Potentials and limitations of Jatropha curcas as a multipurpose crop for sustainable energy supply and soil and water conservation:

a case study in Bati, Ethiopia, using the WOCAT approach

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Executive Summary

Energy is a crucial factor for development. Without sufficient access to energy, the development of the agricultural sector for example is hindered. In Ethiopia, a country dominated by the agricultural sector, a big part of the total energy consumption is still covered by traditional energy forms. Transportation is often done by animals such as donkeys or camels whereas oxen are used for plowing. Cooking is dominated by traditional fuels such as wood or charcoal. The dependency on these traditional fuels in combination with a high population density puts the environment under great pressure - also in the research area near Bati.

Bati is located on the east side of the Ethiopian highland at 1560 m a.s.l. on the edge to the Afar lowlands. The average rainfall in Bati is around 900 mm per year. The area is characterized by hilly topography and bush-, shrub- and degraded grassland used for the extensive grazing of animals and cultivated land wherever farmers need it to grow their crops. Overgrazing put the environment in the area under pressure and therefore soil erosion is a widely spread form of land degradation.

Soil erosion is a major problem worldwide, endangering the livelihood of nearly one billion people. In Ethiopia, around 90% of the population lives in degraded areas where agricultural productivity is reduced. In the 1970s the Ethiopian government supported by international organizations started a nation wide campaign to combat soil erosion by treating degraded land with different technologies. In the research area near Bati, stone walls are the dominant soil and water conservation technology.

However, in recent times the plant Jatropha is increasingly used not only as a hedge or living fence but also as a soil and water conservation technology in Ethiopia. Jatropha is a larger shrub that grows fruits with oil containing seeds. Since energy as well as soil conservation are important development issues in Ethiopia, finding approaches that address both at the same time is of particular interest. The goal of this thesis is therefore to assess the potentials and limitations of Jatropha as energy source and soil conservation measure in the region of Bati in Ethiopia. In order to fulfill this goal, two different watersheds are chosen, Tullu Iyensa watershed with a large active gully and some stone wall technologies, and Dodota watershed

with large parts of inactive or rehabilitated gullies, with a lot of stone walls but also with some Jatropha hedge technologies.

A comparative study using field mapping and vertical profiles of both watersheds shows that the different soil and water conservation technologies applied in the region are helping to trap alluvial soil an therefore to reduce rill erosion. The vertical profiles of each watershed also show that farmers treated all the steeper slopes first; furthermore the large active gully can be found in gentler slopes where no technologies are implemented at the moment.

Jatropha hedges are a potential conservation technology in early stages of erosion as a mitigation measure or even as a prevention measure before erosion starts since Jatropha hedges are implemented in a short time and with very little work input. Jatropha cuttings simply have to be put into the soil and the spacing between each cutting has to be filled with litter. As soon as the plant has rooted it is flexible enough to even sustain heavy runoff. Since Jatropha can prevent or mitigate rills or gullies up to a maximum of one meter depth it is recommended to use stone walls for deeper gully rehabilitation although more work and time is needed to create them.

Besides its main purpose of acting as a living fence there are several local uses of Jatropha in Bati: For example the leaves can be crushed to a medicinal paste to treat animal wounds. The oily paste of smashed seeds can be used for smoothing the clay plate for Injera baking. However, no real market for Jatropha seeds exists in Bati at the moment. In addition, farmers are pruning the Jatropha hedges every year to prevent water and light competition with their crops. This is hindering high Jatropha seed yields. Since Bati is already connected to the national power grid it remains questionable if decentralized energy production with Jatropha oil for use by an adapted diesel generator even makes sense in the town. This type of energy production may better be done in remote, larger villages without access to the power grid. But since technology and knowledge is needed, it can not be done without additional support from outside.

Since power generation with Jatropha oil remains questionable in the Bati area, using Jatropha and its products on smaller scale is recommended. Stoves fired with crushed Jatropha seeds or lamps lit with Jatropha oil already exist. These technologies could be introduced to local craftsmen and after some time be locally produced in Bati. However, due to widespread poverty, investment costs for these technologies might be out of reach for the local population. If for once such technologies are adopted by the population, growing Jatropha may become more attractive for farmers as well. To sustainably produce Jatropha seeds farmers do not have to replace their crops or implement large scale Jatropha plantations. There is enough space to increase production by increasing Jatropha as a living fence, a hedge or as a soil and water conservation technology in the area on degraded land.

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List of abbreviations

BIA	Bioenergy In Africa
BWARDO	Bati Wereda Administration and Rural Development Office
C (°C)	Degree Celsius
CDE	Center for Development and Environment, University of Bern, Switzerland
CHF	Canadian Hunger Foundation
CIA	Central Intelligence Agency
cm	centimeters
CO_2	Carbondioxide
CSA	Central Statistical Agency of Ethiopia
DBGL	Degraded bushy grazing land
DPSIR	Drivers, Pressures, State, Impact and Response
E	East
e.g.	for example (Latin: exempli gratia)
EEA	European Environment Agency
EEPCo	Ethiopian Electric Power Corporation
et al.	and others (Latin: et alii)
etc.	and so on (Latin: et cetera)
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GJ	Gigajoules
GLASOD	Global Assessment of Human-induced Soil Degradation
GPS	Global Positioning System
ha	hectare
IEA	International Energy Agency
KM:Land	knowledge from the land
km^2	square kilometer
kWh	kilowatt hour
L. (Jatropha Curcas L.)	Botanic citation for Carl Linnaeus
LCA	Life Cycle Assessment
m	meters
m a.s.l.	meters above sea level
m^3	cubic meters
MA	Millennium Ecosystem Assessment
mm	millimeters
N	North
NGO	Non-Governmental Organization
ORDA	Organization for Rehabilitation and Development in Amhara
p.a.	per year (Latin: per annum)
QA	Questionnaires on SLM Approaches
QT	Questionnaires on SLM Technologies
RECIPES	Renewable Energy in developing countries: Current situation, market Potential and recommendations for a win-win-win for EU industry, the Environment and local Socio-economic development
SLM	Sustainable Land Management
SVO	Straight Vegetable Oil
SWC	Soil and Water Conservation
tWh	terawatt hour
UN	United Nations
UNDP	United Nations Development Programme
WBGU	German Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen
WCED	World Commission on Environment and Development
WOCAT	World Overview of Conservation Approaches and Technologies

Preface and acknowledgment

Almost as long as I can remember, ongoing discussions on energy, its production, its savings, its waste and new or sustainable forms of its production are discussed in the media. I was particularly interested in the alternative forms of energy production (wind or solar) since I realized that fossil fuels are not available forever. During my teenage-hood many types of biofuels were discussed in the media and sometimes praised as the ultimate solution to satisfy global energy demand. But after some time all of these solutions also showed their negative and even sometimes unsustainable sides.

