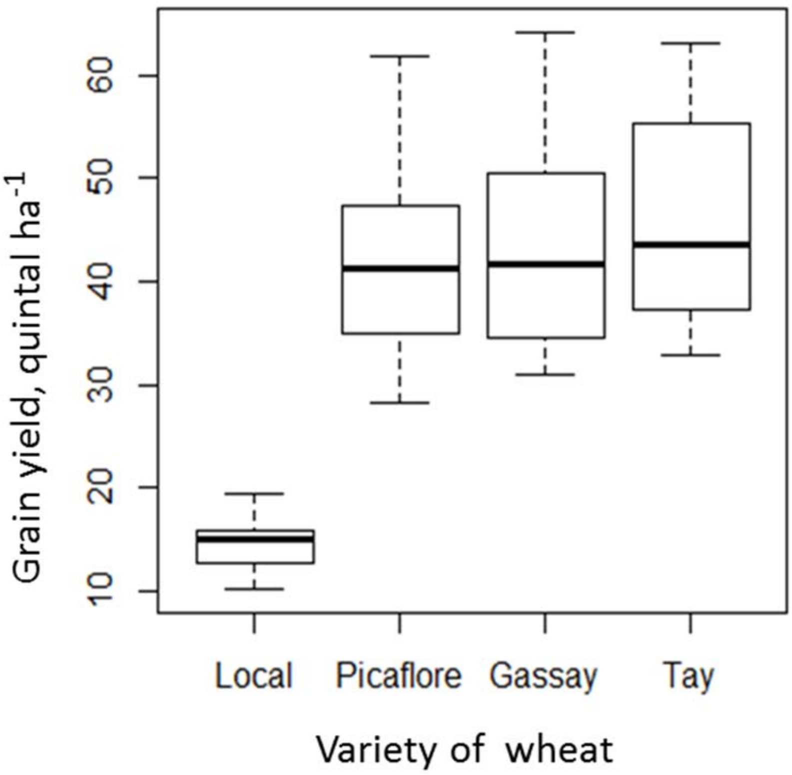


Figure 14. Boxplot showing the yield distribution of wheat varieties

Gassay showed relatively positive skewness as compared to other varieties. Tay has the longest box (Figure 14) compared to others, showing that the grain yield has a possibility to expand more in both directions (to lower or higher grain yield) depending on the management.

4.4 Ecosystem service based scenario modeling

4.4.1 DPSIR concept for ecosystem services

The DPSIR framework is adapted for Tara Gedam Watershed in the following way as shown in Figure 15, which lists the elements of the five components. The components are described with their respective elements and the indicators chosen to serve as gauges for these elements in quantitative modeling.

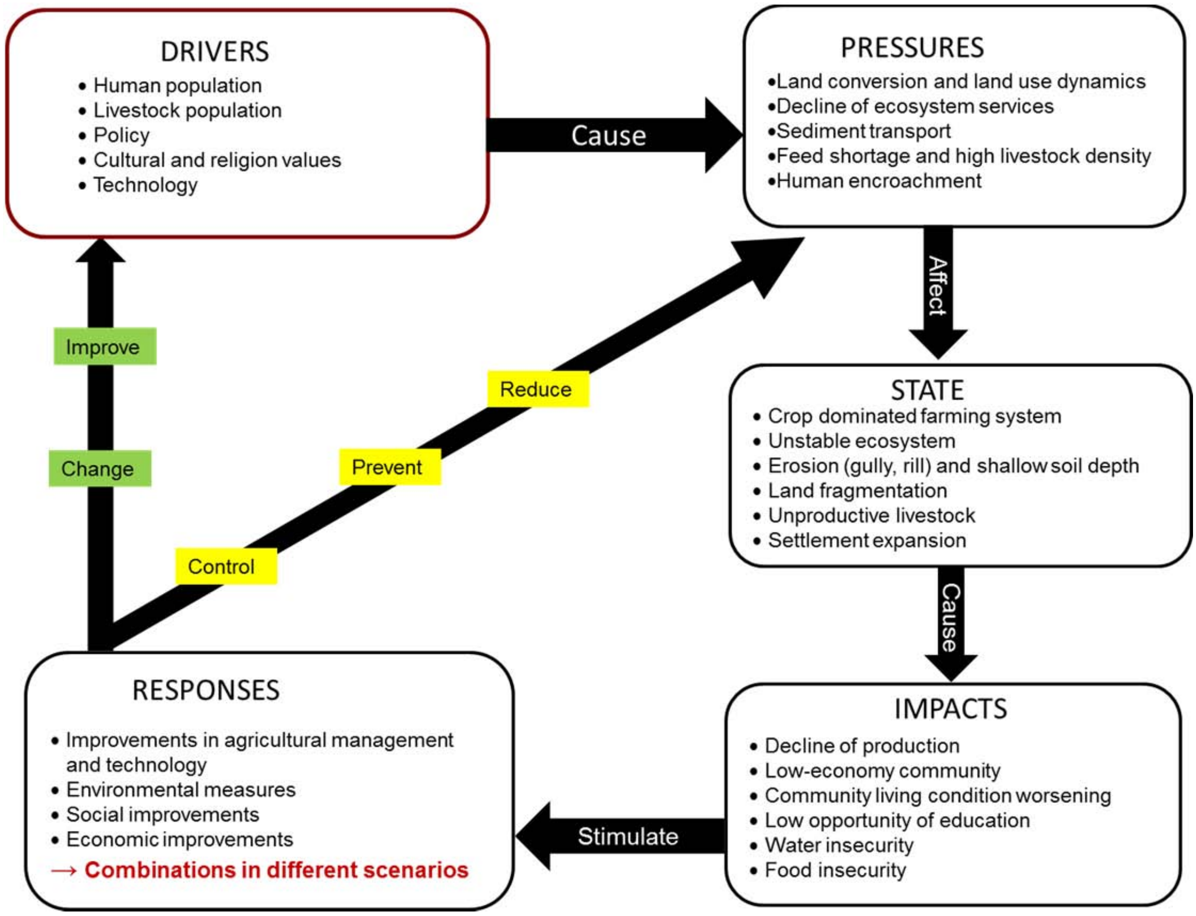


Figure 15. The DPSIR concept for ecosystem services scenario modeling in Tara Gedam

These components are described with their respective elements and the indicators chosen to serve as gauges for these elements in quantitative modeling.

4.4.1.1 Drivers

Drivers in this study in essence are the population with its demands, policy and cultural/religious structures. The population requires food, water and wood, and also induces, within the scope of the farming system, the demands of the livestock population and farming technology.

Human population:

Indicator(s): population count and population increase

It is known from experience in other areas and in particular from the previous investigations in Tara Gedam watershed (as described in chapter 4.2.2) that the population severely affects the type and amount of ESs production and consumption. Rapid population growth and decrease of farm size per capita in the past resulted in the inability of smallholder farmers to achieve food self-sufficiency (Josephson et al., 2014). The Ethiopian highlands are densely populated because of suitability for agriculture and the favorability of the environment (Kloos and Adugna, 1989). Thus, about 80% and 70% of human and livestock population reside in the highlands (Hawando, 1997). Consequently, that causes increased demand as well as shortage of ESs. In this study, therefore, population dynamics is considered as the main and primary driver.

Livestock population:

Indicator: livestock (cattle) count

There is a considerable livestock population of cattle, in particular of oxen, in the watershed at present. The number of cattle is chosen as indicator. There are also sheep, goats and equines, whose numbers, however, frequently change. The increasing livestock population is grazing and browsing on shrinking areas because of conversion of grazing land to cropland. Livestock production in Tara Gedam is based on a free grazing system. Grazing in degraded and hilly areas that are not suitable for crop cultivation is a common practice. Free grazing has negative impacts on soil, water, forest and other resources. Overgrazing causes soil erosion due to compaction. Formation of gullies are observed close to communal grazing land.

Policy:

Indicator(s): subsidies, production target (outlined in the Growth and Transformation Plan (GTP) document of the Ethiopian Government], and acceptance by population

There are different policies and strategies developed by the Ethiopian government to alleviate poverty in the country. Food subsidies provided by the government support the poorest part of the population. Agricultural Development-Led Industrialization (ADLI) is one of the strategies developed to diversify products through use of agricultural technologies, extension services, better management of land resources and access to market. Commercialization of small landholding farmers is the motto emphasized in ADLI. The recently evolved five year Growth and Transformation Plan (GTP) (2010/11 to 2014/15) targets at achieving the millennium development goals by doubling GDP. Through the GTP, the Government aspires to see a food-secure and middle-income country by 2020. These national policies have direct or indirect effect on the watershed development. The acceptance of policy plans by the population is a substantial condition for success of political measures.

Cultural and religious values:

Indicators(s): church grounds with forests and management of church forests

Forests around churches have been preserved since time immemorial. They are managed in a sustainable way and are important hotspots of biodiversity and may be starting points for further conservation efforts. The spiritual, educational and recreational benefits of these areas may also be seen as a driver for improving the quality of life of the population.

Technology:

Indicator(s): crop yield, number of people with access to water supply, area of irrigated land and number of farms with runoff/rainwater harvesting

Poor land management accompanied by increase of population leads to degradation of resources. On the other hand, proper agricultural technologies can help to attain food-self-sufficiency of a growing population on shrinking landholding areas. In any case, technology governs ecosystem modification.

4.4.1.2 Pressures

Pressures are created on the ecosystem by the drivers, affecting the various types of landscape elements and their functioning.

Land conversion and land use dynamics:

Indicator(s): Conversions and dynamics of LCUTs

The dominant LCUT conversions of the past, mainly forestland to cropland, are described in chapters 4.2.3. Depending on the driving forces, future conversions may act positively or negatively. The dynamics and conversion of LCUTs are to obtain the required ESs.

Decline of ecosystem services:

Indicator(s): percentage of decline of land productivity per year and increase of wasteland/marginal land per year

Land productivity may decline due to soil degradation, erosion etc. Cropland and grassland may become wasteland because of long years of cultivation and soil compaction.

Sediment transport:

Indicator: soil loss in tons

Improper use and management of steep terrain (e.g. for crop cultivation by plowing, overgrazing) will destroy the vegetation cover necessary to prevent erosion.

Feed shortage and high livestock density:

Indicator(s): ratio livestock count / grassland area and percentage of livestock with feed shortage

High livestock density causes feed shortage which in turn will result in low productivity of livestock. Farmers attempt to develop forage in backyards and on their parcels to obtain supplemental feed for their livestock. Negative consequences of high livestock density (overgrazing) on the ecosystem have already been mentioned.

Human encroachment:

Indicator(s): increase of number of houses

The number of houses increased from 1957 to 2013 because of an increase in population as described in subchapter 4.2.4. Forests are encroached and croplands are expanded. Expansion of houses also competes for land that would have been used for food production.

4.4.1.3 States

States describe the resulting biophysical conditions and changes of the ecosystem. The states can be illustrated by the mosaic of landscape elements and the ESs offered by them.

Crop dominated farming system:

Indicator(s): cropland area on suitable terrain and cropland area on unsuitable terrain

The size of cropland area is one of the direct consequences of the pressure of land use conversion. Cropland area can have positive (food production) and negative (land degradation and loss of biodiversity) effects. Currently, land is mainly allocated for food production irrespective of its suitability.

Forest, agroforestry:

Indicators: area of natural forests and density of trees outside forests

The natural forests are declining due to pressure caused by the local people. Indigenous trees are substituted by fast growing exotic tree species. Regarding forest activities, small woodlots and boundary planting have been established by farmers to fulfill their wood and related demands by planting eucalyptus species. Besides, the number of trees per parcel declines due to land fragmentation and low tree planting activities.

Unstable ecosystem:

Indicators: area of degraded/fragile land and eroded area

The landscape is exposed to degradation. Steep terrain devoid of vegetation often is characterized by shallow soil depth (Figure 16). It is endowed with rill and sheet erosion. There are areas used for grazing or left marginalized due to high erosion. Livestock production based on free grazing, especially in steep terrain, aggravates degradation.

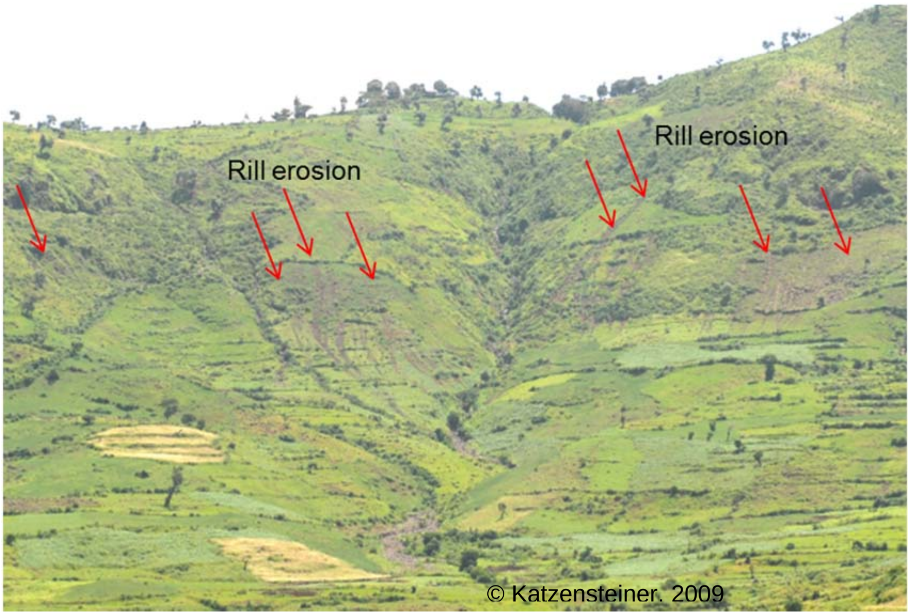


Figure 16. Part of the Tara Gedam watershed showing eroded areas devoid of vegetation

Land fragmentation:

Indicator: subdivision of land

The increase of human population together with changes of land reform policy and degradation has implications on land fragmentation. The overall increased trend of further subdivision of land increased the fragmentation of LCUTs and ESs. This has an effect on the livelihood system.

Settlement expansion:

Indicator: number of houses

Settlement expansion is observed in flat and agriculture land. The number of houses increased from 29 houses in 1957 to 395 houses in 2013 as obtained from the analysis of remote sensing data. The settlement expansion caused increased food demand and poor land management.

4.4.1.4 Impacts

Impacts are the effects of the states of the environment on the livelihood of the people in the watershed and their socioeconomic situation.

Decline of production:

Indicator: decline of production

The agriculture production has declined due to deterioration of the soil quality by erosion, whereas the population increased by 3% per year. This caused unbalanced supply and demand which further impacted the livelihoods of the people negatively. This declining production trend can be reversed by using improved crop varieties and proper management.

Low-economy community:

Indicator: average income per year

Agriculture is the basis of the economy. Decline of production has raised the risk of food insecurity and poor economic development. This caused low income per household that resulted in a lower probability to support the minimum living condition. The economic situation of the population is indicated by the average income per person per year.

Worsening of living condition of the community:

Indicator: percentage of dependent persons per landholding size

Expansion of settlements is an indication of the increased number of population as it was obtained from remote sensing data analysis. This increased the dependent group aged under 18 years as well as the unemployment rate. Land is the only capital for the Tara Gedam Watershed and there are low opportunities for alternative income sources. Land was subdivided into the number of family members and decreased the landholding size over time. A certain land holding area is needed to feed one person. An increase of the number of dependent persons per ha of land holding size indicates worsening of living conditions.

Low opportunity of education:

Indicator: school attendance

Affordability and accessibility of education services is affected by low income and wealth. Children and youth from low-income families and less-educated families are getting poor education and health services. Inefficient farming practices with a high workload on the farmers lead to the practice of not sending their children to school so that they work on the farms during certain times of the year. This reduces school attendance and increases the number of illiterate people in the community.

Water insecurity:

Indicator: change of water supply

Water security is threatened due to less protection of the watershed, low vegetation cover in steep terrain and low experience of farmers in water management. This affects the sustainability of water supply (quantity and quality) in the system. In drier seasons, the amount of water available and its quality is decreasing resulting in negative impacts on the health and food supplies of the people.

Food insecurity:

Indicator: percentage of households depending on food aid

Human pressure on natural resources, low adoption of appropriate technologies and less activities on watershed protection lead to insecure and inadequate food supply. The subsistence farming is highly dependent on rain-fed agriculture. Rare practice of irrigation has implications on food security.

4.4.1.5 Responses

Responses are the possible measures counteracting negative impacts. They include technological, environmental, social and economic measures. Any combination of these measures with certain weightings will change the situation in a watershed in a certain way, thus resulting in a certain scenario.

Improvements in agricultural management and technology:

Indicator: increased production

Delivery of nutritious, safe and affordable food to a growing population is a major challenge for an agriculture-based economy of this highland watershed. Agricultural productivity is a result of the biophysical situation, technology, economy and policy. Agriculture productivity can be boosted by investing in agricultural technologies. Yield can be increased 2-3 fold through available knowledge and improved land management.

Environmental measures:

Indicator: increase of conserved area

Prevention of land degradation is the top priority for Tara Gedam Watershed. Protection of the watershed can be achieved through well designed conservation, management and development strategies.

Social improvements:

Indicator: percentage of persons in stable living conditions

Social improvement is inseparable from environmental, economic and technological advancement. Increased production and environment stability by agricultural technologies result in improved living conditions of the people. Stable living conditions refer to people living decently on their farm holdings without the need for migration.

Economic improvements:

Indicator: income diversification

The promotion of watershed development and management using different alternatives sustains economic growth and brings sustainable development. Growth in production improves employment and income levels, which is a basis for social development.

4.4.2 Selection of scenarios

Four scenarios including business as usual (BAU) were constructed, based on different assumptions about population development, policy influences, acceptance of technological change and cultural priorities. The four ecosystem service scenarios that are assumed suiting to the highlands are named: (a) Business as usual (BAU) (b) Transition agriculture (TAG) (c) Intensified agriculture (INA) and (d) Optimized ecosystem services (OPE).

BAU is the trend of the current status that is considered as a reference to compare and contrast with the new scenarios. These three new scenarios i.e. TAG, INA and OPE were developed as options for the improvement of the livelihoods of the people. The scenarios were designed based on assumptions, theoretical considerations, field experiments, interviews, discussions and workshops. The scenario development was participatory in the sense that beneficiaries and stakeholders were part of the development process. ESs were the central subject to structure the pathways of scenario development by connecting the ecosystem, local community, policy and benefits. The scenarios were developed based on the DPSIR framework. Each scenario is characterized by its main features (Table 11).

Table 11. Characterization of the different scenarios identified.

Scenario	Characterization
Business as usual (BAU)	Keep the existing land use practice and rely on the current land management system. The population trend is assumed to continue as it was derived from the direct census, i.e. 3.1% $year^{-1}$ (field survey).
Transition agriculture (TAG)	Priority is given to food security by adopting available crop technologies with appropriate management systems. Less attention is given to conservation and environment protection. Population growth is assumed to be 2.7% $year^{-1}$ (expert judgment).
Intensified agriculture (INA)	Well-designed land use plan, targeted to crop and forage production. High yielding crop varieties, improved forage development, and productive livestock specifically fit to the highland agroecology are introduced. The economy is focused on market-orientation and food security simultaneously. Rapid agriculture-based economic growth is assumed. The population growth is assumed to be 2.4% $year^{-1}$ (in accordance with CSA, 2013, for the whole of the country), which is low as compared to BAU and TAG.
Optimized ecosystem services (OPE)	Well-designed land use plan incorporating all issues related to food security and environmental protection. Simultaneous focus is placed on improved food production on suitable sites and restoration of degraded areas. Free grazing is ruled out, temporary subsidy is granted for conservation and restoration. Population growth is assumed to be 1.8% $year^{-1}$ (CSA, 2013, for ANRS).

The key features of the four scenarios can also be described and visualized by underlining the weights given in each scenario to the four factors of population, technology, economy and environment (Figure 17).

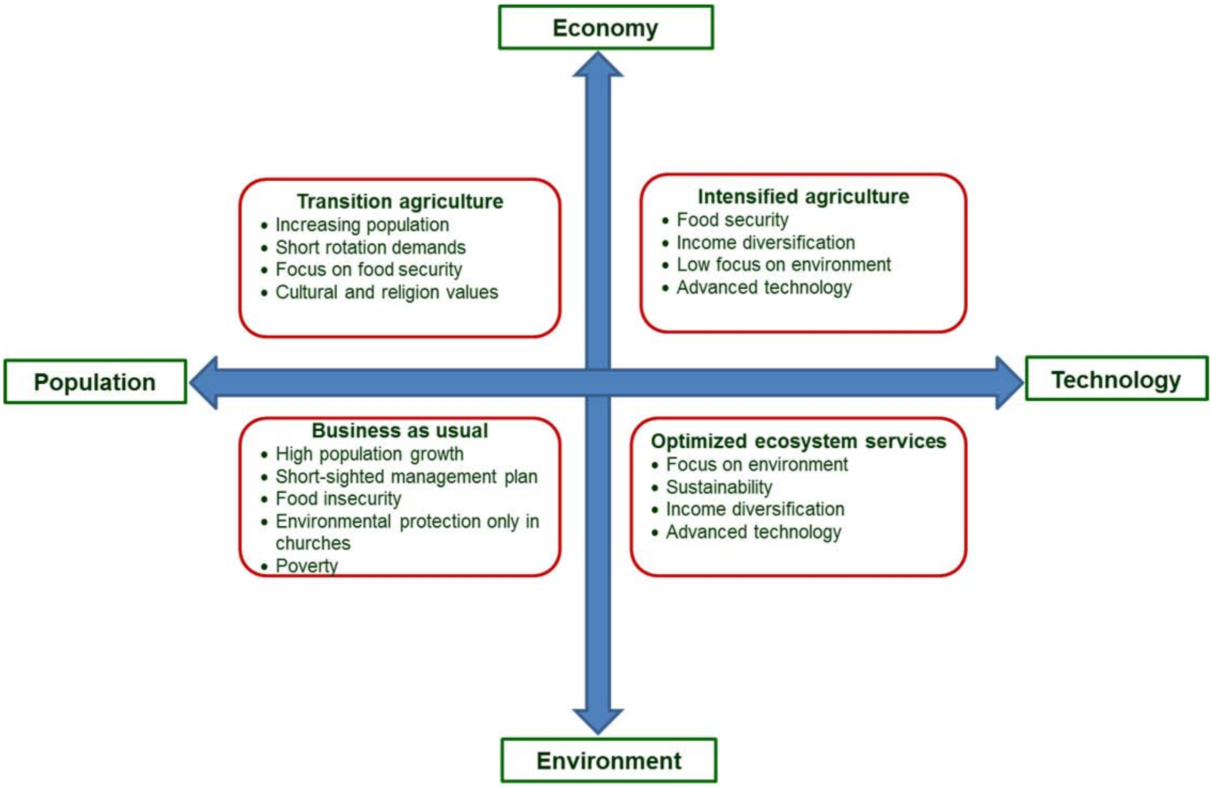


Figure 17. Scenario axes with respect to drivers

The scenarios are set as a matrix. The position of each scenario in this system of factor axes indicates the weights given to the factors. Economy and environment are in opposite direction, and the same applies to population and technology. It is known that in developing countries the need to grow in economy may have contrasting effects on environment protection. This is because the economy often is based on natural resources the use of which may be accompanied by overexploitation and mismanagement. Similarly, the increasing population may limit the access to technology due to the decreasing capacity of farmers to purchase technologies.

BAU is characterized by environment and population. The growth of population and the low access to technology aggravates food insecurity. TAG also has high population growth. However, it attempts to improve the economic conditions with the introduction of very few new management systems and technologies. INA has its focus on technology and on economy. It is an opportunistic strategy targeting economic development through enhancement of improved technology. Implicitly the population growth slows down in INA, thereby reducing the pressures on the environment. In OPE, advanced technology is applied both to ensure food security and to protect the environment. This is the most optimistic strategy with economic and ecologic priorities to be fulfilled simultaneously.

4.4.3 Qualitative descriptions of the pathways of the scenarios

In the following, the scenarios are described from a qualitative point of view. The quantitative modeling is treated later.

4.4.3.1 Scenario 1: Business as usual

This scenario assumes food, feed and wood production according to the current management practice which has to be described as poor management. There is no concern on conservation except church protected forest resources that are kept and managed since long times. The current livelihood system, the existing management and socioeconomic characteristics as well as the presently accessed and available ESs are assumed to continue without changing the tradition. Variable policy, technology and social trends are ignored.

Ecosystem productivity, specifically regarding crop production, can hardly fulfill the growing demand of the population in a deteriorating environment. This scenario shows the incapability of the ecosystem to accommodate demands. It is characterized by low ability and readiness to implement improved land management systems. There is little access and utilization of improved agricultural technology. The ability of farmers to purchase the recommended inputs is beyond their financial capacity. With this present management, the yield per unit area is declining. On the other hand, the number of consumers increases. This results in an unbalanced supply-and-demand relationship. The likely outcomes are aggravated degradation, food insecurity, migration and threatened livelihood. The proportion of people living in poverty increases with this relatively constant production system. The situation of environmental conservation/protection and of other ESs (e.g. water and soil fertility) is deplorable.

In addition to the decline of food and feed, there are high demands for wood for energy (cooking and heating) but little activities in forest development. The number of trees per farm parcel is low. The survey showed that at present less than 30% of the farm parcels in the watershed are endowed with trees (1-8 trees per parcel). Most of these parcels have only 1-2 trees. More than 70% of the farm plots are without trees. There are different soil and water management practices, but with poor construction designs, and very few of them are maintained. This farming practice negatively changes the structure and processes of the ecosystem.

This scenario ignores the consequences of degradation. The present trend is continuing without or with very little actions. Economic growth per capita and technological adaptations are missing. The economic orientation is not dynamic and there is no recovery of the household income. Farmers' wealth inequality and inequity increase, hence only a very small percentage of residents become food-self-sufficient. Unemployment, instability, migration and a high rate of dependency are the characteristics of BAU that may result in social insecurity. As a result, more people are expected to be dependent on aid than there are today. Consequently, the living strategy is aid dependence and the people develop a dependency syndrome. Finally, the situation may bring additional stress on the proximity watersheds and the nation at large. The overall situation can be categorized as a food-self-insufficient low-income community.

4.4.3.2 Scenario 2: Transition agriculture

The transition agriculture (TAG) scenario shows a distinct increase in ecosystem productivity as compared with BAU. The TAG scenario pays attention to the introduction of available agricultural technologies from elsewhere into the watershed. The major focus is on securing food and feed supply. The increased crop production is assumed to ensure better livelihoods in the short run. The economic orientation is relatively dynamic and relies upon the effectiveness of short rotation agriculture. Improved varieties and management practices are introduced to maximize crop yields. The existing conventional breeding/research method holds the promises of increasing crop yields and thereby improving nutrition, securing the availability of trees for energy demand, and for conserving water resources. The technologies introduced are assumed to provide grain yields increased by 1.2 times as compared with BAU. This estimate is based on demonstration experiments. The overall production increase is set to an average of 1% year^{-1} in the whole watershed using wheat equivalent.

Technological improvements are searched, accessed and used by interested farmers. The approaches and governing factors for the success of this scenario are field demonstrations, evaluation of the results, scaling out progress, sharing of experiences among the farmers, acceptance and adoption rate of improved technologies, and the ability of the farmers to purchase the required inputs. The experience of field demonstrations conducted in 2012 and 2013 showed that farmers can adopt the technology if they can get support for agricultural inputs. During this time, only 19% of the farmers who hosted field demonstration experiments were able to purchase the appropriate agricultural inputs. Due to long-year traditional-based farming system, a few early adopters are prepared to use the new technologies. Most of the farmers are reluctant to try new management approaches. There is a large degree of uncertainty on the chance of success of the scenario because of complex interacting components of the newly introduced technologies, the willingness to adopt them and the financial capacity of the farmers.

In this scenario, the farming system is dominated by cereal-based agricultural land use. Monocropping and less diversified production systems are practical to satisfy the immediate demand without looking into sustainability. The policy of this scenario is focusing on short term needs. Less emphasis is put on conservation, forest development and environmental protection. The communities see environmental protection as a secondary issue. Problems of sustainability are neglected. The efforts focus on short rotation farming. Tradeoff exists between forest and other land uses because of land demand for cropland. Attempts are made to convert marginal land into agroforestry.

The TAG scenario likely results in the decline of the number of food-aid-dependent households as compared to BAU. The change of livelihood varies from household to household and from parcel to parcel. It shows a dynamic pattern of food, forage and wood production.

4.4.3.3 Scenario 3: Intensified agriculture

Intensified agriculture (INA) is associated with the introduction and rapid adoption of high-yielding crops and the related technologies (monocropping or agroforestry) to achieve faster economic growth in a short period of time. Suitable crops have been released by local research institutes that perform best in the Ethiopian highland agro-ecology. The primary focus of INA is on food security. Cereal crops, annual forage and agroforestry development are the key factors of this strategy. INA tries to replace the halfhearted and simplistic approaches of TAG by the strict introduction of a knowledge- and input-intensive agriculture.

High agricultural inputs are required to double production and to eradicate food insecurity. The basic assumption is adopting the crop production rate in the high case scenario of the policy set in the Growth and Transformation Plan (GTP) developed by the Government. The efforts to improve the livelihood and the economic situation of the people comprise not only a high annual increase of the agriculture production but also the value-addition of products.

Food production in INA is 2-3 times that of BAU. Estimated wheat grain yield per hectare is improved from 1.5 ton ha^{-1} to 4 ton ha^{-1} as indicated from GTP. (It must be noted that there are wheat technologies providing more than 4.5 ton ha^{-1} grain yield as it was observed from demonstration experiments.) The rate of adoption and purchasing power of farmers is higher than in the case of TAG. INA enables to ensure food security of each household in a short time.

The environmental situation develops more favorably in INA than in TAG. The main reason for this is that the improvements in land productivity will help to maintain resources and will enable farmers to start caring for resource management. Conservation of natural resources and restoration of degraded areas become the next steps after ensuring food security. As the use of chemical fertilizers to increase productivity may have long-term negative effects on soils and groundwater, these factors are taken into consideration. Environmentally friendly land management is therefore applied at the later stage of the implementation phase.

The transformation of agriculture from traditional and subsistence way of farming into intensive and market-oriented farming is initiated and accelerated. The aim is to intensify and diversify high value farm products for domestic market and thus to increase household income.

The agricultural production is expected to boost at a faster rate (6.6% per year) and the community should become food-secured in not more than 5-7 years.

The key consideration of this scenario is to place it in a systemic framework. It fulfills immediate needs to ensure food security and also cares for the ecosystem comprehensively. It enhances agricultural productivity to fulfill household consumption and to improve household income. Then, improvements in environment and sustainability come at the later stage.

INA requires new research and development initiatives and strong cooperation between beneficiaries and stakeholders. It follows specialized and demand-driven as well as problem-oriented research and extension services. INA assumes farmers can purchase agricultural inputs either by themselves or through government subsidy. Farmers respect policies regarding natural resource management and land use planning regulations. The realization of high agricultural efficiency requires high investments. The new intensive management system includes new crop varieties, fast growing forage species, ecologically fitting agroforestry species, market-oriented crops, water harvesting technologies (e.g. geomembrane), irrigation facilities, and other appropriate inputs boosting production.

4.4.3.4 Scenario 4: Optimized ecosystem services

The optimized ecosystem services (OPE) scenario envisions a future Tara Gedam Watershed as a land of diversity, conservation and enhanced ESs production including subsistence-based farming. It describes a landscape with elements diverse and heterogeneous in composition. While the current livelihoods are characterized by food insecurity and a deteriorated ecosystem, the efforts of OPE are to reverse this situation. OPE tries to ensure food security and to minimize negative impacts on the environment simultaneously. It implies reclamation and rehabilitation of degraded areas to bring more land into production. The central theme is optimizing ESs production. This optimization includes introduction of suitable management systems, but also rehabilitation of degraded areas, protection of the environment, biodiversity conservation and strengthening of cultural/spiritual values as accepted by the farmers.

OPE strictly follows the laws and regulating policies to give up mismanagement and overexploitation. Some of the measures to be taken are avoiding ploughing steep terrains, minimizing free grazing and limiting the number of livestock per unit area. Marginal and underutilized land is going to be used for conservation and production purposes such as alley cropping, fruit-based agroforestry, *Rhamnus*-based agroforestry and improved forage development. This scenario includes gender-agroforestry-livelihood as a new system approach for expanding tree-based farming and to enhance the role of women in agriculture. The focus of this concept is the contribution of agroforestry to food security from a gender perspective (Kiptot et al., 2014). This enhances the participation of women and children in modern agriculture. It encourages continuous improvement by tackling environmental problems in a participatory way.

This scenario is an optimistic strategy that tries to reduce natural resource degradation with a suitable ecosystem management approach and to solve the food security issue with improved technology to maximize production of food and feed. This is supported by family planning to slow down population growth. It is concerned with the creation of both tangible and intangible products. OPE assumes that ecological processes are well understood and readily manipulated in a sustainable way to produce the intended and diversified ESs in sufficient amount. This includes, besides food production, soil fertility maintenance, carbon sequestration, pollination and water regulation. When the local people make ecosystem management decisions, there may be a requirement of environmental subsidies in the first few years, specifically until area exclosures and rehabilitated lands start to provide benefits. This helps to intensify the farmers' appreciation for environmental issues.

The population growth rate is lower in OPE than in the other scenarios. The social change may not be so complex and may not put so much pressure on the environment. Parts of the land may lie fallow and allow rehabilitation to maintain soil fertility. Land fragmentation due to family inheritance will be lower.

The pattern of economic development at the earlier stage is slow. Economic development is not only based on agriculture but also on ecologically balanced farming. At the later stage the economy is sustainable and boosts household income. The primary economic basis lies both on food/feed production and on conservation/rehabilitation with compatible off-farm activities such as non-timber forest products (e.g. honey), ecotourism and carbon trading. In order to minimize dependency on wood-based energy, it also considers other renewable energy sources e.g. solar energy for cooking. Communal regional planning may be another approach for infrastructure development. If clustering of villages is supported by the policy, the upgrading of infrastructure viz. electricity and institutional setups may bring positive effects for the reclamation and rehabilitation of natural resources.

Technologies are introduced that establish a win–win situation between conservation and development. Proper land use planning is accepted and deliberated in the watershed. For example, mountains and hills are set aside for forest development, conservation, protection and cultural values. Instead of chemical fertilizers, which have long-term negative effects on soil and water, other options such as compost, green manure and other organic farming practices may be considered. The integrated involvement of stakeholders is the effective way of implementing technologies. This improves the capacity of people to mitigate existing problems by adapting new management systems. At the same time, however, the cultural change of the local people may become a challenge to go forward. Substantial participation and trust of farmers on the management system requires capacity building, experience sharing, stimulating best traditions (knowledge) and strengthening social institutions.
In comparison with other scenarios, OPE puts emphasis both on economy and on environment simultaneously at the initial stage. It may therefore take longer to bring economic improvements. However, the improvements will be sustainable.

Advanced and graded technologies are introduced based on suitability according to a carefully designed implementation plan. The average overall production starts to grow by 7% $year^{-1}$ for the first 10 years and then by 10% $year^{-1}$ for the remaining 15 years. ESs optimization and the connected management can be improved with adaptive technologies to reduce the costs of experimentation. Adaptive approaches are believed to accelerate development, facilitate community learning and provide the ability to cope with environmental deterioration problems in short time. This helps to adopt new systems for quick delivery of outputs so that beneficiaries develop trust in the ability to counteract environmental deterioration.

4.4.4 Quantitative descriptions of scenarios

In order to check, proof and demonstrate the viability of the scenarios, the following factors were quantitatively modeled: population, LCUT areas and area changes, and crop yield.

4.4.4.1 Population

In total, four population projections were assumed in the four scenarios (Figure 18). The population growth data already mentioned in the storylines were acquired from three sources. The field survey result (Wondie et al., 2014, unpublished) showed an annual population growth rate of 3.1% $year^{-1}$. This was assumed unchanged for the BAU scenario. The Ethiopian Central Statistical Agency (CSA, 2013) reports the growth rates 1.8% $year^{-1}$ for Amhara National Regional State (ANRS) which was taken for the OPE scenario and 2.4% $year^{-1}$ for the country as a whole which was taken for the INA scenario. A growth rate of 2.7% $year^{-1}$ was assumed for the TAG scenario, based on expert judgment. It is the average of the highest (3.1%) and the second lowest (2.4%) growth rate. Population projection for the years 2014-2040 was done with these figures, assuming exponential growth (equation $N = N_0 e^{rt}$). The details are shown in Appendix 1.