During my time at the Institute of Geography at the University of Bern I also developed interest in the problem of soil degradation, which is not as popular in the media as energy questions but equally important. I realized that soil is a key resource for humanity. I concluded that without motorized energy mankind should be able to survive . But without soils to grow food no human life would be possible.

To combine the topics of energy and soil and sustainability in a master thesis quickly caught my attention. A lot of people supported and helped me during the process of achieving this thesis. Special thanks therefore go to:

Habtamu Ayele who organized my field work and supported me wherever he could during the whole time in Ethiopia. Wondimeneh Asefa, the local Agricultural Officer, who helped us a lot in the field with his knowledge and his network of contacts. The Agricultural Office in Bati for letting us work in the area and sharing their knowledge and contacts with us. The local branch of ORDA for letting us use their motorcycle from time to time and taking me on one of their trips in the Bati area. Yehaya Shehyimam, a watershed leader, for showing us his watershed and sharing his lunch with us. Abdu Ahmed, Adam Mohammed, Hussein Abdu and Said Mohammed for sharing their knowledge on soil and water conservation technologies with us. The Vasco Tourist Hotel in Bati with Mohammed, Awel and Assis for their hospitality. Albrecht Ehrensperger and Hanspeter Liniger for their support from the beginning to the end of this thesis.

1. Background

With sustainability in mind, this thesis brings together the topics of soil conservation and bio-energy with a special focus on the plant Jatropha as a source for biofuel as well as a plant for soil conservation. Since energy is a crucial factor for the development of a country and soil erosion is a big problem for a lot of farmers worldwide there might be potential for this plant to contribute to a solution of both.

This thesis is written at the CDE (Center for Development and Environment) at the University of Bern. The CDE is coordinating the Bioenergy in Africa (BIA) project, the goal of which it is to develop a knowledge base on biofuels (focusing on Jatropha) which governments, development agencies and other stakeholders can use as a reference (BIA 2011).

The BIA project aims to identify opportunities and risks of Jatropha in Eastern Africa to verify claims of its high potential for marginal lands. The production of Jatropha increased during recent times in Eastern Africa which made it necessary to take an in-depth view on its environmental, economic and social impacts. Therefore the BIA wants to develop decision support tools for a sustainable energy production in East Africa (BIA 2011). By taking a combined look at Jatropha's potential as a soil conservation measure and as an energy crop, this thesis is contributing to these decision support tools for a sustainable energy production in East Africa.

1.1. Energy as a crucial factor for development

Access to sufficient and affordable energy is a crucial condition for development. In developed countries a major part of energy consumption is covered by energy sources such as crude oil, natural gas and coal. Per capita energy consumption per year including industries and transportation in Germany for example was at 32.8 GJ (gigajoules; 1 GJ ≃ 23 l of diesel oil) in 1989 compared to Ethiopia at 0.1 GJ. Traditional energy consumption (e.g. fuel wood, charcoal, dung, field residues) remain dominant in developing countries. Per capita traditional energy consumption in Africa in the year 1993 was 6.9 GJ while in Europe it was only 0.8 GJ.

In rural areas of developing countries up to 100% of energy consumption is covered by traditional energy (Mayer-Leixner 1999).

Due to the dominance of the traditional energy systems in developing countries and lacking access to global energy markets together with unsustainable land management and agriculture there is a big pressure on the environment. It can be seen in loss of flora and fauna and loss of soil fertility due to erosion or nutrition depletion (since field residues or manure are used as an energy supply) (Mayer-Leixner 1999). Creating decentralized access to biofuels that are not necessarily linked to the global energy markets could be a possible solution for developing countries to overcome global dependencies (Asselbergs et al. 2006).

Both, fossil fuels and biofuels have in common that the energy they contain originates from stored solar energy. Unlike fossil fuels, biofuels are renewable, since they are grown and used today and can therefore be considered CO_2 neutral (Asselbergs et al. 2006). In recent years the importance of biofuels has increased rapidly because one is not sure how long fossil fuel sources may endure. One possible thread from biofuels is that they might compete with food production. Biofuels are not yet a big player in the global energy debate: the percentage of fossil fuels in the global energy consumption will still be at 82% in the year 2030 according to a Food and Agriculture Organization of the United Nations (FAO) forecast (FAO 2008).

1.2. Land and soil degradation: endangering livelihood security

Worldwide "nearly 2 billion hectares of land, an area about the combined size of Canada and the United States, is affected by human-induced degradation of soils, putting the livelihoods of nearly 1 billion people at risk" (UN 2000:61). Every year, 20 million hectares of land additionally become too degraded to grow something on or are lost to urbanization (UN 2000).

Land degradation is not to be confused with soil degradation. Land degradation is a broader term relating to the degradation of soil, flora, fauna, water, climate and losses due to urbanization and is endangering whole regions (e.g. worldwide area of desertification). Soil degradation itself includes erosion of soil by water , wind, chemical degradation (e.g. depletion of soil nutrients), physical degradation (e.g. compaction of soil) and biological degradation (e.g. decline of soil organic matter) (Hurni et al. 1996).

Liniger et al. 2011:18 defines land degradation as “a decline in ecosystem goods and services from the land”. According to this definition, soil erosion is part of land degradation. Sub-Sahara Africa is particularly vulnerable to degradation processes because of its high population growth rate, its climate and market sensitive agriculture and its often poor land management. Therefore sustainable land management (SLM) is essential for Sub-Sahara Africa.

According to Liniger et al. 2011:18 land degradation has a negative influence on the state of natural resources (water, soil, animals, plants) as well as their management. Therefore agricultural production is hindered or even impossible (in case of massive gully erosion for example). For Sub-Sahara Africa assessments show severe land degradation and the need of an improvement of natural resources through sustainable land management.

Besides a lot of negative examples of land and soil degradation from all over the world there are also examples on how to reduce or prevent land and soil degradation. The World Overview of Conservation Approaches and Technologies (WOCAT) collects these best practices in a database so they are available to the global community of soil and water conservation (SWC) specialists.