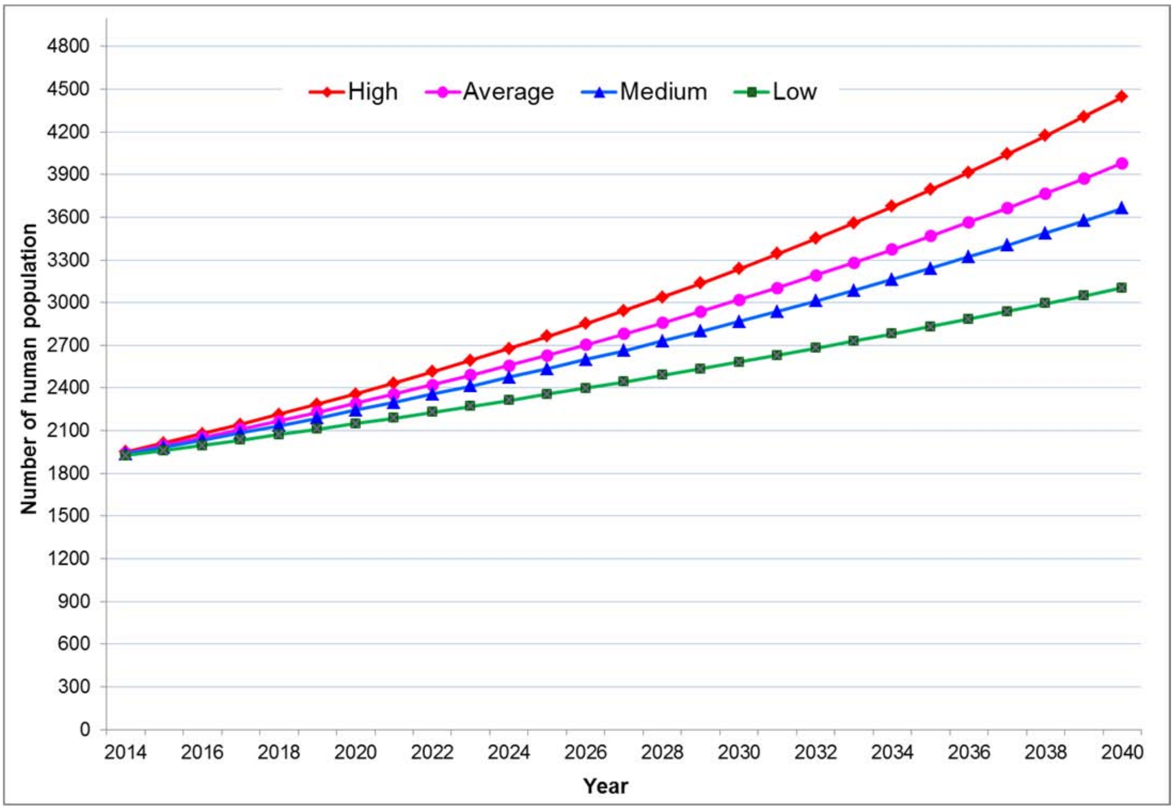


Figure 18. Trend of population growth for different scenarios

4.4.4.2 Change of land cover/use types

LCUT areas and their changes were modeled in constant time-steps of 5 years by spreadsheet calculations (Appendix 2). Yearly transformation rates which are constant within the 5 years time-step intervals were assumed based on expert knowledge on the various influencing factors according to the respective scenario assumptions. As an example, Table 12 shows the assumed transformation rates for the OPE scenario and the time-step 2016 – 2020. The values in the main diagonal (no transformation) were automatically set in such a way that the sum in every column is 100%, i.e. that the total area remains unchanged. Transformation matrices of this type were set up for all scenarios and for all time-steps.

Table 12. Transformation rates for the OPE scenario between 2016 and 2020 (sample)

Scenario OPE 2016-2020		LCU change in % per year from						
		Crop	Forest	Grass	Shrub	Agroforestry	Underutilized	Road
	Crop	100.0	0.5	1.0				
	Forest		99.5					
	Grass			99.0				
to	Shrub				100.0		1.0	
	Agroforestry					100.0	5.0	
	Underutilized						94.0	
	Road							100.0

The resulting developments for the LCUT areas in the different scenarios is shown in Figure 19 below.

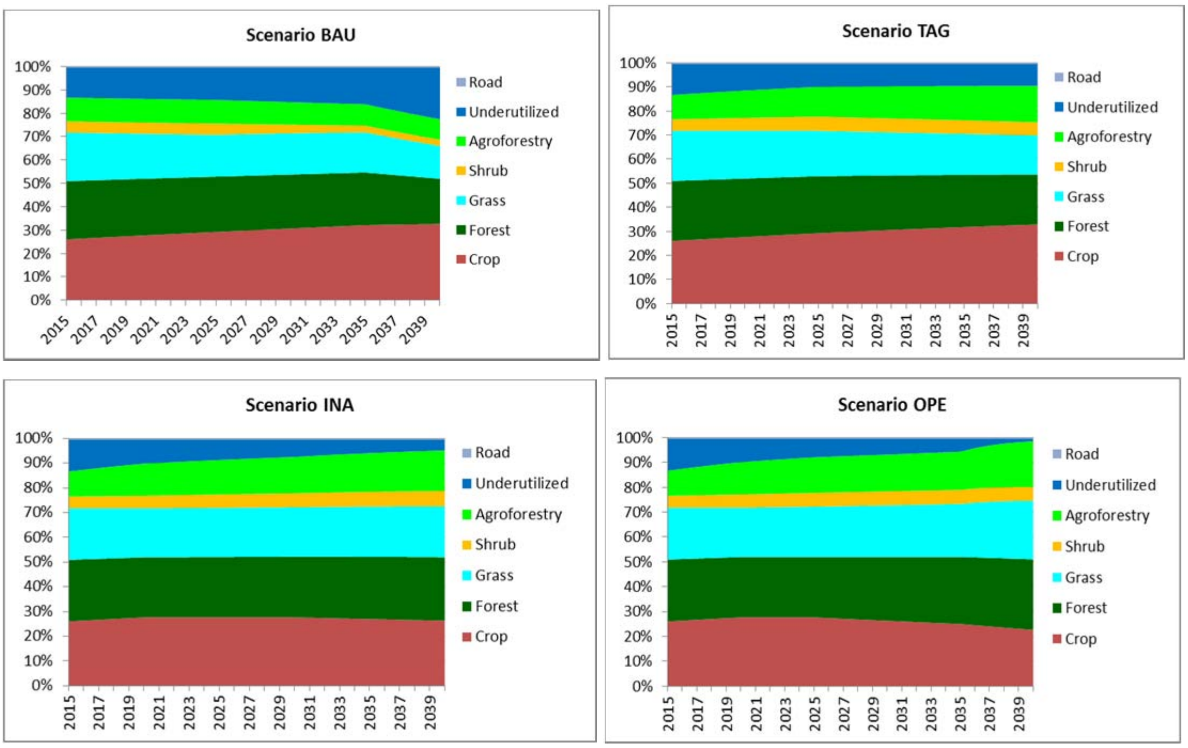


Figure 19. The scenarios with a combination of the LCUTs

The trend of different LCUT areas is indicated in Figure 20 below.

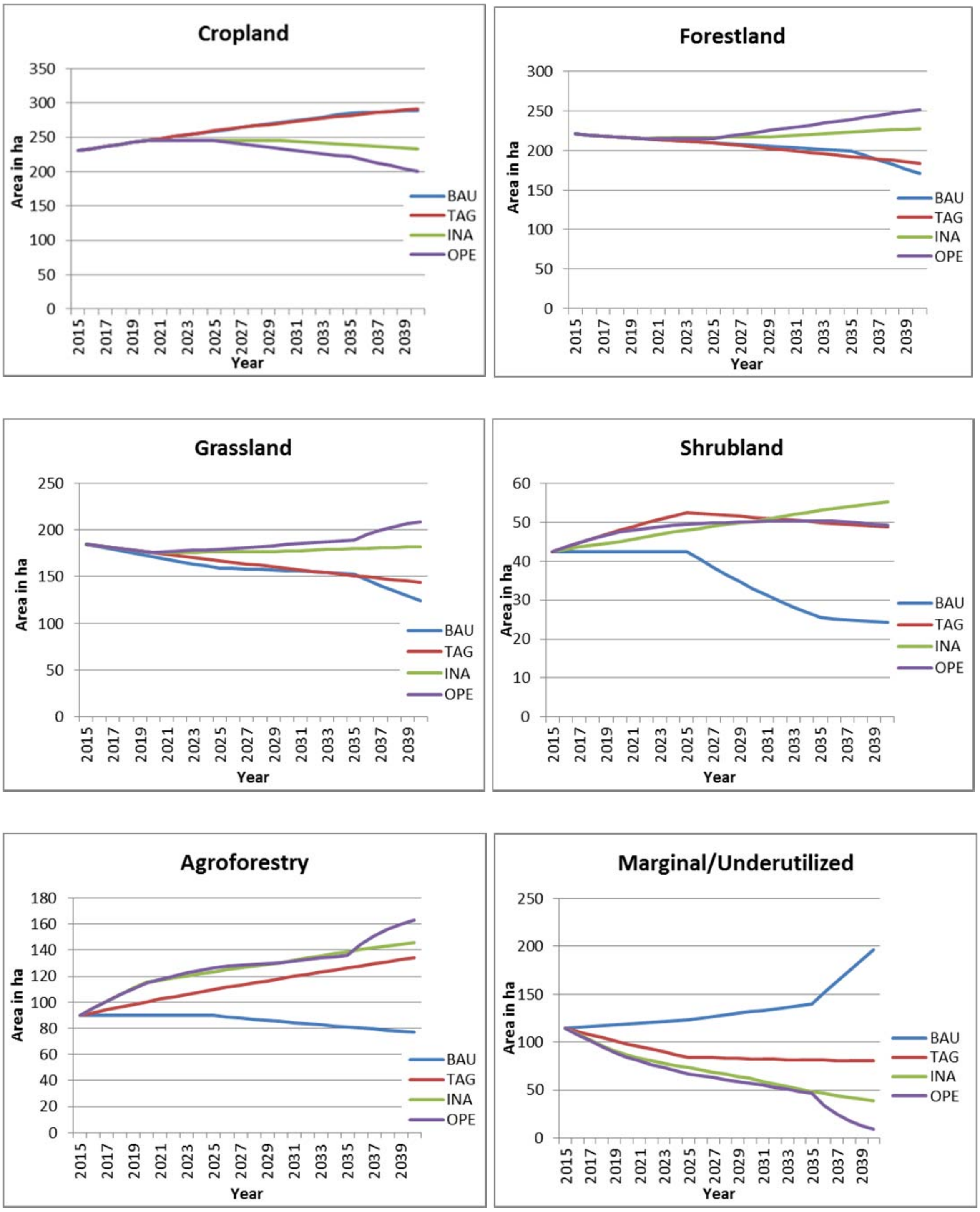


Figure 20.Temporal trend of land cover/use under each scenario

In general, there is relatively little change in the first years of the scenario period. Increasing changes occur in the later years. Exceptions are agroforestry which increases for all scenarios except for BAU right from the beginning of the scenario period, and marginal land which decreases for all scenarios except for BAU. The trends of forest land differentiate at a later stage only (approximately from 2026) because of the slow growth of forests. Besides, time is required for delineating the areas to be rehabilitated and also for training and other capacity building activities. The studies of Mengistu et al. (2005), Descheemaeker et al. (2006), and Mekuria et al. (2007) were the references for assuming 5-7 years for forest rehabilitation. Degraded areas are converted into forestland in 3-8 years depending on the motivation and efforts of the society and the level of degradation. The average time for conversion of shrubland (young forest) into forest is assumed to be 5 years from the respective decision (mainly in OPE, and to a lesser degree also in INA and TAG).

Forestland and grassland develop favorably from 2026 onwards in the case of OPE and INA. This improvement is due to land restoration and reclamation of marginal/underutilized land and conversion into forestland, grassland and agroforestry land. Intensive farming and forest development go hand in hand. Livestock production can be improved through controlled grazing in the forest and using a cut-and-carry system in agroforestry practices. However, in BAU due to the free grazing tradition, land degradation is advanced.

The general trend and magnitude of LCUT change in BAU and TAG scenarios may be comparable to other highlands due to similarity of biophysical and socioeconomic characteristics. However, the spatial pattern of each LCUT will vary due to location-specific management and biophysical conditions. There is an increase of forest to be expected in steep terrains in the case of OPE and INA, whereas BAU and TAG show deforestation and expansion of cropland in these areas due to differences in the choice of land management options and in demand. The population in BAU and TAG believes in land expansion (extensification) instead of intensified agricultural management. Between 2020 and 2030, the INA and OPE are expected to change their distinctive trends and deliver magnificent results for the livelihood of the people, as compared to BAU and TAG. BAU shows a significant increase of cropland as compared to INA and OPE. Both BAU and TAG continue to show expansion of agricultural land as it occurred from 1957 to 2013 according to the trend analysis.

Two contrasting ideas may arise in the case of INA. The first one is the use of advanced agricultural technologies suiting to small landholding farmers, which supports surplus production and accelerates economy. This helps to reclaim as well as to maintain the soil conditions through fallowing and rehabilitation programs. Care for environment increases because of food self-sufficiency. Opposite to the above idea, as the time horizon expands to 2040 there may be an increase in agricultural land and a change of idea of the farmers not to focus on forest expansion and rather to focus only on short rotation crops. Besides, the farmers may underestimate deforestation because of agroforestry. Protected forests will be removed for cropland expansion. This may cause unexpected environmental change, which may result in an adverse effect. This may reverse the land productivity and may turn out as a negative consequence for the whole watershed.

As it is expected from the model, BAU shows a decrease of forests and expansion of cropland. This scenario also shows increase of marginal land due to monocropping and less focus on conservation of natural resources.

The Figure 21 below shows the relative area change in percent of the respective LCUT for each scenario.

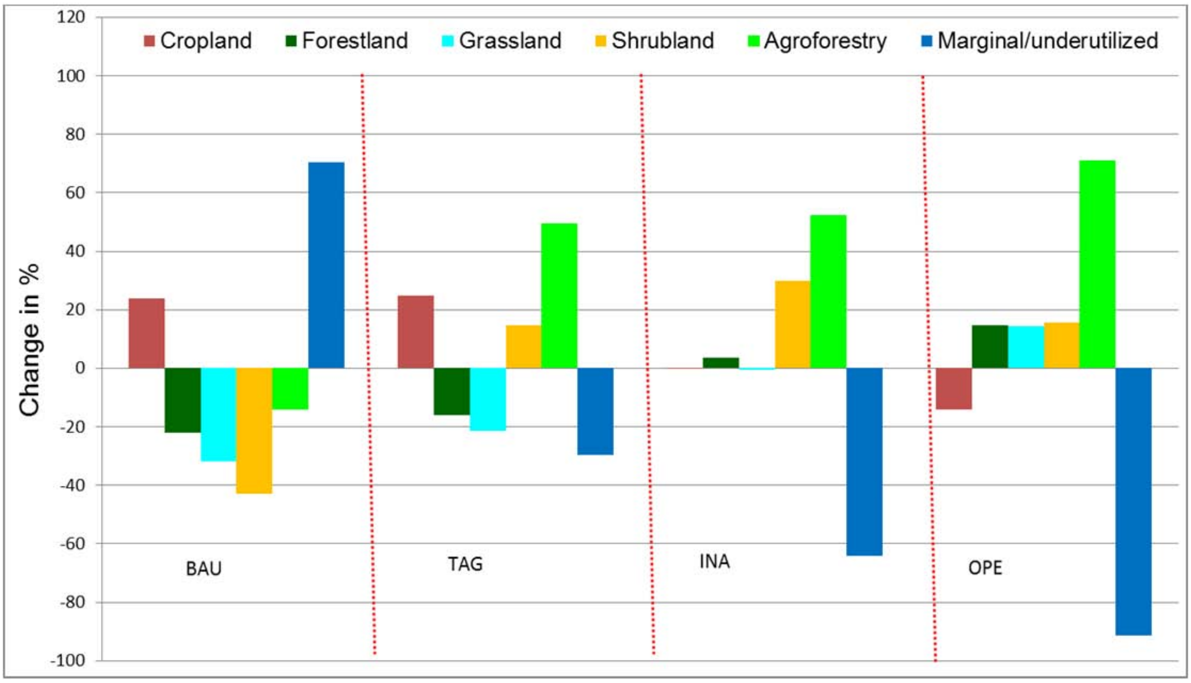


Figure 21. The change in percentage of each LCUT at the end of the scenario period

The changes are generally highest in the OPE scenario and BAU but lowest in the INA scenario. BAU shows an increase of cropland and marginal areas at a significant rate, but a large reduction in forest and grassland. As described before, the current management has the short-sighted target of increased food production by cropland expansion instead by intensification. TAG also shows a decline of forestland and grassland because of conversion into cropland and of a small part into marginal land. Marginal lands are partly converted into agroforestry and shrub/bushes.

The INA scenario shows less change in all LCUTs except a high increase of agroforestry and a high reduction in marginal/underutilized areas. There may be a tradeoff between agroforestry and shrubland expansion when converted from other LCUTs. INA shows virtually no expansion of cropland because the principle and target of it is intensification and conversion of marginal land into agroforestry and of some parts into forestland.

The OPE scenario reveals a significant increase of agroforestry and a significant decline of marginal and underutilized land. The increase of forestland, grassland, shrubland and agroforestry originates from the rehabilitation of marginal (degraded) land and partly from cropland. The increase of forestland can be also related to low pressure due to the slow population growth rate. Protected areas are expanded for biodiversity and improved wildlife management. There are unmeasured increases of environmental services such as improvement in soil fertility, microclimate amelioration, upgrading of water resources, increase of pollinators (e.g. bees) and an enhanced aesthetic value of the landscape. The benefits are optimized through income diversification obtained from other practices such as honey production, ecotourism and possibly from payments arranged for compensation for carbon sequestration due to conservation and protection. Ecosystem use may also be optimized through nature conservation, dry season pasture for livestock and continuous access to water for different uses due to protection of headwater.

The geographic distribution of the changed LCUTs is determined by expert knowledge. Patches of land of the changed LCUTs are geographically allocated by hand. The suitability of land for the different uses is mainly rated according to the slope, which is known from the digital elevation model. The expert knowledge is mainly based on focus group discussions and the information obtained there from beneficiaries and stakeholders. The resulting maps are shown in Figure 22. For the BAU scenario, no map was produced, as it would appear very similar to the map of the present situation: the changes in BAU (e.g. increase of marginal land) mainly occur in small fragmented patches which do not show up on a coarse-scale map.

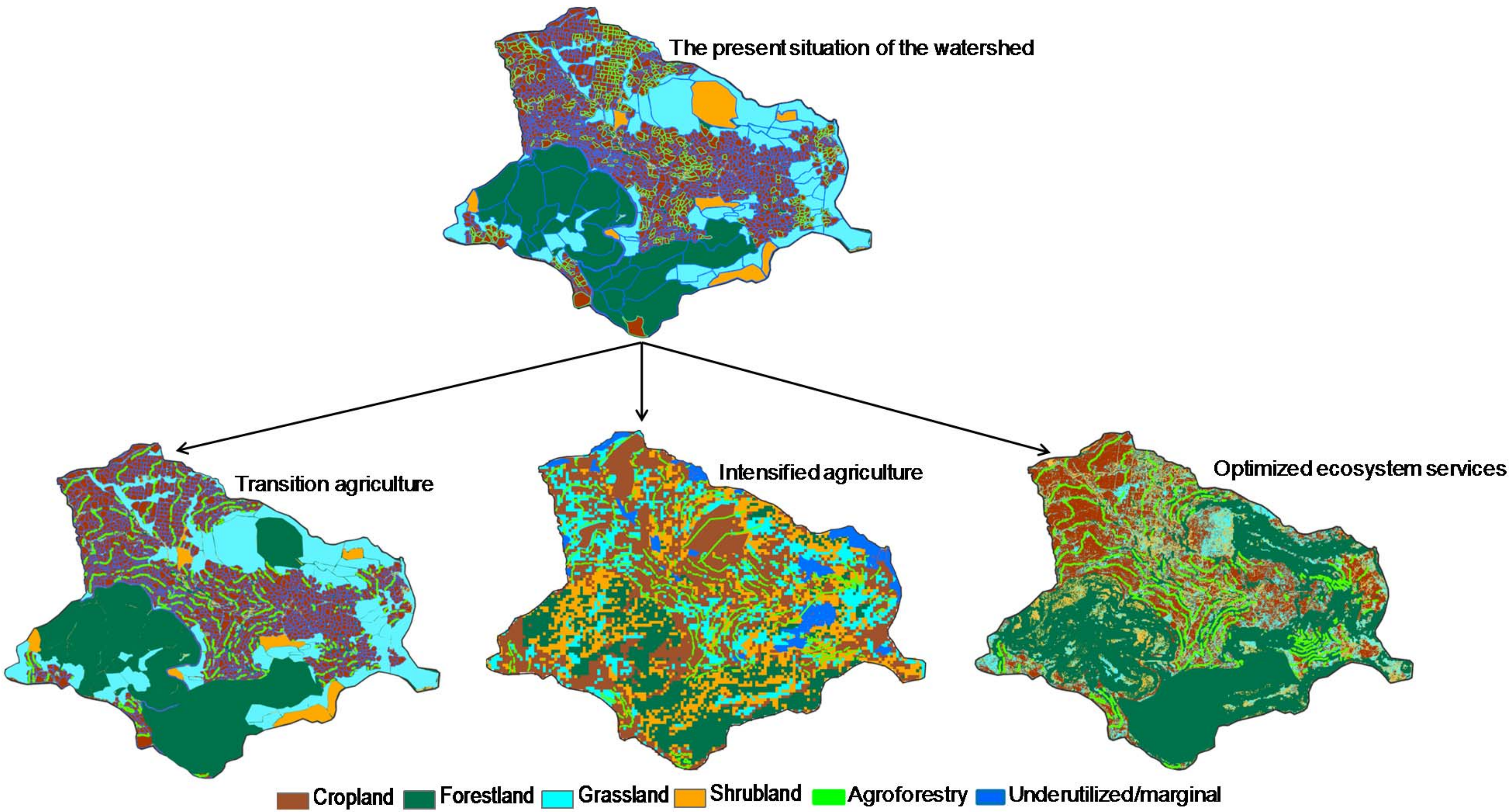


Figure 22. Geographic distribution of LCUTs at the end of the scenario period

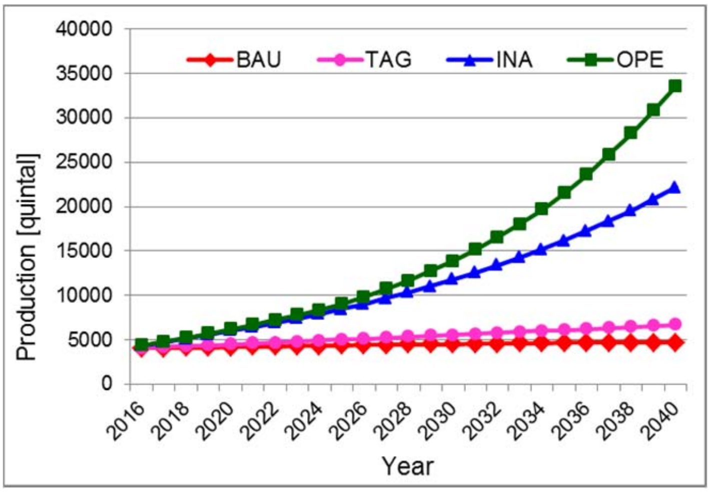
Different LCUT patterns evolve in the different scenarios. TAG involves the introduction of improved technologies in the existing farming system without significant spatial changes of LCUTs except of cropland and agroforestry. Marginal areas, underutilized and degraded areas are converted into agroforestry. It may also change the shrublands located at the peaks of the watershed into forests. There could be a probability of conversion of croplands into marginal land.

INA focuses on a farming system dominated by intensified crop and forage production. It converts marginal or underutilized land into productive land e.g. by agroforestry and soil improving activities. It reduces of the number of livestock to the actual carrying capacity to minimize pressure on natural resources. It may show reduction of forestland and grassland specifically on flat land. It transforms cropland as well as degraded areas into forests or shrubland or agroforestry at the later stage when food security is achieved as planned. At the final stage, food self-sufficiency will be maintained by updating and keeping the best management system and improved technologies.

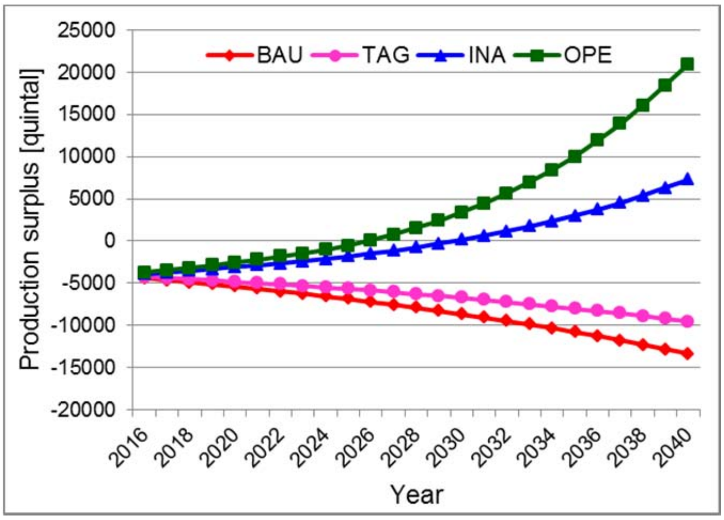
OPE replaces most of the agricultural lands located in steep terrain. Southern and south eastern parts of the watershed which are liable to erosion and the already marginalized areas are converted into forests or agroforestry. Marginal land is converted to be used for agroforestry, pasture (feed production), conservation and other cash crops through improved land management.

4.4.4.3 Crop yield

Agricultural production and its surplus compared to basic requirements of the population were examined based on wheat yield (Appendix 3). The production and surplus trend from the beginning to the end of the implementation of each scenario is indicated in Figure 23 below.



(a) Trend of wheat production in the watershed



(b) Production surplus/gap

Figure 23. The crop production trend and surplus based on population requirement

Baseline data were acquired from field experimentation to obtain the production in the beginning and to model the production trend. The starting production was 14 quintal ha^{-1}. As it is indicated on Figure 23 (a), the INA and OPE showed an increased trend of production, whereas BAU showed constant production because of low access of technology. Examining the production trend and surplus, OPE and INA clearly showed the gains of improved technology and management. As it can be seen in Figure 23 (b), production surplus is achieved by OPE and INA in 12 and 15 years, respectively. However, under the stagnant production of BAU the demand gap is widening with the increasing population.

4.4.4.4 Compilation of numerical results of quantitative modeling

Table 13 summarizes the assumptions made in the different scenarios for population growth and increase of agricultural yield. It also shows the results for the LCUT areas at the end of the scenario period.

Table 13. Assumptions and results in 2040 for each scenario

Parameters	**Assumptions/Results**			
	BAU	TAG	INA	OPE
Population	3.1% $year^{-1}$	2.7% $year^{-1}$	2.4% $year^{-1}$	1.8% $year^{-1}$
Agriculture yield	0% $year^{-1}$	1% $year^{-1}$	6.6% $year^{-1}$	8.2% $year^{-1}$
Cropland (ha)	289.2	291.6	233.3	200.5
Forestland (ha)	171.4	184.0	227.6	251.7
Grassland (ha)	124.2	143.6	182.1	212.2
Shrubland (ha)	24.2	48.7	55.2	208.9
Agroforestry (ha)	77.1	134.5	145.5	163.2
Marginal/wasteland (ha)	196.7	80.5	39.0	9.4
Living condition	Food insecure	Food insecure	Food secured	Food secured and stable environment

5. DISCUSSION

5.1 Ecosystem services

5.1.1 The nexus between livelihood and ecosystem services

The livelihood of the people living in Tara Gedam Watershed is heavily dependent on and has a strong link to ecosystem products. Water, food, feed and wood were ranked as most important for the inhabitants' existence and development. However, there is shortage of food for human consumption and feed for livestock due to environmental degradation. Farmers of Tara Gedam Watershed predominantly grow cereal crops for subsistence farming. In Ethiopia, crop cultivation and grazing are the most popular practices in subsistence agriculture (Bantider et al., 2011). There are four main reasons for the dominance of subsistence crops. Firstly, the farming community in the watershed has much experience and tradition in crop production. Secondly, due to the prevalent food insecurity, there is a high demand for cereal crops as compared with other crops. Thirdly, priority is given to food security by the Government and agricultural extension promotion programmes are biased towards enhancing crop productivity compared with other agricultural activities. Fourthly, research and development institutions also focus on short rotation crops targeting local demand, i.e. annual crops, mainly cereal crops. This result is in line with Costanza et al. (1998) who stated that food production is the most important and dominant ecosystem product, specifically in developing countries. A limited number of farmers (landless farmers) are of the opinion that benefits from ESs available in the watershed make no difference to their livelihood. They stated that they are landless and their benefits depend on the willingness of farmers who have landholding right. This has an implication on the watershed management and sustainable use.

From the livelihoods point of view, there is a strong link between natural products and the communities' way of life. Despite the importance of ESs, the nexus of ecosystem and people in terms of management for sustainability is weak. Development actions and poverty reduction programs as implemented in the watershed do not pay explicit attention to and rather marginalize the integral concept of ESs in the watershed as a system unit. This diminishes the synergetic effects of the different aspects of ESs. Fragmented and inadequately integrated farming systems are practiced on nutrient-poor soil and less productive ecosystems. In general, gaps occur when attempting to put ESs concepts into practice (including the concepts in the decision-making processes) and to proactively find solutions in a holistic way (at the watershed level).

There are also interrelationships and competition between individual ESs. For example, conservation of the upland forests protects downstream areas from flood, erosion and leaching. Farmers and experts explained that the land allocated for crop production closer to and downstream from the protected forests is less liable to flood and, hence, produces better crop or higher grass yield than land farther from the forests. This indicates the synergy of forests with crop production. However, forest grazing and cropland uses compete with the protection and conservation potential of forests. Illegal collection of wood products by the farmers in state protected forest may have negative effects on conservation and microclimate improvement. Both cases show the tradeoff between food demand and forest conservation. Food production competes with feed production. This applies to farmers who own land neighboring to communal pastureland. Lands used as collective property (e.g. grazing lands) do not have clear boundaries, and farmers who own cropland closer to these lands push and expand their parcels without the approval of the community. Hence, gradually, the pasturelands are converted into food production farms. This increased the number of grazing animals per unit area beyond the carrying capacity of the land. It is also a cause of conflicts among community members.

Trees retained and/or planted on private land in traditional agroforestry practices or woodlots are used for wood production. In addition to wood products, forests have other ecological, economic and social benefits that may not be considered to have comparable value by all beneficiaries. For example, they are sources of medicinal plants and surface water, protect from flood, reduce soil erosion, absorb moisture, foster infiltration and ground water renewal. In addition to medicinal plants, twigs for cleaning teeth and walking sticks are obtained from forests. Farmers partially pointed out the importance of forests in mentioning the importance of harvesting medicinal plants. They described the general uses of each forest species. Members of the FGDs were not transparent in describing the species used for the remedy of the different diseases. Medicinal plants were described as “life-saving” products, obtained from the forests and shrublands for free. Some of the species used for medicinal value were *Bersama abyssinica* Fresen., *Hagenia abyssinica* Willd., *Croton macrostachyus* and *Vernonia amygdalina* Del. They are used to treat ascaris, tapeworm, skin disease and intestinal problems, respectively. The leaves of *Croton macrostachyus* treat fungal skin disease like ring-worm (Fichtl and Adi, 1994). *Clausena anisata* (Willd.) Hook.f. ex Benth., *Salix* spp. and *Olea europaea* subsp. *cuspidata* are sources of twigs used for cleaning teeth. Fichtl and Adi (1994) noted that the roots of *Clausena anisata* are also used against ascaris.

Monasteries and churches found in Tara Gedam Watershed are endowed with old, dense and diverse forest plant species (Zegeye et al., 2011) protected because of cultural and religious values. From local farmers' point of view, the existing EOTC-owned forests sufficiently provide for spiritual, religious and conservation demands. The priests, monks and church scholars explained that the rich forest plant diversity makes the church attractive, and forests host different wild animals, e.g. birds and wild mammals. Church forests are used and have a potential to provide spiritual satisfaction, to draw attention and to aid concentration during prayers. In line with this de Groot et al. (2002) indicated that ecosystems provide socio-cultural services, such as cultural, heritage and spiritual values. Wassie (2007) who studied church forests in Tara Gedam Watershed and similar areas found out that forests retained in the compounds of churches granted prestige for the site, spiritual fulfillment and relieved a stressed mind. Spiritual satisfaction has a role in decision making of daily life. Church owned forests are also used as shade for livestock and as the place for cemeteries. Farmers do not see environmental/regulatory services obtained from forests as priority demands. Hence, protection and conservation have lower importance to them.

Free grazing from the communal land is seen as a major source of feed in the study area. However, it negatively affects sustainability of the ecosystem. Benin and Pender (2002) also noted that community managed grazing lands are vital sources of feed and alleviate feed shortage temporarily. However, free access results in degradation of natural resources and has negative effect on soil and water conservation efforts. In his work on the "tragedy of the commons", Hardin (1968) argued that common property certainly caused overexploitation of resources only by targeting short-term benefit. For example, community-owned grassland faced accelerated degradation because of overstocking of livestock without proper management (Banks et al., 2003). In the highlands of northern Ethiopia, communal grazing lands are exposed to degradation (Benin and Pender 2002), or community managed resources are liable to deterioration if no shared norms and common interests for conservation exist (Agrawal and Gibson, 1999). Farmers explained that a lack of feed resources and mismanagement of communal grazing lands are the major bottlenecks for livestock productivity. These problems need to be resolved by introducing improved forage species that produce high biomass per unit area, improving the natural pastureland and limiting the number of animals to the carrying capacity of the land. Improved health care of cattle and the choice of breed should also be considered to improve livestock productivity.
The different interests result in different management strategies to sustain ecosystem productivity.

5.1.2 Implications of land administration/management on ecosystem services

The involved parties (private, communal, state and church) have different prime interests in the utilization of ESs. It is known that ecosystems are reflections of people's preference (Fisher et al., 2014) because they are the basis for social, economic and sustainable development (MEA, 2005). The difference in the way of administering or managing the ESs requires different management strategies to sustain ecosystem productivity. For example, farmers are more interested in water, food, feed and wood products, while the state gives priority to climate regulation, flood protection and biodiversity conservation. Churches set emphasis on the religious or spiritual services of their forests. Government-administered upstream areas, dominantly characterized by fragile and steep terrain, are allocated for flood protection as well as biodiversity and wildlife conservation. Terrain of similar types owned by farmers and used for crop production are less stable due to frequent tillage. This in turn leads to decreased agricultural sustainability and ecosystem products being less available, which in turn, forces farmers to depend on food/income aid. Because of this, 16-25% of the farmers in the watershed are registered under the 'safety net' programme where they earn cash for work to buy food. This program aims to provide recipient households sufficient income to meet their food gap and protect themselves against asset depletion. Communal lands show degradation and indications of marginalization because of mismanagement and a lack of protection, which, in turn, causes deterioration of ecosystem services.

Landless farmers (youth farmers) are provided with areas for bee and honey production in the forest. They have user rights over the product gained from the beehive. No activities other than bee colony and honey production are allowed for these farmers.

The efforts for improved livelihood strategies and management actions taken to enhance productivity of the area are unbalanced. Discrepancies between farmers' needs and ecosystem management exist. The current subsistence-oriented farming has few alternatives (less market-oriented production) and no diversified income source. Poor farmers experiencing low productivity per unit area are struggling to feed their families. Land under individual farmer use rights is intensively cultivated and kept permanently for food production with little focus on improved practices. This aggravates the decline of soil fertility, leads to a reduction of productivity, and contributes to low availability of food, feed and wood. However, the desire of the Government is not only food production, but also conservation, reclamation of degraded land and afforestation. Hence, the state is involved (since 2011) in a big move towards and in a campaign for natural resource conservation and management. Poorly managed traditional farming, massive livestock grazing on small units of land, intensive grazing in communal pasture, deforestation, soils erosion and poor land use planning threaten the ecosystem and lead to decline of productivity and production. This resulted in a vicious circle of decline of natural resources, increased food insecurity and, thereby, aggravated poverty (Figure 24).