1.3. Jatropha curcas

Jatropha curcas Linnaeus (English:physic nut, in this thesis referred to as Jatropha) is a small, drought resistant tree or larger shrub, approximately three to four meters tall. The plant belongs to the Euphorbiaceae genus and grows fruits that contain seeds with an oil content of approximately 30%. Today, Jatropha can be found in tropical regions of Africa and Asia and South America where it originates from. Roughly, Jatropha grows in the so called “Jatropha Belt” which has an extent from 30° North to 35° South (Jongschaap et al. 2007).

As discussed in the next chapters Jatropha is viewed by some authors as a possible new energy supply since the seed's oil can be used as a fuel or be further processed into bio-diesel. In addition, it is also said that Jatropha can be used as a soil and water conservation measure to hinder soil erosion. Therefore, the question arises, whether this plant could be an optimal solution for problems in rural areas in Ethiopia: hindering soil and land degradation as well as contributing to rural energy supply. In this thesis Jatropha's potential to address both issues is investigated.

Because Jatropha is toxic and animals do not browse it, it is often used as protection hedges of homes or gardens. Jatropha oil is not edible either so it is used to make soap or for medicinal applications. Jatropha is also used to gain biofuels. But as soon as Jatropha is used as an oil source for biofuels (aiming high yields), proclamations on low nutrient requirement, low water use, low food production competition and a high tolerance to diseases are not true. Even the plant's capability to gain high yields at a larger scale farming is not backed up by literature and therefore additional research is needed (Jongschaap et al. 2007:27).

The potentials of Jatropha for reclamation of marginal or eroded soil is backed up by scientific literature (Spaan et al. 2004). As the plant is said to be drought tolerant, rural and remote areas in Ethiopia for example could benefit from it to improve their access to sustainable energy as well as for reclamation of marginal or degraded soils.

As seen above some proclamations about Jatropha have been proofed as true, others as wrong and some uncertainties are still present. Since the combined potential of Jatropha as an energy supply and as a soil conservation measure is not yet investigated, additional research is needed. This thesis tries to close this knowledge gap and contribute to the ongoing Jatropha discussion by doing research in the region of the town Bati in Ethiopia.

1.4. Ethiopia

Soil degradation and erosion as well as access to energy are important challenges for rural regions in Ethiopia. In this thesis a possible solution to both problems is investigated in a case study in Ethiopia - the plant Jatropha. In some regions of Ethiopia, Jatropha is used by farmers for different purposes. In the region of the town Bati, a lot of farmers are using this plant for several years now, first as hedges and more and more as soil and water conservation technologies.

Ethiopia is a landlocked country at the horn of Africa neighboring Djibouti, Eritrea, Kenya, Somalia, South Sudan and Sudan with a total size of 1'104'300 km^2 and the capital city Addis Abeba. The country's large scale climate is dominated by tropical monsoon but a wide variety of different topographically influenced climates can be identified on the smaller scale. Major environmental threads are deforestation, overgrazing, soil erosion, desertification and water shortages in some areas from water-intensive farming and poor water management (CIA 2012).

For July 2012 the population is estimated to count approximately 93.8 million people with a population growth rate of 3.18% per year. In the year 2010 17% of the population lived in urban areas whereas 83% of the population lived in rural areas. The median age of the total population is estimated to be 16.8 years and the life expectancy at birth is 56.5 years. Access to improved drinking water sources is possible for 98% of the urban population but only for 38% of the rural population. On average a woman in Ethiopia gives birth to six children. The gross domestic product per capita in Ethiopia is 1'100$ and 85% of the labor force is occupied in agriculture (CIA 2012).

1.4.1. Soil and land degradation in Ethiopia

Soil degradation is a severe problem in Ethiopia. According to the FAO of the United Nations (UN) in the 1980s in the Global Assessment of Soil Degradation (GLASOD) 25.11% of the country were classified as moderately to very severely degraded. In the year 2000 90% of the country's population lived in these areas (FAO 2005). A moderate degradation is defined as “terrain that has greatly reduced agricultural productivity but is still suitable for use in local farming systems” whereas extreme (or severe) degradation stands for “terrain that is unreclaimable beyond restoration” (Oldeman et al. 1990). Almost half the population (41%) was living in very severely degraded land which forms 10% of the overall area of the country (FAO 2005).

Although rain-fed agriculture is possible in wide parts of Ethiopia, there is a risk for hunger crises. A high variability of rainfall from time to time causes droughts. But not droughts are the most important factor for a famine but unsustainable utilization of resources. Soil degradation and erosion in Ethiopia is thus caused by depletion or unsuitable management of land in many cases. The first level of combating soil degradation is therefore a socio-cultural approach looking at the land management and the land-(over-)utilization. After that, physical measures should be implemented. The overall goal is to achieve a sustainable usage of the soil (Herweg / Hurni 1993).

1.4.2. Energy in Ethiopia

According to Wolde-Ghiorgis 2002 indicators for Ethiopia's underdevelopment are shown by the small amounts of energy produced and used in the country. In the year 2009 Ethiopia used 3.72 tWh of electrical energy whereas in Switzerland for comparison (with a 11 times smaller population) 62.11 tWh of electrical energy was used (IEA 2011). Ethiopia's per capita electrical energy consumption is the smallest in the world with 28 kWh per year (GIZ 2009). A reason for the very low usage of electrical energy is the very low access to electricity in Ethiopia due to the high input costs of power grids. The country is large and the villages and households are scattered. To access more households and settlements the power grid has to be expanded (Wolde-Ghiorgis 2002). In the year 2006 less than half of Ethiopia's towns were connected to the electrical power grid but the Ethiopian Electric Power Corporation (EEPCo) connected 80 new towns only between 2001 an 2003 (RECIPES 2006).

The domestic sector is dominating the energy consumption in Ethiopia with 89% of the total energy consumption. Traditional energy is used in rural households for cooking and lighting (RECIPES 2006). Thus the major part of energy supply in Ethiopia in the year 1996 was covered by traditional energy sources such as wooden biomass (77%), crop residues (8%) and dung (9%). Petroleum based energy resources only covered approximately 5% and electricity less than 1% of the total energy consumption in Ethiopia (Wolde-Ghiorgis 2002). It is likely that these values have changes somewhat until today, but after visiting the country it is obvious that in rural areas traditional energy still outperforms electricity or petroleum by far.

For rural areas there might be potential for Jatropha to close the lack of sufficient energy since the plant's seeds can be used as a biofuel source. In addition it could help to substitute charcoal and firewood and therefore reduce pressure on the environment. People in the research area in the region of Bati in Ethiopia are already using Jatropha as a measure for combating soil erosion. If it was possible to locally process Jatropha seeds to biofuel the whole region could benefit from a better access to energy since petroleum and electricity can only be afforded by a minority of the people.