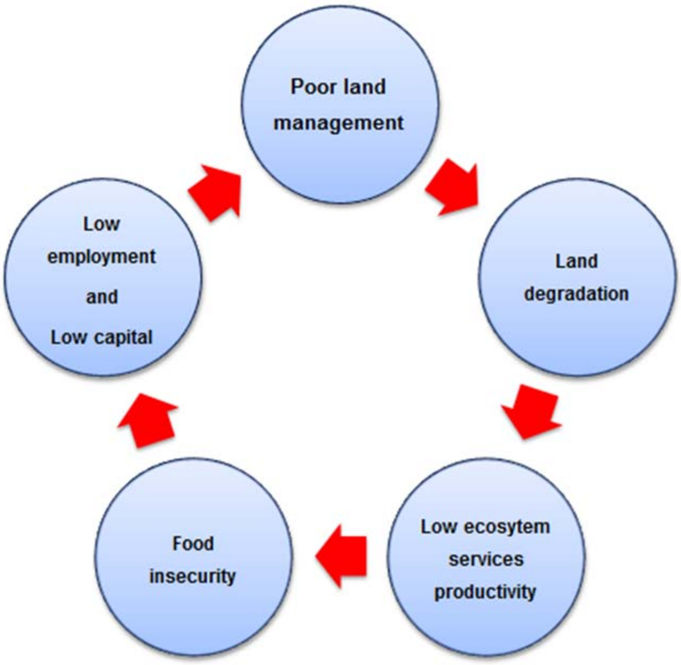


Figure 24. Vicious circle of natural resource degradation as well as declining productivity and ecosystem services.

The people residing in the watershed have lower incomes and there is a higher rate of unemployment. Hence, they have not been able to invest in agricultural technologies, which has resulted in poor land management activities. Increased demand of agricultural products because of population increase accompanied with poor land management has caused unsustainable land use management. This has resulted in land degradation and, thereby, low productivity. Lack of capital coupled with low productivity has caused the persistence of food insecurity and affected the economic growth negatively.

5.1.3 Influence of environmental variables

The spatial distribution of ecosystem benefits is partly determined by environmental gradients. ESs are ecological products influenced by biophysical and economic activities (de Groot et al., 2002). The variability in the production of food crops is caused to a high extent by environmental variables. For example, the difference in soil type determines the ecosystem products. Fertile and/or gentle slope areas are commonly allocated for cereal-dominated crop production used for subsistence. Feyisa (2012) showed that farmers' long-term experience regarding land quality determines the type of crop produced in a unit of farmland in the highlands of Tara Gedam Watershed. For example, Vertisols on flat lands are used for *Eragrostis tef* and Cambisols for *Zea mays* (Feyisa, 2012). The difference in the onset of the seasonal rainfall also determines the cover type and production system. Late onset of rainfall urges people to plant early maturing crops, for example teff and wheat. Moreover, more land is allocated for foraging (grazing and browsing) than it would have been the case during the normal rainfall onset season to resolve feed shortage. Farmers have a tradition of sowing sorghum and finger millet during dry conditions. Late rainfall onset causes seeds to desiccate and leads to less or no germination of these seeds. Consequently, the land is left fallow for pasture and producing forage for livestock.

Farmers' traditions and topographic features of the area are both limiting factors in the negative sense and regulating factors in the beneficial sense. Best practices of local knowledge (e.g. stone terraces) are beneficial to conserve soil. Stony and steep terrains in parts of the watershed are used for grazing, browsing, growing pulse crops and hay production. However, crop cultivation in steep terrains causes the soil to be washed away by runoff and results in rill and sheet erosion. Decline of soil fertility and lower moisture retention potential are the consequences.

EOTC-owned forests and state-protected forests are situated in the northwestern, northern, northeastern and eastern expositions in the southern part of the watershed. The allocation of forests in the respective exposition was not planned by the church in line with ecological requirements, but due to historic reasons. Eventhough no study was carried out in Tara Gedam regarding the relationship between aspect and vegetation, studies in other parts of the world showed that these topographic positions are good for vegetation growth because of less water loss compared with other expositions (Jin et al., 2008). The study of Wondie et al. (2012) in the Simen Mountains National Park (Ethiopia) also showed that different forest types occupy the northwestern and northern aspects and have better vegetation cover. However, the local farmers are not concerned about the significance of exposition (aspect) for land use allocation. Land requirement and availability are also governing factors for the type of ESs. Forests, shrublands and communal grazing lands are located in the steepest areas. The reason for this is that more fertile land is urgently needed for food production by food-insecure farmers.

5.1.4 Underutilized ecosystem services

In addition to forests, other upstream lands can be used as wildlife, biodiversity and fragile ecosystem conservation sites. Forests have the potential for bee forage due to the presence of diverse flowering plants that encourage honey and bee colony production. Apiculture can be used as a job opportunity for landless and young farmers. Youth in the area organized themselves in a group for honey and bee colony production in and around the forest in November 2012. A total of 17 beehives (16 traditional and one modern beehive) were brought together in one location (Figure 25). Training and subsidies were given from government and non-governmental organizations.

Figure 25. Traditional beehive for honey and bee colony production near the forest.

In 2013, the farmers produced, on average, 10 kg (ranging 7-12 kg) of honey per traditional beehive. Bee colonies were produced and sold to other farmers for 30 - 35 US dollar per colony. This experience can be promoted as an alternative strategy for livelihood diversification and as a source of income. In addition to job opportunities, apiculture has a protective function for the natural forest. One new group has already been established and introduced 12 beehives following the previous group. This can be replicated in or around the forests or rehabilitation projects of the highland and similar agro-ecological systems. Services, such as water quality, pollination and biodiversity conservation are obtained by ecosystems even though they are difficult to measure quantitatively (Butler et al., 2013). The existence of protected forests is important for pollinators like birds, bees and useful insects, which enhance the reproduction of plants and maximize seed production of vector-dependent plants, e.g. Niger seed (Dhurve, 2008).

Vacant land left between parcels of different land use and paths can be used for hedgerow intercropping. This is beneficial for soil and water conservation and improves soil fertility and moisture holding capacity. It can be used also for feed and fuelwood production by promoting agroforestry technologies. In the division of labor of the family, women are responsible for taking care of children, fetching water and collecting fuelwood. Using the vacant land for agroforestry helps to improve access to fuelwood for women so that their work burden can be reduced. Besides this, the presence of church forests and the variety of the landscape may be used to promote ecotourism development, mountain trekking and research for mountain development.

Continuous removal of riverine forests (there are almost no trees along the river), steep areas with no conservation measures, mismanagement of the upper catchment area and free grazing have led to a decline in the base flow of surface water. The water holding capacity of the soil is also affected because of the steepness of the landscape accompanied by low vegetation cover. There is high runoff and wastage of running water during peak rainfall season. Irrigation is seldom practiced because of surface water shortage during the dry season and a lack of agricultural water management technologies. Water should be harvested using surface (runoff) and roof (rainwater) water harvesting technologies. These measures help to improve water availability for drinking to ensure water security, to produce additional crops to subsidize food requirements or earn additional income. Such measures may also significantly contribute to the improvement of subsistence at the household level and the provision of environmental services at large. However, water harvesting may create favorable conditions for breeding of insects e.g. *Anopheles mosquitoes* that transmit Malaria. These potential health risks should be considered during planning of construction of water harvesting structures.

5.2 Land cover change and population growth

In the earlier time (1950th), forestland and grassland accounted for the largest share of the study area. There were low disturbances and dynamics of the landscape induced by human interference. However, the growing demand for agricultural products by the population over the past 56 years increased the share of cropland cover. On the other hand, forestland and (in recent years) shrubland declined. From the visual interpretation of the maps, cropland expansions initially were away from steep terrain and followed the flat land. Eventually, also steep terrain was used for crop production because of limitation of land and increase of population.

A distinct increase of cropland was observed between 1957 and 1986 and a cessation or even decline between 1986 and 1995. The annual increase between 1980 and 1986 was around 12%. This was probably because of free access to forests for shifting cultivation. Shifting cultivation and fallowing were common practices in previous times because of low population density and availability of sufficient land for fallowing (FAO, 1984). Individual households had the chance to get sufficient land for crop production. In the 1950s, the crop landholding was 2.6 ha per household. The production of major cereals was sufficient and a yield gap might be compensated by increasing the cultivable land. However, the current crop landholding size is as low as 1.1 ha per household, which is a decrease of 58% as compared to the 1950s. The increase of population and the decline of crop holding size resulted in a shortage of food and energy and puts pressure on natural resources. The land productivity (soil qualities) declined due to long-year crop cultivation (monocropping) accompanied by poor land management system.

Before the land redistribution law has been in effect (i.e. before 1997), there were no legally recognized institutions to prevent or regulate land conversion. Farmers expanded their cropland whenever needed as far as forestland and shrubland was available. Cropland and settlements (houses) were expanded without any restrictions. The predominant type of land cover conversion occurring from all other LCUTs was into cropland. This result is in line with the study by Zeleke and Hurni (2001) conducted in the highlands of Ethiopia in agricultural landscape focusing on mixed farming (crop production and livestock rearing), but it is contrary to the study of Wondie et al.(2011) conducted in the Simen Mountains National Park. The study of Wondie et al. (2011) revealed that forest and shrubland increased, whereas cropland and grassland declined over time. The comparison of these two studies shows that the locality and policy interventions by regional planning measures have an influence on the trend of landscape transformation.

The land transformations are strongly influenced by land reform measures as discussed in various land policy papers (Crewett and Korf, 2008; Baye, 2013; Teka et al., 2013). The fixed policy of the years between 1950 and 1980 gave priority to rural people. i.e. for agriculture, which caused the direction of landscape transformation into cropland. The policy acknowledged up to 10 ha of land per household for cropping (Holden and Yohannes, 2002). Then, the land redistribution of 1997 defined landholding rights for individual farmers, community government and church. This factor slowed down the conversion of LCUTs to cropland and caused the changes to approach a steady state. The oscillations of land uses at the later dates of analysis may partly be due to the effect that cropland and grassland replace each other depending on the onset of the rainfall. The area of cropland may decline temporarily due to fallowing to improve the soil fertility and to alleviate feed shortage.

The cumulative area of other land use types shows the trend in the direction opposite to cropland. The transition of forest to cropland deteriorates the quality of natural resources (e.g. it decreases soil fertility and facilitates soil erosion). Watershed degradation occurred systematically as exemplified by the development of rill, sheet or gully erosion near and in the croplands and grazing lands.

The trend analysis shows that forestland decreased from 51% in 1957 to 18% in 1995, followed by a modest increase to 25% in the year 2013.

Comparing the earlier dates to the later dates, the fuelwood demand increased proportional to population size. The ability of the natural forests to regenerate and the faster rate of wood demand were unbalanced. This brings about a deficit of wood and related products extracted from the forest. Hence, two factors for fuelwood deficit are perceived: increase of population and decline of forest cover.

The decline of forestland to the opposite of cropland does not mean that the demand for forest products was not high. Rather, the existing natural forests allowed the farmers to fulfil their local demand. Focusing on the products most urgently demanded, farmers were not concerned with tree planting or natural forest enrichment activities for forest development. Indicators for the conversion of natural forests into cropland are the existence of remnant naturally grown trees scattered on cropland. The increase of population with scanty forest development activities, eventually, resulted in shortage of forest related products. Hence, forest product demands were substituted by other resources. For example, cow dung and crop residues (mainly maize stalk) are used as energy source (cooking and heating). This in turn has negative consequences on the nutrient cycle of the system.

Forestland and grassland showed a slight increase in later years, for example between 2011 and 2013. This result seems inconsistent with the earlier trends of deforestation and decline of grassland. The following reasons have been identified for the increase of forestland and grassland at the later years: (a) The government protected and conserved forests for biodiversity and environmental reasons, while EOTC managed forests for cultural, spiritual and religious services. (b) Farmers planted trees to fulfil their household demand. (c) Farmers may convert their landholdings into pasture when there is high feed demand for their livestock. (d) Farmers fallowed their parcels at certain times to recondition soil fertility. (e) Farmers allocated their land for grass/hay production during late onset of rainfall.

The data on shrubland development are not too reliable due to the difficulty of differentiation from forestland and grassland, particularly also on black and white photographs. In recent years, shrublands were gradually transformed into grazing and browsing land due to the increase in the population of livestock. After 2001, shrubland was dominantly converted into cropland. Government- and church-administered shrublands were also converted into forestland, but community-managed shrublands were changed to grassland to fill the feed demand.

The first settlements were in and near the forestland. The increase in the number of houses was associated with the land resource availability and suitability for farming. Most of the houses are situated on flat land, close to rivers (water source), relatively suitable for cereal production and less prone to flood.

The average rate of change (increase) of houses was 4.8% per year in the Tara Gedam Watershed. The highest increase was observed between 1980 and 2001 with 7.6% per year. This could be due to free access of the land for occupation and due to resettlement programmes, bringing immigrants from resource-scarce parts of the region. The least rate was seen between 2001 and 2011, which was 2.5% per year. After the land redistribution had been carried out, the landless farmers migrated to other places to look for land for survival.

Due to the interaction of the population with the environment, the settlements can be seen as the primary influencing factor for landscape dynamics. This result is also in line with Zhang et al. (2014), and Ellis et al. (2006).

5.3 Crop productivity

There is no statistically significant difference in the mean grain yields among improved crop varieties. However, there may be differences revealed for the future due to changing environmental factors such as variations in rainfall, temperature and management. In that respect, a diversification of varieties may be a safeguarding strategy.

ANOVA showed that grain yield responses of teff and wheat can be explained by differences in effects of variety, toposequence and year. The effect of the interaction of explanatory variables such as variety with year and variety with toposequence had an influence on grain yield of both crops. Technology adoption and planning have to consider such factors. The new varieties coupled with improved management practices provide the highest grain yield to satisfy food demands. The increased production rate due to new management practices and varieties have to be maintained to ensure food security as soon as possible. In agreement with this study, Agegnehu et al. (2014) showed that combined use of inputs (fertilizer and improved seeds) and improved management practices can provide more yield compared with separate application of fertilizers. Besides, experimentation conducted in the highlands showed that teff grain yield can be doubled using improved varieties and application of fertilizers (Berhe, 2010). The grain production obtained from improved management can provide sufficient yield for the highlands if the right technology and management are introduced to the area. The increase in grain yield also helps to increase food supply at reasonable prices for the local market.

Teff or wheat yields better at higher altitudes than at lower altitudes of the watershed. This could be due to the cultivation of fields in lower elevations for a long time. Soil erosion and nutrient depletion may limit crop yield. The first year (2012) experimentation gave lower yield, whereas the second year (2013) showed increased yield. This could be contributed from differences in site characteristics, rainfall distribution and/or management activities. There was high rainfall in 2012. This caused high leaching of nutrients due to runoff, which may have had an effect on grain fill. In the second year (2013), it may also be due to progress of farmers' skill and ability to accomplish as per recommendation.

Such adaptation experiments provide open discussion in the field as a clue for development planning and projecting future scenarios. The information investigated can be combined with more detailed socioeconomic characteristics to search effective adaptation and development options. In addition, the analysis does not account for the weather patterns, soil variation and other factors. These factors definitely affect the grain yield, which in turn affects food availability. A further refinement would be needed by employing crop suitability analysis using detailed survey data to improve the impacts of management.

Farmers preferred Kuncho variety from teff because of its high grain yield. (Assefa et al., 2011) noted that Kuncho is attracting farmers and seed growers due to its yield and colour. Grain yield and colour of teff are producer- and consumer-preferred criteria and quality for selection. Eventhough Tay variety from wheat gave higher yield, Picaflore variety was also chosen for its earliness. Picaflore matured and was harvested 25-30 days earlier than other varieties. In the rainy season, the highland areas faced shortage of food at household level. This can be solved by early maturing varieties like Picaflore. Besides, an early maturing variety is more likely to escape early cessation of rainfall. It is relatively resistant to wheat disease as compared to others. On the other hand, Tay variety has good stand and has the longest straw, which can be used for roofing. The major use of wheat is to make bread for human consumption and as a source for income. With the existing yield advantage, the improved varieties together with improved management meet the needs of small landholder farmers. The performance of varieties can be maintained through proper use of research recommended packages such as improved management, fertilizer use and improved seed (Kruseman et al., 2006; Agegnehu et al., 2014).

5.4 Scenarios

The four scenarios described and modeled in the previous chapters start with the present situation of food (in)security and land degradation in a highland watershed. Based on predefined assumptions, rationales and targets, possible future developments are examined. The concept of ecosystem services is used. The causal human-environment interactions and the resulting landscape transformations and modifications are considered within the loop network of DPSIR. Using a combination of data sources and assumptions, pathways of each alternative are outlined to provide directions and to support the decision-making process. Proactive measures and strategic actions are designed and can be chosen depending on the availability of resources.

The scenarios result from combinations of the differently weighted factors of exploitation of land resources, management methods (including both ecological and technological measures), environmental protection, economic diversification, social considerations and political interventions.

5.4.1 Land cover changes

The scenarios differ in the degree and implications of land cover changes. Land use scenarios are affected by demand, supply and type of products such as food, wood and forage (Schröter, 2005). Expansion or shrinkage of a particular LCUT has a direct connection to the trend of ESs. ESs are the function of land characteristics, demand and land cover/use pattern practiced by the people in a specific area (Nelson et al., 2009).

In the BAU scenario, the urgently needed increase of agricultural production is attained solely by the expansion of crop area, which is connected with a related decrease of forest area. Continuing the present-day management practices, this necessarily has long-term negative effects. In the long run, food productivity and feed availability decline despite the increase of agricultural area.

The OPE scenario represents the contrary approach and development. By introducing new agricultural technology and by simultaneous intelligent observance of environmental aspects, an increase of production is achieved even with a concurrent decrease of cropland area. Marginal land is converted to productive land, mainly to agroforestry landuse, and forest area is increased.

TAG and INA scenarios lie in between. In the sequence BAU-TAG-INA-OPE, marginal land development changes from a strong increase to a strong decrease. The importance of agroforestry rises in this sequence.

5.4.2 Spatial and temporal changes of ecosystem services

The productivity and availability of ecosystem services are dependent on land use situation and demand of the people. Demand influenced the supply and type of products, such as food, wood and forage (Schröter, 2005). Forest clearance in BAU is for agriculture (food and feed) and wood production devoted for subsistence farming at household level. In the case of BAU, the crop dominated farming system continues. Even though there is increase of cropland, food productivity and feed availability declined for BAU scenario. This is due to low availability of improved technology, increasing of population and poor land management. In the case of TAG, the consequence of land management and improved technology is better but the production trend remain constant. This may not accommodate the demands of the growing population. However, INA and OPE scenarios showed less change on cropland area expansion but surplus production of food, feed and wood expected.

The fundamental difference in food production between BAU and INA scenarios is due to population growth and improved technologies. The demand for food and feed over time for BAU is higher than INA and OPE scenarios because of increased human and livestock population. Besides, the low access of technology increases the gap between supply and demand of the ESs. Hence, for BAU, the supply gap is becoming higher over time. The supply followed a decline trend.

The demands for agricultural and forestry products increased in the watershed. Hence, over the next few years people will increasingly be confronted with food, feed and wood shortage if the current situation (BAU) continues. However, INA and OPE are considered the best options among the scenarios to improve the ESs production. The estimated land productivity was smaller for BAU, particularly after 2023. In contrast, the INA and OPE showed higher productivity and emphasized both environmental conservation and subsistence production. The result of the storyline of BAU indicated that it is less likely to introduce improved technology, and there will be less access to an improved land management system. This contributes to the decline of yield below the present productivity. The productivity is negatively correlated with population trend. The growing demand may not be compensated with the current performance. Thus, the gap is substituted by government aid. The food insecurity will be aggravated within the time frame until 2040. However, INA and OPE are expected to improve the future productivity.

For the INA and OPE, the increase of food, feed and wood might be due to intensified technology and substitution of marginal land by forest, agroforestry and grassland. OPE attempts to change all abandoned land into production using rehabilitation, conservation and development techniques. However, INA may not allocate all abandoned land into forest or other land use to maximize ESs. Some parts of the overall marginal land may remain unchanged.

5.4.3 Land management including environmental protection

Cereal-based farming scenarios (BAU and TAG) focus on short-term benefits. Less productive mixed farming methods consisting in the integration of crop, livestock and trees are employed. The outcome of land management in BAU is soil fertility depletion and decline of productivity due to erosion, which is common in the highlands of Ethiopia. Such trends are characteristics of highlands and consistent with studies in Ethiopia and elsewhere in African highlands (Nyssen et al., 2000; Zeleke and Hurni, 2001; Hurni et al., 2005; Kagabo et al., 2013; Wickama et al., 2014). In contrast, the land management system in INA represents intensified and improved land management practices. There are many opportunities for improved land management (Bewket, 2007; Wickama et al., 2014) as it is assumed in INA and OPE. It uses improved seed, fertilizer, improved small scale irrigation and investment in soil water management. Production of market-oriented products is practiced to draw the attention of small landholding farmers towards improved land management. However, ecosystem degradation accompanied by poor management creates a barrier to achieve the desired targets. Therefore, environmental issues are observed after ensuring the availability of food for the people. Increasing agricultural productivity can therefore be seen as a prerequisite and a key for reducing natural resource degradation (Leadley et al., 2010).

Land management in the case of OPE follows the principle of "conservation and development". It targets ESs optimization by observing conservation and development simultaneously. It focuses on rehabilitation and reclamation of degraded environment back into production. Natural resources such as soil status, water storage, vegetation biomass and fauna are recovered through rehabilitation of degraded areas (Mekuria et al., 2007). Land management systems focus on soil fertility, water, biodiversity and microclimate improvement. Nowadays, conservation policies turn their faces towards market-oriented interventions by reconciling the conflict between conservation and rural livelihood (Roth and Dressler, 2012). The quality of land for farming improves through rehabilitation, reclamation, fallowing and construction of conservation measures. Community members share benefits (e.g. grass for feed and thatching houses) from enclosures. Off-farm activities such as honey bee farming are promoted. Ecotourism provides an additional incentive for resource management. It helps to secure livelihood in the watershed.

In INA and OPE, a highly increased production compensates for or provides sufficient time for fallowing. Diversification (Mutoko et al., 2014) such as agroforestry that includes fruit trees, nitrogen-fixing trees and multipurpose trees/shrubs in hillsides is implemented in these best case scenarios. Soil fertility management through use of composting, mulching and farmyard gardens are also options to enhance productivity. These soil management methods provide higher value and cash crops that improve livelihood. There is also the option to use manure produced from intensive livestock farming as a source of soil fertility. Up to now, such activities have not been practiced in large scale due to economic and technological reasons. Planting high-value perennial plants such as *Rhamnus prinoides* around homegardens may be also an effective income source. The conversion of degraded areas to forestland specifically to fruit and economically important shrubs e.g *Rhamnus prinoides* will impact farmers' livelihood and their ability to maintain productive agricultural lands and produce crops to supply foods. However, to close the degraded areas for rehabilitation, farmers require a substitution for what they obtained from the land. This may require incentives to substitute their consequent immediate demands. This should be taken into consideration to implement the best case development alternatives.

Participatory methodologies have been proven that they are effective to enable people to take part in the development process and facilitate integrated natural resource management (Amede et al., 2006). Both in INA and OPE, the decision of land holders is governed by a participatory planning, a land use plan, laws/regulations, expert advisory services and the availability of technology. In line with this, German et al. (2007) and Liu et al. (2008) pointed out the requirement of participation of the community and different stakeholders from planning to decision making in integrated watershed development. The development plan in INA and OPE answers the questions "Where and when to put the right input to enhance productivity" by incorporating both biophysical and social components in the planning processes. Hence, all the activities conducted in each parcel are subjected to a development plan based on farmers´ experience, indigenous knowledge, multi-stakeholder decisions and laws.

The success story of community forestry development in Nepal can be an example for a participatory process (Wagley and Ojha, 2002; Ojha et al., 2009). In Nepal, the participatory planning and decision-making process in community forestry development empowers the poor people in order to diversify and improve their livelihoods (Springate-Baginski et al., 2003; Ojha et al., 2009). In the highlands of North Ethiopia, Gebremedhin et al. (2004) indicated that collective action of the community in natural resource management, specifically in grazing land management, resulted in sustainable management due to the learning effect in participatory actions. In contrast, in BAU and TAG the individual land holders decide what to produce where, in absence of a participatory process. The general trend set by the population affects the decisions of allocation of land. However, TAG differs partly in the use of expert advisory service for the newly introduced technologies. For example, development agents provide training on the use of introduced technology as per the recommended package.

5.4.4 Socioeconomic and policy issues

An increase of the population implicates an increase of the consumption of food, energy and water. The demands for agricultural and forestry products in the watershed grow with the number of people. Ecosystem deliverables are dependent on space, time and consumer characteristics of users (Limburg et al., 2002; Hein et al., 2006).

The fundamental difference in food requirements between the different scenarios is due to different assumptions about population development. If there is both high population growth and weak management (such as in the BAU scenario), the land will be overexploited, and soil fertility will decline. Despite an expansion of the agricultural area, the number of food aid dependents will increase. There are policy changes to achieve the desired development goals. However, ecosystem degradation accompanied by poor management creates a barrier to achieve the desired targets (MEA, 2005) unless best case scenarios are taken into consideration. INA and OPE scenarios have slower population growth rate and may have a higher rate of adaptation as well as diffusion of technologies for improved livelihood. This may lead to income diversification, reduced unemployment and improved economy.

The best-case scenarios of INA and OPE may bring dynamic economic shifts not yet to be foreseen. Learning processes and adaptations may open up surprise development options. Developing specific strategies for quicker development may be possible better than expected in this study.

Access to markets is critical for the success of agricultural goods produced with improved management methods in INA and OPE. Livestock products such as meat, milk and fattening may generate income and create avenues for faster shift towards intensive production.

Income diversification and food security are possible in a short period. OPE gives priority both for environment protection and food security simultaneously. Biodiversity conservation and protection are promoted. The expansion of protected areas in OPE thus diversifies the benefits and income level of the landscape through ecotourism, non-timber forest products, education, promotion of cultural values and etc. Income diversification and risk tolerance are higher.

Perhaps the most difficult question to answer is how to analyse economic values of each scenario due to uncertainties of the market. The modeling of economic values of scenarios requires synthesizing multi-dimensional, complex and dynamic processes of economy and ecology. This study is restricted to the qualitative description of economic situations. Economic analyses in monetary terms with empirical and quantitative methods are beyond the scope of this study.

The best-case scenarios of INA and OPE require both human and capital investments to speed up development. These investments in turn require prospects of a sustainable development for economic justification. This lead to the integrated efforts of development measures by allies for long-term benefits. For example, vegetable production using irrigation in INA requires facilities for storage and market access.

The economic level of the current highland watershed, Tara Gedam, is low as compared with farming communities in other areas. The immediate food shortage problems have to be alleviated by government aid. However, strong policy interventions and managerial decisions are required for a long-term change of the situation.

5.4.5 Communicating scenarios

For the success of development, the choice of the best-case scenarios needs to be communicated with decision makers, technical experts and beneficiaries. Communication catalyzes the networking for shared interests and experiences (Olsson et al., 2006) especially in the case of watershed development where many parties are taking part. Communication is going to be arranged in the form of training, reports and visualizations. Illustration of the past, the present and the optimistic future of the ecosystem are displayed for choice by beneficiaries either in maps or charts. Communications for partnership and integration are needed to facilitate the start of best case scenarios to achieve justifiable development. Experiences in the northern part of Ethiopia showed that joint efforts of local communities, government and development partners are effective in reclamation of degraded areas and rehabilitation of environment (Mengistu et al., 2005; Descheemaeker et al., 2006; Mekuria et al., 2007; Asres, 2012). This showed that mutual understanding between parties hastens the success of development plans.

After the scenarios are developed and established, means of communication should be designed to have a common understanding for the public and to make a scenario true on the ground. The success of adaptive management is dependent on interaction, networking, leadership role and performance of institutions (Dietz et al., 2003; Olsson et al., 2006). Besides, the form of communication should comply with the type of audience and the message to be conveyed. For scientific communities and decision maker, it can be presented in the form of scientific papers and reports. However, for the less educated people living in Tara Gedam and for experts who have less access to different media, illustrative and descriptive communication methods about the scenario options are tp be chosen. For example, the development plan is to be prepared in the form of maps and precise illustrative guidelines and manuals.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The major focuses of the study were participatory assessment of ecosystem services, analyzing the dynamics of landscape transformation and human population development using remote sensing data, land management practices using improved technology and setting different ecosystem-service-based scenarios that can serve as development options to improve the living condition of the people of Tara Gedam Watershed.

The ecosystem services were categorized into three classes based on predominant tangible outputs and direct benefits in a highland watershed of Northwest Ethiopia. These were subsistence, religious-cultural and environmental services. The concepts and typology of ESs varied fundamentally, depending on the different points of views. From an anthropocentric point of view, one may emphasize the values for human beings (de Groot et al., 2002), one may put the focus on the interface between human demands and the ecosystem (Potschin and Haines-Young 2006) or one may emphasize ethical implications and uses (Jax et al., 2013). We learned from the discussions with inhabitants of the Tara Gedam Watershed that they initially saw the dominant role of ESs in fulfilling basic needs in the subsistence-oriented local economy. The economic values of ESs were well understood. There was however a certain lack of understanding regarding the intangible ESs such as nutrient cycling, pollination and carbon sequestration. This understanding varied depending on the individual interests, educational levels, and knowledge of government policies and global issues.

The analyses of remote sensing data provided comprehensive information on land cover change and population dynamics during the past 56 years (1957-2013). The analyses link change of land cover with human activity and population growth. The principal trends of land cover patterns show a decline in forestland/shrubland and a shift towards cropland. The study revealed that population growth is positively correlated with cropland expansion and is inversely related to forestland change. This is attributed to the increasing demand on agricultural products to feed the families in the households. The results showed a slowing-down of the dynamics of the landscape transformation in recent decades, which can be explained by a combination of limited availability of land, land use right, ownership, policy restrictions and land degradation.

A deterioration of the landscape and a decline of production per unit area were observed. This worsens food security and availability of agricultural products to feed the increased population. Up to 25% of the population in Tara Gedam Watershed depend on food aid in different years. Special efforts are needed to maximize the yield per unit area to fill the gaps between the existing food demand and the supply. This requires strategic, economic, social, environmental and policy decisions to attain food self-sufficiency. Proactive measures such as family planning and agriculture intensification are required to balance supply and demand. The limitation of land expansion for crop production can be compensated by using improved agricultural technologies (e.g. improved crop varieties) and management, as recommended by Kruseman et al., (2006) for the highlands of Ethiopia.

Participatory field experimentation with improved crop varieties (teff and wheat) and their management conducted during 2012 and 2013 resulted in 2-3 times grain yield as compared with the existing farm management. This increased productivity in turn offers sufficient time for fallowing, establishing exclosure as well as rehabilitation and restoration activities in the degraded areas. Based on this experience different development alternatives were designed in the form of scenarios using DPSIR framework.

As a methodological approach, DPSIR provides a roadmap for resource assessment (e.g. ecosystem services), designing proper land management (proactive measures) and far reaching outcomes (scenarios) contributing to the livelihoods of the people. The complex environmental structures and human actions were simplified and represented in a well elaborated way using the DPSIR framework. Three new scenarios were designed by considering ESs as a central theme in the decision making process, namely, Transition Agriculture (TAG), Intensified Agriculture (INA) and Optimized Ecosystem Services (OPE). The current farming system (Business as Usual, BAU) was incorporated for comparison purpose. The scenarios were simulated for 25 years starting from 2016 to 2040. Qualitative description of the storyline and quantitative analyses for numerical information and visualization were conducted for decision makers and the public. These scenarios addressed the ecosystem services-development-policy interface. All scenarios differ in population trend, land productivity, land cover composition, type of ecosystem services and way of management.

The new scenarios have their pathways regarding ESs to predict the effects of management that can help to uplift the people from food insecurity. The storyline is based on the changes in LCUTs that are to a high extent coupled with changes in ESs. The study presents a storyline of multi-scale (spatial and temporal) dynamics. This dynamics through the pathways may help to trace and visualize the far reaching development plan. Land cover/use simulations showed an overall increase of forest and agroforestry LCUTs in INA and OPE, whereas marginal land, cropland and population showed an overall decline. In the case of BAU, expansion of cropland, increase of population and further abandonment of land as marginal/wasteland is observed and the situation of food insecurity kept worsening. INA and OPE emphasize on family planning to slow down population growth rate. Substantial increase in productivity is projected in the INA and OPE scenarios. OPE shows an increase in rehabilitated land and optimized biomass production. In addition, OPE and INA require compliance of policy and/or legislations and require commitments of villagers and government for implementation. OPE emphasizes also participatory planning, development and implementation. INA is knowledge- and technology-intensive focusing on short rotation outcomes, whereas OPE is a scenario instrumental for the transformation of the current agricultural practices into approaches that focus on conservation and development. INA seems to be the most preferable option by farmers to ensure food security within a short time. With technology and capital investment OPE may be of the highest priority because it simultaneously focuses on environment improvement and economic growth. OPE emphasizes optimization, diversification and synergy among ESs. For example, climate change may shift crop suitability and growth conditions; however, best case scenarios provide resilience against such uncertainties because of diversification.

Decision makers in BAU have less option for choices of LCUTs and ESs. Cumulative effects of mismanagement of natural resources and degradation cause low access to food which may result in social instability. Through new scenarios (either in INA or OPE) decision makers will be assisted in identifying the best combination of LCUTs for optimum production. These options improve the livelihoods of small landholding farmers and can help to bring environmental and human problems under control within a short time span. A delay of application of best management options may aggravate deterioration and may further worsen food insecurity. TAG may be of interest as a bridge to shift from deteriorated natural resources and poor land management to improved landscape management, minimizing a development cultural shock caused by abrupt changes.

The scenarios showed the trade-offs and the synergies among LCUTs as well as ESs. For example, improvements in food, feed and wood production may come at the expense of biodiversity conservation and cultural services (trade off). Planting nitrogen fixing trees/shrubs improves soil fertility and food production simultaneously (synergy).

The application of DPSIR bridges the gap and provides a linkage between the drivers, the state of ecosystem services and the decision making process (responses). However, it was difficult to differentiate the concepts of DPSIR components, namely; pressure, state and impact. The description and structuring of their feedback and interrelationship depends on the perspective of the modeler. Hence, participatory methodological definitions of DPSIR components together with their elements are required prior to modelling.

Policy scenario and gender-segregated activities were not treated explicitly. They were implicitly addressed and can be incorporated during implementation of the selected scenario. Benefits, costs and risks were not described completely and were hard to predict because of uncertainty of the future market and the knowledge gap. Hence, further development approaches are required to estimate potential benefits in terms of costs (risks) to further provide fine-tuned decision making. Two key problems remain unsolved and require further exploration. The first is uncertainty of natural catastrophes, climate change and market. Second, administration of landscape management (commitments and budget allocation) is required to implement either of the new scenarios to transform the food-insecure community into a community with better living conditions.

6.2 Recommendations

The following recommendations are proposed for further development, conservation, management and policy actions of the Tara Gedam Watershed for the improvement of the livelihoods of the inhabitants:

- Availability and accessibility of improved agricultural technologies and improved land management practices are required to fulfill the current demand.
- Protection of the upstream watershed is required for the conservation and management of natural resources.
- Protection of forests, rehabilitation and restoration of the degraded lands need to be encouraged to improve the state of the watershed. This requires participatory planning and decision-making of the multi-stakeholders.
- Population growth and land degradation must be taken as top political and economic agendas to address the issues of environment. This requires proactive measures such as technology adaptation and agriculture intensification to balance the supply and demand.

- OPE and INA will result in positive impacts for improving the living condition of the people of Tara Gedam Watershed. Comparing the three alternative scenarios, OPE can help the policies to bring sustainable development. OPE can be adapted as the best case scenario for the highland watershed because it combines both conservation and development. It requires participation of multi-stakeholders, integration of multi-disciplines and higher human and capital investment. OPE also requires investments in research and development.
- INA can be a second-best option for the development of the watershed in order to meet short-term demands and improve food security.
- TAG may be the last option to be chosen as a rapid response of low-economy-communities in areas such as Tara Gedam Watershed.
- Through the new scenarios (either in INA or OPE) decision makers and resource managers will be assisted in identifying best combinations of LCUTs either for improved or even for optimum production of ESs compared with BAU.

7. REFERENCES

Abiyu, A. (2012). The role of seed dispersal, exclosures, nurse shrubs and trees around churches and farms for restoration of ecosystem diversity and productivity in the Ethiopian highlands. University of Natural Resources and Life Sciences, Vienna, Austria.

Agegnehu, G., van Beek, C. and Bird, M. I. (2014). Influence of integrated soil fertility management in wheat and tef productivity and soil chemical properties in the highland tropical environment. Journal of Soil Science and Plant Nutrition 14.