1.4.3. The research area in Bati

Bati is the name of an administrative district (locally called Wereda) in Ethiopia and its biggest town. The town is located approximately 400 km North-East of Addis Abeba on the main road from Kombolcha to Djibouti at 11.19° North and 40.01° East and 1560 m a.s.l. on the eastern edge to the Afar lowlands (see figure1). In the year 2007 107'000 people lived in that district from which almost 17'000 lived in the town Bati (CSA 2007). The population density in the Bati district is around 92 persons per square kilometer (Ayele 2011).

According to Ayele 2011 (referring on BWARDO 2007) 19% of Bati district can be classified as mid altitude (1500 – 2300 m a.s.l.) and 81% as lowland (500 – 1500 m a.s.l.). Bati district is characterized by hilly topography and dominant land cover types of bush-, shrub- and degraded grassland used for the extensive grazing of animals. Cultivated land where farmers grow their crops can be found wherever needed even on very steep slopes. There are two rain periods in the area: the short rainy season (locally called Belg) from January to April and the long rainy season (locally called Meher) from June to September. The erratic rainfall ranges from 500 to 1000 mm per year and the temperatures are between 18 – 36 °C.

Figure 1: Bati's location in Ethiopia (adapted from CIA 2012)

To compare the different effects of soil and water conservation technologies and the utilization of Jatropha, two different study sites were chosen. These two sites are located on approximately 1560 – 1630 m a.s.l. South and South-West of Bati town and they both are located in the transition zone of the local agro-ecological zones of dry (less than 900 mm rainfall p.a.) and moist (900 – 1400 mm rainfall p.a.) Weyna Denga (1500 – 2300 m a.s.l.) and Kolla (500 – 1500 m a.s.l.). However, due to the rather limited amount of rainfall and the altitude starting above 1500 m a.s.l. the research areas can be assigned to the Dry Weyna-Dega zone. Meteorological data from the years 2007 to 2010 show a yearly amount of 934 mm of rainfall (see figure 2). Averaging this amount with the literature findings of 500 – 1000 mm of rainfall per year for the area is supporting the decision to assign the area to the Dry Weyna-Dega zone.

Following problems enhancing soil erosion and degradation are identified for the the Dry Weyna-Dega zone by Bekele-Tesemma et al. 2005:68f: overgrazing of grasslands, erratic rainfall in relative short rainy seasons, few and little remaining forests and the difficulty to grow trees because limited water availability and browsing animals (especially goats) and small land holdings. These factors support soil erosion and land degradation. To overcome the problems of land degradation the authors suggest building bunds and terraces and to dig cutoff drains as a precaution for heavy runoff. In steeper slopes it is suggested to reinforce SWC structures by biological measures. For very steep slopes they suggest not to disturb the soil at all.

Jatropha is used in the region of Bati for soil and water conservation as a single measure or in combination with stone walls or small terraces. This thesis will investigate if the plant really contributes to erosion prevention and if it might be one possible key player for local sustainable land management. Since Jatropha seeds can be used as an energy resource there might be a possible double benefit of the plant: preventing soil erosion and providing energy for a rural community.

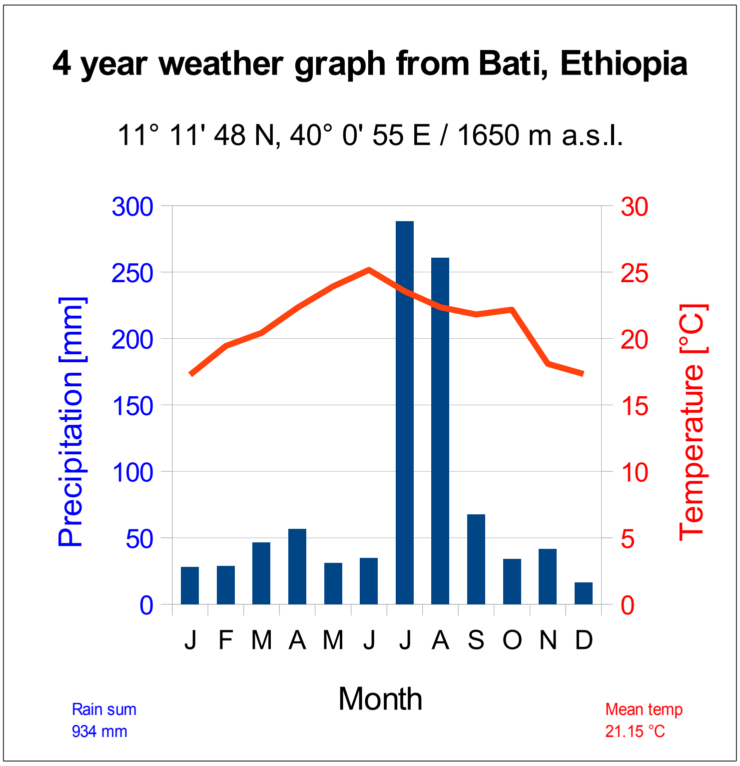

Figure 2: Four year weather graph of Bati (S.Bach 2012. Data: Bati weather station).

2. Objectives

As shown in chapter 1 and 3, there are a lot uncertainties concerning Jatropha and its different utilization purposes and their impacts on environment, humans or economy. Because of these uncertainties and different approaches, this thesis is looking at the possibilities of Jatropha to combat extreme soil erosion (in this case gully erosion) including the plant's possibilities as a biofuel through a transdisciplinary approach trying to include expert's knowledge as well as farmer's knowledge like intended by the WOCAT approach.

The **main objective** is therefore to assess the potentials and limitations of Jatropha as a multipurpose crop for soil and water conservation and sustainable energy supply in Bati, Ethiopia.

In order to gain information to answer the main objective following **specific objectives** are addressed:

- Identify and assess gully rehabilitation technologies in the research area.
- Describe, valuate and compare identified technologies.
- Estimate potentials and limitations of Jatropha as an energy crop in the local context.

3. State of knowledge and literature review

3.1. Soil and soil degradation

As shown in the background chapter of this thesis, soil erosion and therefore loss of soil is a major concern worldwide as well as in Ethiopia since without soil, food production is hindered. Thus it is crucial to have some knowledge on soil and on soil degradation processes.

Soil is a multifunctional natural resource. According to Herweg et al. 1998:28 four soil functions can be distinguished:

- Production functions: capacity of the soil to produce food, fodder, fuel, fiber and construction wood; raw material and mineral resources to manufacture pottery, bricks, etc.
- Physiological functions: value of the soil for producing nutritive plants, decomposition of pollutants, filtering water, etc.
- Cultural functions: soil as the dwelling place of ancestors, family and social security, "stemming from the soil", etc.
- Ecological functions: soil as a value that controls energy, matter and water flows; storage of water, nutrients and pollutants, etc.

Soil productivity is an "intrinsic value of soil, expressed by such factors as soil quality and health, or physical, chemical and biological properties as a potential for biomass production. Long term productivity is an indicator of soil sustainability." (Hurni et al. 1996:11). Agricultural production therefore is a measure of the soil sustainability in a specific system or area. It can be maintained by technology to a certain degree but under certain costs with uncertainties for the future (Hurni et al. 1996).

The German Wissenschaftliche Beirat der Bundesregierung Globale Umweltveränderungen (WBGU) distinguishes four basic soil functions (WBGU 1994:42ff):

- Habitat function: Soils are the habitat for a wide range of life forms from plants, fungi, animals down to smallest micro organisms. These soil organisms contribute to processing of soil nutrients as well as to biodiversity. Soils are needed for plant rooting and are therefore a first step of primary terrestrial production and essential for a broad range of organisms in the food chain including humanity.

- Regulation function: This function includes the accumulation, transformation and transportation of energy and substances within the soil.

- Utilization function: This soil function refers to the wide range of actions that people undertake to satisfy their needs. A distinction between production functions (e.g. agriculture or forestry), carrier functions (use of the land for settlement, infrastructure etc.), and information functions (a meaning given by people e.g. climate archives, soil fertility etc.) can be made.

- Cultural function: This function describes the soil and the land as the basis of human culture and history. Colonization or abandoning of land , thus history of culture, is often related to the soil's condition.

If land and soils are not managed in a sustainable way they may degrade. Liniger et al. 2011:18 identifies different forms of land degradation which occur on different types of land use (here, forest land is excluded since there are no forests in the research area):

- On cropland (land used for the cultivation of crops WOCAT glossary 2012) soil erosion by water and wind can be identified. Furthermore a decline of fertility (chemical degradation), sealing or crusting of the soil (physical degradation) may occur. A decline of local crop varieties and the dominance of monoculture agriculture (biological degradation) and pollution of water caused by an increased fraction of soil-particles in the water due to increased run off can be found.

- On grazing land (land used for grazing animals WOCAT glossary 2012) loss of vegetation cover and species as well as introduction of undesired species (biological degradation) may occur. Due to the loss of vegetation cover the land is vulnerable to other degradation processes for instance increased runoff and therefore increased soil erosion.

According to Oldeman et al. 1990:6 two categories of human induced soil erosion can be distinguished: soil degradation by displacement of soil material and soil degradation as a result of internal degradation. For the latter, three main types can be characterized: (1) Physical soil degradation (or also called mechanical soil degradation) concerns processes that have a negative effect on the soil's physical components such as structure, texture or include compacting or crusting of the soil. (2) Chemical soil degradation describes processes that negatively influence soil salinity, acidity or nutrient content. (3) Biological soil degradation considers decline in biological activity in or on a soil such as disappearance of cover vegetation or a lower earth worm activity in the soil. Naturally these three different degradation types seldom appear as a single problem but rather in combination with each other (Mitiku Haile et al. 2006:38).

Soil erosion by water (which is important for gully formation) is a form of soil degradation by displacement. Soil erosion by water (or also by wind) can be defined as “the detachment and transport of solid particles on the soil surface by water and wind” (Mitiku Haile et al. 2006:39). Erosion leads in almost all the cases to a worsening of the soil's conditions, since larger areas with rather fertile topsoils are washed away by water (or carried away by wind) and deeply accumulated in catchment traps but with a small areal extend (Mitiku Haile et al. 2006).

According to Mitiku Haile et al. 2006:42f soil erosion by water is closely linked to the water cycle. Therefore, following water erosion processes can be identified after Bergsma et al. 1996:

- Splash erosion happens if raindrops fall on an uncovered soil and smaller soil particles bounce away because of that impact and are then more vulnerable to be washed away after landing again on the very top of the soil.

- Runoff occurs when water is not able to infiltrate in the soil. As long as the runoff does not concentrate there is areal erosion called sheet flow.

- If runoff is concentrated rill erosion may occur. If the rills are only a few centimeters deep one speaks of pre-rills and if the rills are approximately 50 cm deep they are simply called rills.

- If rill erosion goes on, gullies are formed which are defined as rills deeper than 50 cm. Often additional side effects appear with gully erosion, for example small land slides on both sides of the gully into itself because the erosion is digging deeper in the ground and the gully walls become unstable. After an area is destroyed by a gully and can not be used anymore it is called badlands.

- If rain is able infiltrate into the soil, there is a higher risk for landslides in steeper slopes (after Nyssen et al. 2002).

- Soil accumulation can occur as diffuse accumulation, which means that soil particles are accumulated in near distance (a few meters) to the source and intensify the crusting or sealing processes. Concentrated accumulation can be observed at slope ends, on field borders or on tracks or roads when a bigger amount of soil is deposited at a specific area.

From their experiences concerning soil erosion in Ethiopia, Herweg / Hurni 1993:47 conclude that:

- Pressure must be taken out of the agricultural sector whereas the non-agricultural sectors must be promoted.

- Since individuals must accept changes or adaptations, socio-cultural research is needed.

- Indigenous as well as innovative technologies have to be considered.
- Immediate aid (e.g. during a famine) as well as long term aid, that leads to autonomy, are necessary.

3.2. Jatropha as a multifunctional plant

This thesis is looking at Jatropha from two different angles. On one side the plant shows potential in being an efficient SWC measure and on the other side its seeds can be used for biofuel production. To be able to make conclusions in the end, a literature review on both sides is necessary.

3.2.1. Jatropha as a biofuel

Jatropha grows fruits with an oil containing seed. Following steps are needed to produce vegetable oil from Jatropha (Asselbergs et al. 2006:13): harvesting of the fruits, drying, cleaning of the seeds, extracting the oil, filtering oil and packaging of the final product. These steps only need little knowledge and technology and are therefore suitable for rural areas. Through transesterification of the vegetable oil biodiesel is produced. But for biodiesel production more knowledge, technology and chemicals are needed.