Agrawal, A. and Gibson, C. C. (1999). Enchantment and Disenchantment: The Role of Community in Natural Resource Conservation. World Development 27(4): 629–649. doi:10.1016/S0305-750X(98)00161-2

Ahmed, D. M., Sundaram, D. and Piramuthu, S. (2010). Knowledge-based scenario management — Process and support. Decision Support Systems 49(4): 507–520. doi:10.1016/j.dss.2010.06.004

Alcamo, J., Schaldach, R., Koch, J., Kölking, C., Lapola, D. and Priess, J. (2011). Evaluation of an integrated land use change model including a scenario analysis of land use change for continental Africa. Environmental Modelling and Software 26(8): 1017–1027. doi:10.1016/j.envsoft.2011.03.002

Amede, T., German, L., Rao, S., Opondo, C. and Stroud, A. (Eds.) (2006). Integrated Natural Resource Management in Practice: Enabling Communities to Improve Mountain Livelihoods and Landscapes. Proceedings of a conference held on October 12-15, 2004 at ICRAF Headquarters, Nairobi, Kenya. Kampala, Uganda: African Highlands Init. In Proceedings of the African Highlands Initiative Conference.

Asres, H. G. (2012). Effect of exxlosure on environment and its socioeconomic contributions to local people: In the case of Halla exclosure, Tigray, Ethiopia.

Assefa, K., Aliye, S., Belay, G., Metaferia, G., Tefera, H. and Sorrells, M. E. (2011). Quncho: the first popular tef variety in Ethiopia. International Journal of Agricultural Sustainability 9(1): 25–34. doi:10.3763/ijas.2010.0545

ATCOR (2013). User Manual ATCOR2 and ATCOR3: Haze Reduction, Atmospheric and Topographic Correction.

Bakker, M. M., Hatna, E., Kuhlman, T. and Mücher, C. A. (2011). Changing environmental characteristics of European cropland. Agricultural Systems 104(7): 522–532. doi:10.1016/j.agsy.2011.03.008

Banks, T., Richard, C., Ping, L. and Zhaoli, Y. (2003). Community-Based Grassland Management in Western China Rationale , Pilot Project Experience , and Policy

Implications Community-Based Grassland Management in Western China 23(2): 132–140.

Bantider, A., Hurni, H. and Zeleke, G. (2011). Responses of rural households to the impacts of population and land-use changes along the Eastern Escarpment of Wello, Ethiopia. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography 65(1): 42–53. doi:10.1080/00291951.2010.549954

Baye, T. G. (2013). Peasants , land reform and property right in Ethiopia : The experience of Gojjam Province 1974 to 1997 5(6): 145–156. doi:10.5897/JASD12.056

Benin, S. and Pender, J. (2002). Community Management of Grazing Lands and Impact on Environmental degradation in the Ethiopian Highlands. In International Association for the study common property conference, Victoria Falls, Zimbabwe.

Berhe, T. (2010). Increasing productivity of tef: New approaches with dramatic results. Crops productivity, Sasakawa Africa Association, Regional Office, Addis Ababa, Ethiopia.

Bewket, W. (2007). Soil and water conservation intervention with conventional technologies in northwestern highlands of Ethiopia: Acceptance and adoption by farmers. Land Use Policy 24(2): 404–416. doi:10.1016/j.landusepol.2006.05.004

BoFED, Amhara National Regional State Bureau of Finance and Economic Development (2011). ዜና: Report ot the Amhara National Regional State, bureau of finance and economic development office. Bahir, Dar. Unpublished.

Bryan, B. A., Crossman, N. D., King, D. and Meyer, W. S. (2011). Landscape futures analysis: Assessing the impacts of environmental targets under alternative spatial policy options and future scenarios. Environmental Modelling and Software 26(1): 83–91. doi:10.1016/j.envsoft.2010.03.034

Busch, G. (2006). Future European agricultural landscapes—What can we learn from existing quantitative land use scenario studies? Agriculture, Ecosystems and Environment 114(1): 121–140. doi:10.1016/j.agee.2005.11.007

Butler, J. R. A., Wong, G. Y., Metcalfe, D. J., Honzák, M., Pert, P. L., Rao, N., Griek, van Grieken, M.E., Lawson, T., Bruce, C., Kroon, F.J. and Brodie, J. E. (2013). An analysis of trade-offs between multiple ecosystem services and stakeholders linked to land use and water quality management in the Great Barrier Reef, Australia. Agriculture, Ecosystems and Environment 180: 176–191. doi:10.1016/j.agee.2011.08.017

Carr, E. R., Wingard, P. M., Yorty, S. C., Thompson, M. C., Jensen, N. K. and Roberson, J. (2007). Applying DPSIR to sustainable development. International Journal of Sustainable Development and World Ecology 14(6): 543–555. doi:10.1080/13504500709469753

Costanza, R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O´Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., and van den Belt, M.

(1998). The value of ecosystem services: putting the issues in perspective. Ecological Economics 25(1): 67–72. doi:10.1016/S0921-8009(98)00019-6

Crewett, W. and Korf, B. (2008). Ethiopia: Reforming Land Tenure. Review of African Political Economy 35(116): 203–220. doi:10.1080/03056240802193911

CSA (2013). Population Projection of Ethiopia for All Regions At Wereda Level from 2014 – 2017. Federal Democratic Republic of Ethiopia Central Statistical Agency, Addis Ababa, Ethiopia. http://www.csa.gov.et/images/general/news/pop_pro_wer_2014-2017_final accessed 0. Retrieved from www.csa.gov.et

Cumming, G. S., Alcamo, J., Sala, O., Swart, R., Bennett, E. M. and Zurek, M. (2005). Are Existing Global Scenarios Consistent with Ecological Feedbacks? Ecosystems 8(2): 143–152. doi:10.1007/s10021-004-0075-1

De Groot, R. S., Wilson, M. A and Boumans, R. M. . (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41(3): 393–408. doi:10.1016/S0921-8009(02)00089-7

Descheemaeker, K., Nyssen, J., Rossi, J., Poesen, J., Haile, M., Raes, D., Muys, B., Moeyersons, J and Deckers, S. (2006). Sediment deposition and pedogenesis in exclosures in the Tigray highlands, Ethiopia. Geoderma 132(3-4): 291–314. doi:10.1016/j.geoderma.2005.04.027

Dhurve, S. S. (2008). Impact of honey bee pollination on seed producton of Niger. Thesis submitted in partial fullfillment of the requirement of the degree of Master of Sceince in Entomology. The University of agricultural sciences, Dharwad, India.

Dietz, T., Ostrom, E. and Stern, P. C. (2003). The struggle to govern the commons. Science 1907(5652): 1907–12. doi:10.1126/science.1091015

Duinker, P. N. and Greig, L. A. (2007). Scenario analysis in environmental impact assessment: Improving explorations of the future. Environmental Impact Assessment Review, 27(3), 206–219. doi:10.1016/j.eiar.2006.11.001

EEA (2001). Environmental signals 2001: European Environment Agency regular indicator report. Retrieved from http://www.eea.eu.int

Egoh, B., Reyers, B., Rouget, M., Richardson, D. M., Le Maitre, D. C. and van Jaarsveld, A. S. (2008). Mapping ecosystem services for planning and management. Agriculture, Ecosystems and Environment 127(1-2): 135–140. doi:10.1016/j.agee.2008.03.013

Ellis, E. C., Wang, H., Xiao, H. S., Peng, K., Liu, X. P., Li, S. C., Ouyang, H., Cheng, X. and Yang, L. Z. (2006). Measuring long-term ecological changes in densely populated landscapes using current and historical high resolution imagery. Remote Sensing of Environment 100(4): 457–473. doi:10.1016/j.rse.2005.11.002

FAO (1984). Changes in shifting cultivation in Africa. FAO forestry paper 50. Forestry Department.

Feyisa, T. (2012). Field indicators of soil physical and chemical properties as an aid for the development of sustainable management strategies in northwest Ethiopia. University of Natural and Life Sciences, Vienna, Austria.

Fichtl, R. and Adi, A. (1994). Honeybee flora of Ethiopia. Margraf Verlag, Germany. ISBN 3-8236-1234-4.

Fisher, J. A., Patenaude, G., Giri, K., Lewis, K., Meir, P., Pinho, P.,Rounsevell, M.D.A. and Williams, M. (2014). Understanding the relationships between ecosystem services and poverty alleviation: A conceptual framework. Ecosystem Services 7: 34–45. doi:10.1016/j.ecoser.2013.08.002

Gebremedhin, B., Pender, J. and Tesfay, G. (2004). Collective action for grazing land management in crop–livestock mixed systems in the highlands of northern Ethiopia. Agricultural Systems 82(3): 273–290. doi:10.1016/j.agsy.2004.07.004

Geneletti, D. (2012). Integrating ecosystem services in land use planning: concepts and applications. CID Research fellow and graduate student working paper No. 54. Center for international development at Harvard University.

German, L., Mansoor, H., Alemu, G., Mazengia, W., Amede, T. and Stroud, a. (2007). Participatory integrated watershed management: Evolution of concepts and methods in an ecoregional program of the eastern African highlands. Agricultural Systems 94(2): 189–204. doi:10.1016/j.agsy.2006.08.008

Gregory, A. J., Atkins, J. P., Burdon, D. and Elliott, M. (2013). A problem structuring method for ecosystem-based management: The DPSIR modelling process. European Journal of Operational Research 227(3): 558–569. doi:10.1016/j.ejor.2012.11.020

Hardin, G. (1968). The Tragedy of the Commons. Science, New Series 162(3859): 1243–1248.

Hawando, T. (1997). Desertification in Ethiopian highlands. RALA Report, Norwegian Church Aid, Addis Ababa, Ethiopia.

Hein, L., van Koppen, K., de Groot, R. S. and van Ierland, E. C. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57(2): 209–228. doi:10.1016/j.ecolecon.2005.04.005

Hirschi, C., Widmer, A., Briner, S. and Huber, R. (2013). Combining Policy Network and Model-Based Scenario Analyses : An Assessment of Future Ecosystem Goods and Services in Swiss Mountain. Ecology and Society 18(2): 42. http://dx.doi.org/10.5751/ES-05480-180242

Holden, S. and Yohannes, H. (2002). Land Redistribution, Tenure Insecurity, and Intensity of Production: A Study of Farm Households in Southern Ethiopia. Land Economics 78(4): 573. doi:10.2307/3146854

Hou, Y., Zhou, S., Burkhard, B. and Müller, F. (2014). Socioeconomic influences on biodiversity, ecosystem services and human well-being: A quantitative application of the DPSIR model in Jiangsu, China. The Science of the Total Environment 490: 1012–28. doi:10.1016/j.scitotenv.2014.05.071

Hurni, H., Tato, K. and Zeleke, G. (2005). The Implications of Changes in Population , Land Use , and Land Management for Surface Runoff in the Upper Nile Basin Area of Ethiopia The Implications of Changes in Population , Land Use , and Land Management for Surface Runoff in the Upper Nile Basin. Mountain Research and Development 25(2): 147–154.

IPCC (2000). Summary for policymakers: IPCC special report emissions scenarios. A special report of IPCC working Group III. Published for the Intergovernmental Panel on Climate Change.

Jax, K., Barton, D. N., Chan, K. M. a., de Groot, R., Doyle, U., Eser, U.,Görg, C., GOmez_Baggethun, E., Griewald, Y., Haber, W. Haines, R., Heink, U., Jahn, T., Joosten, H., Kerschbaumer, L., Korn, H., Luck, G.W., Matzdorf, B., Muraca, B., Neßhöver, C., Norton, B., Ott, K., Potschin, M., Rauschmayer, F., von Haaren, C and Wichmann, S. (2013). Ecosystem services and ethics. Ecological Economics 93: 260–268. doi:10.1016/j.ecolecon.2013.06.008

Jin, X. M., Zhang, Y., Schaepman, M. E., Clevers, J. G. P. W., Su, Z., Clevers, J. and Schaepman, M. (2008). Impact of elevation and aspect on the spatial distribution of vegetation in the Gilian mountain area with remote sensing data. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVII (Part B7): 1385–1390.

Josephson, A.L., Jacob, R.G. and Florax, R. J. G. M. (2014). How does population density influence agricultural intensification and productivity? Evidence from Ethiopia. Food Policy. doi:10.1016/j.foodpol.2014.03.004

Kagabo, D. M., Stroosnijder, L., Visser, S. M. and Moore, D. (2013). Soil erosion, soil fertility and crop yield on slow-forming terraces in the highlands of Buberuka, Rwanda. Soil and Tillage Research 128: 23–29. doi:10.1016/j.still.2012.11.002

Khaiter, P. and Erechtchoukova, M. G. (2010). A Model-Based Quantitative Assessment of Ecosystem Services in the Scenarios of Environmental Management.

Kiptot, E., Franzel, S. and Degrande, A. (2014). Gender, agroforestry and food security in Africa. Current Opinion in Environmental Sustainability 6: 104–109. doi:10.1016/j.cosust.2013.10.019

Kiros, G., Haile, M., Gebresamuel, G. and Girmay, G. (2014). Assessing the Input and Output Flows and Nutrients Balance Analysis at Catchment Level in Northern Ethiopia. Journal of Soil Science and Environmental Management 5(1): 1–12. doi:10.5897/JSSEM13.0398

Kloos, H. and Adugna, A. (1989). The Ethiopian Population : Growth and Distribution, 155(1), 33–51.

Koniak, G., Noy-Meir, I. and Perevolotsky, A. (2010). Modelling dynamics of ecosystem services basket in Mediterranean landscapes: a tool for rational management. Landscape Ecology 26(1): 109–124. doi:10.1007/s10980-010-9540-8

Kristensen, P. (2004). The DPSIR Framework. Workshop on a comprehensive/detailed assessment of vulnerability of water resources to environmental change in Africa using river basin approach. UNEP Headquarters, Nariobi, Kenya.

Kruseman, G., Ruben, R. and Tesfay, G. (2006). Diversity and development domains in the Ethiopian highlands. Agricultural Systems 88(1): 75–91. doi:10.1016/j.agsy.2005.06.020

Leadley, P., Pereira, H.M., Alkemade, R., Fernandez-Manjarrés, J.F., Proença, V., Scharlemann, J.P.W. and Walpole, M. J. (2010). Biodiversity Scenarios: Projections of 21st Century Change in Biodiversity and Associated Ecosystem Services. Secretariat of the Convention on Biological Diversity. Technical Series publication no. 50. www.cbd.int (p. 132).

Limburg, K. E., O'Neill, R. V., Costanza, R. and Farber, S. (2002). Complex systems and valuation. Ecological Economics 41(3): 409–420. doi:10.1016/S0921-8009(02)00090-3

Lin, Y. P., Hong, N. M., Wu, P. J., Wu, C. F. and Verburg, P. H. (2007). Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in Northern Taiwan. Landscape and Urban Planning 80(1-2): 111–126. doi:10.1016/j.landurbplan.2006.06.007

Liu, B. M., Abebe, Y., McHugh, O. V., Collick, A. S., Gebrekidan, B. and Steenhuis, T. S. (2008). Overcoming limited information through participatory watershed management: Case study in Amhara, Ethiopia. Physics and Chemistry of the Earth, Parts A/B/C 33(1-2): 13–21. doi:10.1016/j.pce.2007.04.017

Mahmoud, M. I., Gupta, H. V. and Rajagopal, S. (2011). Scenario development for water resources planning and watershed management: Methodology and semi-arid region case study. Environmental Modelling & Software 26(7): 873–885. doi:10.1016/j.envsoft.2011.02.003

MEA, Millennium Ecosystem Assessment (2005). Summary for decision makers. In Ecosystems and Human Well-being: Synthesis, 1-24. Washington, D.C.: Island Press.

Mekuria, W., Veldkamp, E., Haile, M., Nyssen, J., Muys, B. and Gebrehiwot, K. (2007). Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. Journal of Arid Environments 69(2): 270–284. doi:10.1016/j.jaridenv.2006.10.009

Mengistu, T., Teketay, D., Hulten, H. and Yemshaw, Y. (2005). The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. Journal of Arid Environments 60(2): 259–281. doi:10.1016/j.jaridenv.2004.03.014

Minale, A. S. (2013). Population and environment interaction : the case of gilgel abbay catchment , northwestern Ethiopia. E3 Journal of Environmental Research and Management 4(1): 153–162. Retrieved from http://www.e3journals.org

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., van Vuuren, D. P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P. and Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment. Nature 463(7282): 747–56. doi:10.1038/nature08823

Murray, D. (2002). Mathematical Biology: I. An Introduction (Third Edit.). New York; London: Springer.

Mutoko, M. C., Hein, L. and Shisanya, C. A. (2014). Farm diversity, resource use efficiency and sustainable land management in the western highlands of Kenya. Journal of Rural Studies 36: 108–120. doi:10.1016/j.jrurstud.2014.07.006

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D. R., Chan, K.M., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H and Shaw, M. R. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7(1): 4–11. doi:10.1890/080023

Ojha, H., Persha, L. and Chhatre, A. (2009). Community Forestry in Nepal a policy innovation for local livelihoods. International Food Policy Research Institute (IFPRI), Consultative Group on International Agriculture Research (CGIAR). IFPRI Discussion paper 00913. Retrieved from www.ifpri.org/millionsfed

Olsson, P., Gunderson, L. H., Carpenter, S. R., Ryan, P., Lebel, L., Folke, C. and Holling, C. S. (2006). Shooting the Rapids : Navigating Transitions to Adaptive Governance of Social-Ecological Systems. Ecology and Society 11(1).

Pfister, F., Bader, H. P., Scheidegger, R. and Baccini, P. (2005). Dynamic modelling of resource management for farming systems. Agricultural Systems 86(1) 1–28. doi:10.1016/j.agsy.2004.08.001

Plummer, M. L. (2009). Assessing benefit transfer for the valuation of ecosystem services. Frontiers in Ecology and the Environment 7(1): 38–45. doi:10.1890/080091

Poppy, G. M., Chiotha, S., Eigenbrod, F., Harvey, C. A., Honzák, M., Hudson, M. D., Jarvis, A., Madise, N.J., Schreckenberg, K., Shackleton, C.M., Villa, F. and Dawson, T.P. (2014). Food security in a perfect storm : using the ecosystem services framework to increase understanding Food security in a perfect storm : using the ecosystem services framework to increase understanding.