One difference between fossil oil and Jatropha oil, is the higher viscosity of the latter. Due to the high viscosity, problems for stoves, lamps or engines may occur. Therefore the direct use of Jatropha oil as a fuel requires methods to reduce its viscosity (Asselbergs et al. 2006:10ff):

- Mixing Jatropha oil with fossil diesel reduces viscosity. Hence, the blend can be used in normal diesel engines for example. According to Pramanik 2003:247 the maximum blending ratio lies at 50% of Jatropha oil mixed with diesel. However, according to Jones / Peterson 2002:7 long term engine durability remains questionable if the blend exceeds a ratio of more than 20% of Jatropha oil.
- Modification of diesel engines such as the building in of a preheater that lowers

viscosity of the Jatropha oil or of an additional pump that increases the pressure inside the fuel-engine system may help to use Jatropha oil in diesel engines. There is also the method of using a switch that allows to start an engine on normal diesel and after needed temperatures are reached Jatropha oil can be mixed in.

Asselbergs et al. 2006:29ff distinguishes three different scales of Jatropha based biofuel production:

- National scale: At large scale, biofuel production is supported by national politics such as ethanol production in Brazil or Jatropha plantations in India. The goal of these large scale production is to reduce dependencies on the global energy prices. However, with centralized production, rural poor do not benefit greatly from Jatropha. There is even the possibility that these people are exploited as cheap work force by the large scale production facilities.
- Plantation scale: This is addressing Jatropha grown on plantations by local farmers or farmer cooperatives. For these farmers relatively large investments are needed to start producing Jatropha on a plantation scale. Since the Jatropha plant is producing seeds after 3 – 5 years , there is a delay between starting up plantation and getting first revenues from it, that has to be covered somehow. Also, low profit margins and market uncertainties rise the risk of Jatropha plantations for farmers. Therefore, Jatropha plantations are currently not very attractive for rural farmers on a plantation scale.
- Community scale: Local people work in the same project of growing Jatropha and the marketing of its products such as done by women groups in Arusha in Tanzania. Jatropha is not the main income source but an additional part of farmers multi-strategies besides other food or cash crops and livestock. Often at community scale, Jatropha is planted as hedges along fields or roads and not as a plantation.

With the three dimensions of sustainability in mind (economic, socio-cultural and ecological dimension - see chapter 3.4) Asselbergs et al. 2006:13f identifies several advantages of biofuel production through Jatropha:

- Ecology: Since Jatropha is a quite tolerant plant, it can be grown on land that is not needed for other purposes (e.g. degraded land). In addition, due to it's toxicity, the plant is also fairly resistance to pests. Emissions of engines, lamps and stoves fueled on Jatropha oil are considered less harmful to human health than emissions of fossil fuels. So both, indoor household pollution in rural areas (oil stoves) and outdoor pollution in big cities (oil engines), could be reduced with the utilization of Jatropha as a source for straight vegetable oil (SVO).
- Economy: If products of Jatropha are produced locally and sold locally prosperity of the region may increase.
- Society: Due to an emerging Jatropha business, people may find an employment in that business. In addition, since Jatropha oil may be cheaper and less harmful than petrol based oils, people reduce their energy costs and the money can be used elsewhere.

A possible thread of an emerging Jatropha economy is seen by increasing social inequality due to a widening gap between the rich and the poor in a region. Once markets have established, people might depend on Jatropha and its products and are committed to regional or global energy markets and their price dictate. Poor farmers in developing countries with limited access to information will likely be the victims of such a dependency. Another threat is the question, if unused, bare or marginal land is really not used by anything or anyone. Marginal land may be inhabited by small livestock keepers or landless people. There are concerns that once a lucrative market is established, Jatropha will be grown on good agricultural land and compete with food crops and therefore also be a risk for food security in certain regions (Asselbergs et al. 2006:14).

Asselbergs et al. 2006:43 conclude that due to the low profit margins of Jatropha it may be better to focus on Jatropha production in a mixed crop system or as hedges rather than large scale production. The authors see potential for Jatropha oil production especially in remote and rural areas where it could replace traditional energy sources. However, technologies are required in these areas such as adapted stoves or lamps.

3.2.2. Erosion control with Jatropha

According to Behera et al. 2010 Jatropha can be used for fencing purposes and for soil erosion control. Reubens et al. 2011 say that Jatropha is claimed to be a potential measure against soil erosion by water or by wind. They point out that the erosion control is rather linked to how the plant is planted than to the plant's deep root characteristics. Jatropha's potential to combat soil erosion more likely origins of its planting along slope contours and the dense spacing chosen between each plant, the fast growing of the plant and its fine root structures in the topsoil. But still, the authors think that the three dimensional root symmetry may play an important role “not only for superficial water erosion but also for slope stabilization and control of incisive erosion processes such as rill and gully erosion” (Reubens et al. 2011:204). So the differences in planting Jatropha by cuttings or by seeds may be insignificant. Further investigation is needed for final statements.

To find suitable plant species for combating gully erosion De Baets et al. 2009 suggest four characteristics: high resistance against concentrated flow erosion, high potential for slope stabilization, high threshold for bending by water flow and a good ability to trap sediments and organic debris. The authors conclude that optimal soil erosion control is achieved by “a combination of species (e.g. on the one hand a grass having a high potential to resist concentrated flow erosion and a high ability to trap sediments and on the other hand a shrub with a high resistance to bending by water flow and a high potential to improve slope stability) or the allocation of species to specific target areas (e.g. grasses in concentrated flow zones and on terrace walls, deep-rooted species to stabilize gully walls)”(De Baets et al. 2009:1390).

3.2.3. Rooting characteristics

The way Jatropha is planted influences the way in which its roots grow, which, in turn, may influence the plant's potential as a soil and water conservation technology. Jatropha seedlings grow four lateral roots out of the main vertical taproot. These roots develop horizontally at first and after some distance change direction to the deeper soils. Not only are these four roots aligned quite symmetrically but also the biomass is approximated equal in all four roots.

While aging, the vertical taproot becomes more and more unimportant for the plant but still develops little anchoring roots for stabilization. Jatropha's root system has an optimal design for the exploration of deeper soil layers to access water in semi-arid or arid areas (Reubens et al. 2011).

Jatropha cuttings, the most prominent form of propagation in the research area, establish variable numbers of roots depending on the cutting season (planting takes place in the same season) and the age of the plant. Experiments in northern India (Uttarakhand state) showed that the number of roots per cutting varies from an average of 2.7 if cut in dry season (spring) up to 6.3 roots per cutting in wet season (monsoon) for young plants. For older plants an average number of 1.2 roots per cutting established during winter and 3.2 during monsoon. Cuttings taken and planted during monsoon grow longer roots than cuttings taken during dryer times (variation from 3.2 cm up do 10.7 cm after 60 days) (Bijalwan / Thakur 2010). Independent on cutting and planting time an average of 3.4 roots establishes which is not too far off from the four roots Reubens et al. 2011 have observed if Jatropha is planted by seeds. Unfortunately Bijalwan / Thakur 2010 did not observe the roots alignment from cuttings since this could be an important factor if looking at erosion control by Jatropha. According to Jongschaap et al. 2007:5, in the case of cutting propagation, Jatropha only grows secondary roots (vertical roots) and no taproot.

3.3. Energy and development

Mayer-Leixner 1999:57ff mentions that energy consumption in developing countries is strongly depending on traditional energy such as wood, charcoal, dung and field residues (2 billion people are depending on such traditional energy sources UNDP 2004:34). The author emphasizes the strong interdependence between energy and economic and social development. In conclusion he states that as long as developing countries have limited energy access they will stay developing countries.

In their World Energy Assessment, the UNDP (United Nations Development Programme) analyzes energy and development relationships according to the magical triangle of sustainability in the three dimensions of society, economy and environment UNDP 2004:33ff.

Lacking access to energy in developing countries is closely linked to other social problems such as poverty, urbanization, poor health or minimal to non education of women. Poor people tend to use traditional energy sources while people with higher income shift to fossil fuels or electricity. Also, poor households use a relatively larger fraction of their budget for energy than richer households. Traditional energy sources have to be collected somewhere, often away from home. Since this task is often fulfilled by women or children, there is less time for education. In addition, traditional energy sources are often endangering the health of household members since they are openly burned inside the house. The World Energy Assessment estimates that annually 1.6 million people (mostly women and children) die due to indoor air pollution caused for example by cooking fires. Since centralized projects (such as power plants) are mostly providing energy for urban areas and the richer classes living there, UNDP 2004:35 sees decentralized small-scale energy technologies (such as generators etc.) as an important option for poverty reduction. In particular, they see greatest potential for decentralized technologies run with locally available fuels (hydro power, biomass, wind power, solar power etc.). To overcome the above mentioned social issues of lacking energy the World Energy Assessment (UNDP 2004:35, cited) suggests a variety of options:

- Improve health and increase productivity by providing universal access to adequate energy services - particularly for cooking, lighting, and transport - through affordable, high- quality, safe, and environmentally acceptable energy carriers and end-use devices.
- Encourage the use of improved stoves and liquid or gaseous fuels to reduce indoor air pollution and improve women's health.
- Use women's managerial and entrepreneurial skills to develop, run,and profit from decentralized energy systems.
- Reduce the “push” factor in rural-urban migration by improving energy services in rural areas. Take advantage of new technologies to avoid energy-intensive, environmentally unsound development paths.

On the economic side, the UNDP 2004:36ff says that global energy consumption will triple between 2000 and 2060. Increase in developing countries is expected to be above average, as during the period 1970 – 2000, when their commercial energy consumption increased 3.5 times as fast as in developed countries. This trend does not only come from changed consumption patterns in developing countries but also higher efficiencies in developed countries. The World Energy Assessment therefore sees potential for developing countries to leapfrog inefficient technologies (e.g. in transportation, machinery, processes) and to directly use efficient modern technologies. Although initial costs of such efficient technologies are in most cases higher than inefficient technologies, the total costs over the whole expected lifetime of the technologies are smaller. In addition to efficiency, the economic risks for foreign investments should be lowered in developing countries (e.g. clear and stable rules for energy and financial markets). In countries without investments from inside or outside, development is hindered (UNDP 2004:36ff).

On the environmental side UNDP 2004:40ff states that burning of wood over the last centuries has led to deforestation in many areas of the world. The potential of energy to enhance economy and human well being is unquestionable, however conventional energy production and consumption are closely linked to environmental degradation. One big environmental concern is the burning of fossil fuels which contribute to a large amount of air pollution, climate change, acidification of rain and soil and so on. However, also no fossil solutions have weaknesses. For example nuclear power plants and the question where to put their waste or hydro power plants and the need of resettling thousands of people. In developing countries at the local level UNDP 2004:42 suggests to replace traditional energy supply with more intensive energy forms such as liquid fuels or gases with not only environmental benefits on local to global level but also increased health and productivity.

3.4. Sustainable land management

In order to maintain their livelihoods farmer are dependent on the land and other natural resources like water or animals. It is crucial that these resource remain in needed quantity and quality also for following generations. Therefore sustainability is the key. According to the previously identified degradation in Ethiopia, sustainability is not given in the research area in the Bati district. In the Brundtland-Report the World Commission on Environment and Development (WCED) defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987:54).

Sustainable development includes an economic, a socio-cultural and an ecological dimension. These dimensions form the “magical-triangle” of sustainable development (see figure 3). This magical-triangle shows how equity between generations as well as equity within a generation is achieved. Goals and meanings of sustainable development are therefore negotiated within this triangle. But not only is the concept focusing on future values, “ought to be” (= normative perspective), but also on the actual impacts - the “is” (= systems perspective). Since values and norms differ over time and in different societies, sustainable development must be understood and negotiated in a particular social context (Hurni / Wiesmann 2004 in Hurni et al. 2004). This thesis is focusing on the ecological (land and soil degradation, Jatropha as a soil conservation technology) edge but tries not to forget the socio-cultural and the economic edges (covered by the WOCAT questionnaires and the literature review). Mostly the “is” system is investigated in this thesis, however the “ought” is covered in the conclusion and the outlook part at the end of this thesis.