Potschin, M. and Haines-Young, R. (2006). “Rio+10”, sustainability science and Landscape Ecology. Landscape and Urban Planning 75(3-4): 162–174. doi:10.1016/j.landurbplan.2005.03.005

Price, J., Silbernagel, J., Miller, N., Swaty, R., White, M. and Nixon, K. (2012). Eliciting expert knowledge to inform landscape modeling of conservation scenarios. Ecological Modelling 229: 76–87. doi:10.1016/j.ecolmodel.2011.09.010

Puyravaud, J.-P. (2003). Standardizing the calculation of the annual rate of deforestation. Forest Ecology and Management 177(1-3): 593–596. doi:10.1016/S0378-1127(02)00335-3

R (2014). R Archive Network. http://www.R-project.org.

Rodríguez, J. P., Beard, T. D., Bennett, E. M., Cumming, G. S., Cork, S. J., Agard, J., Dobson, A.P. and Peterson, G. D. (2006). Trade-offs across Space , Time , and Ecosystem Services. Ecology and Society 11(1): 28.

Roth, R. J. and Dressler, W. (2012). Market-oriented conservation governance: The particularities of place. Geoforum 43(3): 363–366. doi:10.1016/j.geoforum.2012.01.006

Rounsevell, M. D. A., Ewert, F., Reginster, I., Leemans, R. and Carter, T. R. (2005). Future scenarios of European agricultural land use. Agriculture, Ecosystems and Environment 107(2-3): 117–135. doi:10.1016/j.agee.2004.12.002

Rounsevell, M. D. A., Reginster, I., Araújo, M. B., Carter, T. R., Dendoncker, N., Ewert, F., House, J.I., Kankaanpää, S., Leemans, R., Metzger, M.J., Schmit, C., Smith, P. and Tuck, G. (2006). A coherent set of future land use change scenarios for Europe. Agriculture, Ecosystems and Environment 114(1): 57–68. doi:10.1016/j.agee.2005.11.027

Schröter, D. (2005). Vulenrability to changes in ecosystem services. CID graduate student postdoctoral fellow working paper No. 10. Cambridge, MA: Science, environment and development group, Center for International Development at Harvard University.

Shao, C., Tian, X., Guan, Y., Ju, M. and Xie, Q. (2013). Development and application of a new grey dynamic hierarchy analysis system (GDHAS) for evaluating urban ecological security. International Journal of Environmental Research and Public Health 10(5): 2084–108. doi:10.3390/ijerph10052084

Sileshi, G., Akinnifesi, F. K., Ajayi, O. C., Chakeredza, S. and Matakala, P. W. (2007). Contributions of agroforestry to ecosystem services in the miombo eco-region of eastern and southern Africa. African Journal of Environmental Science and Technology 1(4): 68–80.

Smith, D. A. (1977). Human population growth: stability or explosion? Mathematic Magazine 50:4.

Sohl, T. L., Sleeter, B. M., Sayler, K. L., Bouchard, M. a., Reker, R. R., Bennett, S. L., Sleeter, R.R., Kanengieter, R.L. and Zhu, Z. (2012). Spatially explicit land-use and land-cover scenarios for the Great Plains of the United States. Agriculture, Ecosystems & Environment 153: 1–15. doi:10.1016/j.agee.2012.02.019

Springate-Baginski, O., Prakash, O., Yadav, P. N. and Soussan, J. (2003). Community Forest Management in the Middle Hills of Nepal: The Changing Context. Journal of Forest and Livelihood 3(1): 5–20.

Swetnam, R. D., Fisher, B., Mbilinyi, B. P., Munishi, P. K. T., Willcock, S., Ricketts, T., Balmford, M.A., Burgess, N.D., Marshal, A.R. and Lewis, S. L. (2011). Mapping socio-economic scenarios of land cover change: a GIS method to enable ecosystem service modelling. Journal of Environmental Management 92(3): 563–74. doi:10.1016/j.jenvman.2010.09.007

Teka, K., Van Rompaey, A. and Poesen, J. (2013). Assessing the role of policies on land use change and agricultural development since 1960s in northern Ethiopia. Land Use Policy 30(1): 944–951. doi:10.1016/j.landusepol.2012.07.005

Wagley, M. and Ojha, H. (2002). Analyzing Participatory Trends in Nepal ' s Community Forestry. Ministry of Forests and Soil Conservation, Kathmandu, Nepal. Policy Trend Report (pp 122–142).

Wassie, A. (2007). Ethiopian Church Forests: Opportunities and challenges for restoration. PhD thesis, Wageningen University, Wageningen, The Netheralnds. ISBN: 978-90-8504-768-1.

Wickama, J., Okoba, B. and Sterk, G. (2014). Effectiveness of sustainable land management measures in West Usambara highlands, Tanzania. Catena 118: 91–102. doi:10.1016/j.catena.2014.01.013

Wondie, M., Schneider, W., Melesse, A. M. and Teketay, D. (2011). Spatial and Temporal Land Cover Changes in the Simen Mountains National Park, a World Heritage Site in Northwestern Ethiopia. Remote Sensing 3(12): 752–766. doi:10.3390/rs3040752

Wondie, M., Teketay, D., Melesse, A. M. and Schneider, W. (2012). Relationship between Topographic Variables and Land Cover in the Simen Mountains National Park , a World Heritage Site in Northern Ethiopia. International Journal of Remote Sensing Applications 2(2): 36–43.

Zegeye, H., Teketay, D. and Kelbessa, E. (2011). Diversity and regeneration status of woody species in Tara Gedam and Abebaye forests, northwestern Ethiopia. Journal of Forestry Research 22(3): 315–328.

Zeleke, G. and Hurni, H. (2001a). Implications of Land Use and Land Cover Dynamics for Mountain Resource Degradation in the Northwestern Ethiopian Highlands Implications of Land Use and Land Cover Dynamics for Mountain Resource Degradation in the Northwestern Ethiopian Highlands. Mountain Research and Development 21(2): 184–191.

Zhang, Z., Xiao, R., Shortridge, A. and Wu, J. (2014). Spatial point pattern analysis of human settlements and geographical associations in eastern coastal China - a case study. International Journal of Environmental Research and Public Health 11(3): 2818–33. doi:10.3390/ijerph110302818

Web pages

http://glovis.usgs.gov

http://www.mapmart.com

Appendix

Appendix 1. The number of population over years

Year	High	Average	Medium	Low
2014	1950	1942	1936	1924
2015	2013	1996	1984	1960
2016	2077	2052	2033	1996
2017	2144	2110	2084	2033
2018	2213	2169	2136	2071
2019	2285	2229	2189	2110
2020	2358	2292	2243	2149
2021	2434	2356	2299	2189
2022	2513	2422	2356	2229
2023	2593	2490	2414	2271
2024	2677	2559	2474	2313
2025	2763	2631	2536	2356
2026	2852	2705	2599	2400
2027	2944	2780	2663	2444
2028	3039	2858	2730	2490
2029	3137	2938	2797	2536
2030	3238	3020	2867	2583
2031	3342	3105	2938	2631
2032	3450	3192	3011	2680
2033	3561	3281	3086	2730
2034	3675	3373	3163	2780
2035	3794	3467	3241	2832
2036	3916	3564	3322	2884
2037	4042	3664	3404	2938
2038	4172	3767	3489	2993
2039	4307	3872	3575	3048
2040	4445	3981	3664	3105

Appendix 2. The area of LCUTs (ha) in each scenario

	The area of LCUTs (ha) in BAU						
Year	Crop	Forest	Grass	Shrub	Agroforestry	Underutilized	Road
2015	230.8	220.6	184.6	42.5	89.7	114.6	3.6
2016	233.7	219.5	181.8	42.5	89.7	115.5	3.6
2017	236.7	218.4	179.1	42.5	89.7	116.4	3.6
2018	239.5	217.3	176.4	42.5	89.7	117.3	3.6
2019	242.4	216.2	173.8	42.5	89.7	118.2	3.6
2020	245.2	215.1	171.2	42.5	89.7	119.1	3.6
2021	248.0	214.1	168.6	42.5	89.7	119.9	3.6
2022	250.8	213.0	166.1	42.5	89.7	120.8	3.6
2023	253.5	211.9	163.6	42.5	89.7	121.6	3.6
2024	256.2	210.9	161.1	42.5	89.7	122.4	3.6
2025	258.8	209.8	158.7	42.5	89.7	123.2	3.6
2026	261.5	208.8	158.5	40.4	88.8	124.9	3.6
2027	264.1	207.7	158.1	38.4	87.9	126.6	3.6
2028	266.7	206.7	157.6	36.4	87.0	128.3	3.6
2029	269.3	205.6	157.1	34.6	86.2	129.9	3.6
2030	271.9	204.6	156.5	32.9	85.3	131.6	3.6
2031	274.5	203.6	155.8	31.2	84.5	133.2	3.6
2032	277.1	202.6	155.0	29.7	83.6	134.8	3.6
2033	279.7	201.6	154.2	28.2	82.8	136.4	3.6
2034	282.2	200.6	153.3	26.8	81.9	138.0	3.6
2035	284.8	199.6	152.3	25.4	81.1	139.6	3.6
2036	285.9	193.6	146.2	25.2	80.3	151.6	3.6
2037	286.9	187.8	140.4	24.9	79.5	163.3	3.6
2038	287.8	182.1	134.7	24.7	78.7	174.7	3.6
2039	288.6	176.7	129.3	24.4	77.9	185.9	3.6
2040	289.2	171.4	124.2	24.2	77.1	196.7	3.6

	The area of LCUTs (ha) in INA						
Year	Crop	Forest	Grass	Shrub	Agroforestry	Underutilized	Road
2015	230.8	220.6	184.6	42.5	89.7	114.6	3.6
2016	233.7	219.5	182.8	43.1	95.4	108.3	3.6
2017	236.7	218.4	180.9	43.6	100.8	102.3	3.6
2018	239.6	217.3	179.1	44.1	106.0	96.7	3.6
2019	242.5	216.2	177.3	44.6	110.8	91.4	3.6
2020	245.3	215.1	175.6	45.1	115.4	86.4	3.6
2021	245.3	215.4	175.7	45.7	117.1	83.6	3.6
2022	245.3	215.6	175.9	46.3	118.8	80.9	3.6
2023	245.3	215.8	176.1	46.9	120.4	78.3	3.6
2024	245.3	216.1	176.2	47.4	122.0	75.8	3.6
2025	245.3	216.3	176.4	48.0	123.5	73.4	3.6
2026	245.3	216.5	176.5	48.5	124.9	71.1	3.6
2027	245.3	216.8	176.7	48.9	126.4	68.8	3.6
2028	245.3	217.0	176.8	49.4	127.7	66.6	3.6
2029	245.3	217.3	176.9	49.8	129.1	64.4	3.6
2030	245.3	217.5	177.1	50.2	130.4	62.4	3.6
2031	244.1	218.8	177.7	50.8	132.2	59.2	3.6
2032	242.9	220.0	178.3	51.4	134.0	56.3	3.6
2033	241.6	221.1	178.8	52.0	135.7	53.6	3.6
2034	240.4	222.2	179.4	52.5	137.3	51.0	3.6
2035	239.2	223.2	179.9	53.0	138.8	48.7	3.6
2036	238.0	224.1	180.4	53.5	140.3	46.5	3.6
2037	236.8	225.1	180.8	54.0	141.7	44.4	3.6
2038	235.7	226.0	181.3	54.4	143.0	42.5	3.6
2039	234.5	226.8	181.7	54.8	144.3	40.7	3.6
2040	233.3	227.6	182.1	55.2	145.5	39.0	3.6

	The area of LCUTs (ha) in TAG						
Year	Crop	Forest	Grass	Shrub	Agroforestry	Underutilized	Road
2015	230.8	220.6	184.6	42.5	89.7	114.6	3.6
2016	233.7	219.5	182.8	43.6	92.0	111.2	3.6
2017	236.7	218.4	180.9	44.8	94.2	107.8	3.6
2018	239.6	217.3	179.1	45.8	96.4	104.6	3.6
2019	242.5	216.2	177.3	46.9	98.5	101.5	3.6
2020	245.3	215.1	175.6	47.9	100.5	98.4	3.6
2021	248.1	214.1	173.8	48.9	102.5	95.5	3.6
2022	250.9	213.0	172.1	49.8	104.4	92.6	3.6
2023	253.7	211.9	170.3	50.8	106.2	89.8	3.6
2024	256.5	210.9	168.6	51.7	108.0	87.1	3.6
2025	259.2	209.8	166.9	52.5	109.8	84.5	3.6
2026	261.7	208.0	165.3	52.3	111.5	84.1	3.6
2027	264.1	206.2	163.6	52.0	113.1	83.7	3.6
2028	266.5	204.4	162.0	51.7	114.8	83.4	3.6
2029	268.8	202.6	160.4	51.5	116.5	83.1	3.6
2030	271.1	200.8	158.8	51.2	118.1	82.7	3.6
2031	273.4	199.1	157.2	51.0	119.8	82.4	3.6
2032	275.6	197.3	155.6	50.7	121.4	82.2	3.6
2033	277.7	195.6	154.1	50.5	123.1	81.9	3.6
2034	279.8	193.9	152.5	50.2	124.7	81.6	3.6
2035	281.9	192.2	151.0	50.0	126.4	81.4	3.6
2036	283.9	190.5	149.5	49.7	128.0	81.2	3.6
2037	285.9	188.9	148.0	49.5	129.6	81.0	3.6
2038	287.8	187.2	146.5	49.2	131.2	80.8	3.6
2039	289.7	185.6	145.0	49.0	132.8	80.6	3.6
2040	291.6	184.0	143.6	48.7	134.5	80.5	3.6

	The area of LCUTs (ha) in OPE						
Year	Crop	Forest	Grass	Shrub	Agroforestry	Underutilized	Road
2015	230.8	220.6	184.6	42.5	89.7	114.6	3.6
2016	233.7	219.5	182.8	43.6	95.4	107.7	3.6
2017	236.7	218.4	180.9	44.7	100.8	101.3	3.6
2018	239.6	217.3	179.1	45.7	105.9	95.2	3.6
2019	242.5	216.2	177.3	46.7	110.6	89.5	3.6
2020	245.3	215.1	175.6	47.6	115.1	84.1	3.6
2021	245.3	215.1	176.4	48.0	117.6	80.3	3.6
2022	245.3	215.1	177.2	48.4	120.0	76.7	3.6
2023	245.3	215.1	178.0	48.8	122.3	73.3	3.6
2024	245.3	215.1	178.7	49.2	124.5	70.0	3.6
2025	245.3	215.1	179.4	49.5	126.6	66.8	3.6
2026	242.9	217.6	180.4	49.7	127.5	64.8	3.6
2027	240.4	220.0	181.3	49.8	128.4	62.9	3.6
2028	238.0	222.4	182.3	50.0	129.2	61.0	3.6
2029	235.6	224.8	183.2	50.1	129.9	59.1	3.6
2030	233.3	227.2	184.2	50.2	130.6	57.4	3.6
2031	231.0	229.6	185.1	50.2	131.8	55.1	3.6
2032	228.6	231.9	186.1	50.3	133.0	52.9	3.6
2033	226.4	234.3	187.0	50.3	134.1	50.8	3.6
2034	224.1	236.7	187.9	50.3	135.1	48.7	3.6
2035	221.9	239.0	188.8	50.3	136.0	46.8	3.6
2036	217.4	241.8	195.1	50.3	144.3	33.9	3.6
2037	213.1	244.4	199.9	50.1	150.7	24.6	3.6
2038	208.8	246.9	203.6	49.8	155.8	17.8	3.6
2039	204.6	249.3	206.5	49.5	159.9	12.9	3.6
2040	200.5	251.7	208.9	49.2	163.2	9.4	3.6

Appendix 3. Production (quintal ha^{-1}) and production surplus (quintal ha^{-1}) based on wheat equivalent

Year	BAU		TAG		INA		OPE	
	Production	Production surplus	Production	Production surplus	Production	Production surplus	Production	Production surplus
2016	4086	-4370	4086	-4266	4343	-3933	4367	-3757
2017	4067	-4661	4187	-4398	4728	-3753	4781	-3495
2018	4107	-4901	4290	-4536	5141	-3551	5228	-3202
2019	4147	-5152	4393	-4680	5585	-3323	5710	-2876
2020	4187	-5412	4497	-4831	6061	-3068	6231	-2514
2021	4226	-5682	4601	-4987	6483	-2873	6712	-2196
2022	4264	-5962	4707	-5150	6933	-2656	7228	-1845
2023	4302	-6253	4813	-5320	7413	-2414	7782	-1460
2024	4340	-6555	4920	-5496	7925	-2145	8377	-1037
2025	4377	-6869	5027	-5680	8473	-1848	9015	-573
2026	4407	-7202	5132	-5875	9057	-1520	9831	64
2027	4436	-7546	5238	-6078	9680	-1160	10719	771
2028	4465	-7903	5344	-6288	10346	-764	11687	1555
2029	4495	-8272	5451	-6507	11056	-329	12743	2422
2030	4524	-8654	5559	-6734	11814	146	13893	3380
2031	4553	-9049	5667	-6969	12589	632	15162	4454
2032	4582	-9458	5777	-7213	13414	1159	16546	5640
2033	4611	-9882	5887	-7467	14290	1731	18055	6946
2034	4639	-10320	5998	-7729	15222	2351	19700	8384
2035	4668	-10773	6110	-8002	16212	3021	21492	9966
2036	4677	-11261	6223	-8284	17265	3746	23616	11876
2037	4685	-11767	6337	-8576	18385	4530	25865	13907
2038	4690	-12291	6452	-8879	19575	5376	28260	16080
2039	4694	-12833	6567	-9193	20840	6288	30823	18417
2040	4697	-13395	6683	-9517	22185	7272	33576	20939

Abbreviations

ANRS	Amhara National Regional State
ATCOR	Atmospheric and Topographic Correction software
BAU	Business as usual
BoFED	Bureau of Finance and Economic Development
B/W	Black and white
CSA	Ethiopian Central Statistics Agency
DPSIR	Driver-Pressure-State-Impact-Response
DTM	Digitial Terrain Model
EEA	European Environment Agency
EMA	Ethiopian Map Authority
EOTC	Ethiopian Orthodox Tewahedo Church
ES	Ecosystem service
FGD	Focus group discussion
GCP	Ground Control Point
INA	Intensive agriculture
LCUT	Land cover/use type
LPS	Leica Photogrammetry Suit
MEA	Millennium Ecosystem Assessment
OPE	Optimized ecosystem services
TAG	Transition agriculture

Curriculum vitae

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