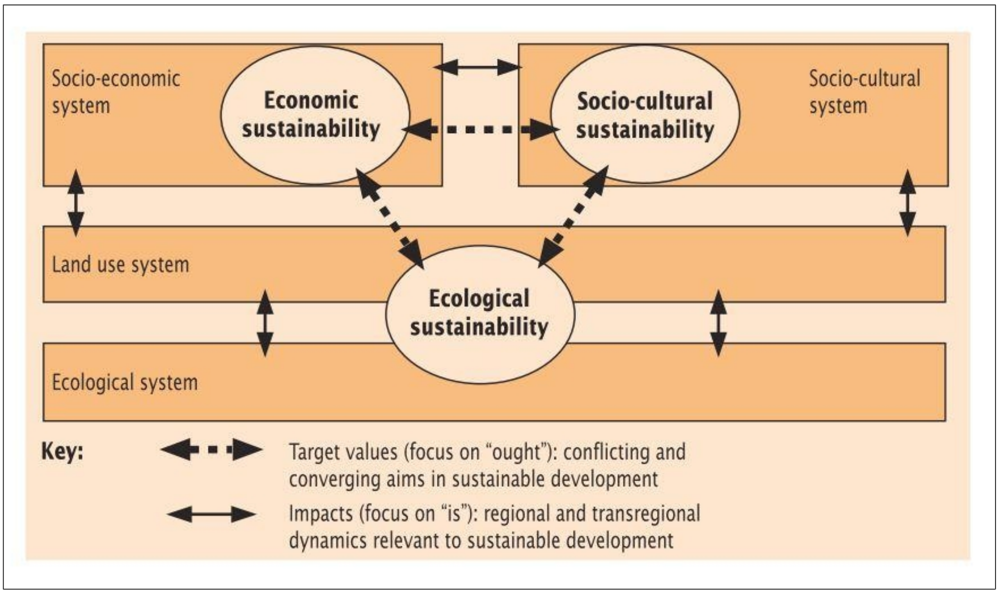

Figure 3: The magical triangle of sustainable development. Source: WIESMANN 1998.

The “magical triangle” also shows conflict potential between each group or corner. Hence, it is important that searching for solutions does not only take place in one scientific discipline but in a transdisciplinary way including natural science, social science, humanities as well as actors or groups from outside of science, for example farmers (Hurni / Wiesmann 2004 in Hurni et al. 2004). The WOCAT approach used in this thesis is designed in regards of these inter- and transdisciplinarities by covering multiple themes of different sciences and including different stakeholders.

Hurni et al. 1996:27 define sustainable land management as a “system of technologies and/or planning that aims to integrate ecological with socio-economic and political principles in the management of land for agricultural and other purposes to achieve intra- and intergenerational equity”. Obviously SLM is closely related to the sustainability concept of the magical triangle which also includes the three different spheres of economy, socio-culture and ecology. Liniger et al. 2011:16 sees SLM as “the antidote, helping to increase average productivity, reducing seasonal fluctuations in yields, and underpinning diversified production and improved incomes”.

One part of SLM that is focusing on the soil and its interaction with water and vice versa is called soil and water conservation (SWC). According to Hurni et al. 1996:27 it is “a combination of appropriate technology and successful approach”. Technologies can grant a sustainable use of soil and thus minimize soil erosion and maintain or enhance soil characteristics. Technologies help to manage water or control temperatures. On the other hand approaches explain, how and why SWC technologies are used in a specific ecological and socio-economic context (Hurni et al. 1996).

To achieve soil and water conservation, SWC technologies may be necessary. WOCAT 2007:10 defines SWC technologies as “agronomic, vegetative, structural and/or management measures that prevent and control land degradation and enhance productivity in the field”.

For a sustainable land management at the local scale Hurni 1997:211 (anticipating Hurni 1998) introduces the so called “multi-level multi-stakeholder approach to sustainable land management” to find “feasible, acceptable, viable and ecologically sound solutions”. It is defined as following:

- "Multi-level" is referring to the fact that not all participants are local people (e.g. farmers) but also administrators (e.g. from the province or the state), researchers, community headmen or international organizations.

- The expression "multi-stakeholder" includes all interest groups, organizations, individuals etc. that have a common interest in a certain topic.

- "Approach" is answering the question of: For whom is SLM realized and for what, by what means and whit what impacts?

- "Sustainable" is seen in the a multidimensional context as mentioned above. Thus economic, social, institutional, political and ecologic dimensions are emphasized.

- "Land" shows the spatial component. It includes ownership rights, resources as well as policy and economy environments.

- The term "management" is seen as activities using suitable technologies in a specific context. To be sustainable, the technology must be "ecologically protective, socially acceptable, economically productive, economically viable and reduce risk".

When applying the "multi-level multi-stakeholder approach to sustainable land management" the dimensions of sustainability have to be weighted against each other and negotiated within the stakeholder group. Indigenous solutions are thus as equal important as scientific solutions. So in order to attain long-lasting solutions a multi-level perspective and approach are essential. According to Hurni 1997:213 a major advantage of the approach is that "it does not provide a predetermined concept, but offers a framework and a procedure for working towards a common point of view and defining the next steps to take".

According to Hurni et al. 1996:28f in a multi-level multi-stakeholder approach three principles of actions must converge:

- Good land husbandry to ensure vegetative cover, maintain favorable soil, enable appropriate water flows, optimize organic matter and support active fallowing.

- A sustainable land use to ensure good land husbandry, increase productive quality, ensure compatible soil functions, control soil erosion, adapt cropping systems, ensure appropriate tillage management and activate nutrient cycles.
- An enabling institutional environment to promote viable social and economic institutions, coordinate farming within the same catchments, share resource-protecting technologies and tools, promote participatory decision making, foster an egalitarian society, ensure enabling land titling and economic policies, promote democratic decision-making in society and apply developed principles of sustainability.

According to Wiesmann 1998:53, strategies of peasant's base on multi-strategies which balance actions in order to minimize risks. In other words, peasants reduce risks by being active in a broad field of actions (for example a mixed agriculture with different crops and different livestock) rather than focusing on one single solution (e.g. growing only maize). If there is an new opportunity, peasants still seek for optimization (“utility-optimization”) and may include that opportunity within their multi-strategy. Wiesmann 1998 concludes that reactions to degradation are only successful in rare cases. Better, but also more complex, are approaches that combat environmental degradation indirectly via opportunity creation which peasant tend to shift to following their multistrategies.

3.5. Conceptual Framework

To be able to embed this thesis in a broader scientific context, the hybrid SLM framework (see figure 4) of the KM:Land (knowledge from the land) initiative by the Global Environment Facility (GEF) is chosen (GEF 2010:12). The hybrid SLM framework combines the DPSIR model (Drivers, Pressures, State, Impact and Response) used by the European Environment Agency (EEA 2007) and the Millennium Ecosystem Assessment (MA) introduced by the United Nations (MA 2005:vii).

According to Schwilch et al. 2010:215 the hybrid SLM framework suits various methods of soil degradation and SLM assessment including the WOCAT methodology and provides "an overview of the cause- effect interactions of degradation and SLM on environment and human well-being". Although mainly the blocks "Response" (the SWC technologies) ,"State" (maps of the watershed and its land use and the gully) and the "Impact on Ecosystem Services" (accumulation of soil behind the technologies, new plots of land for production) are covered in this thesis, the whole framework is helpful to see interrelations and to finally make conclusions in a broader view.

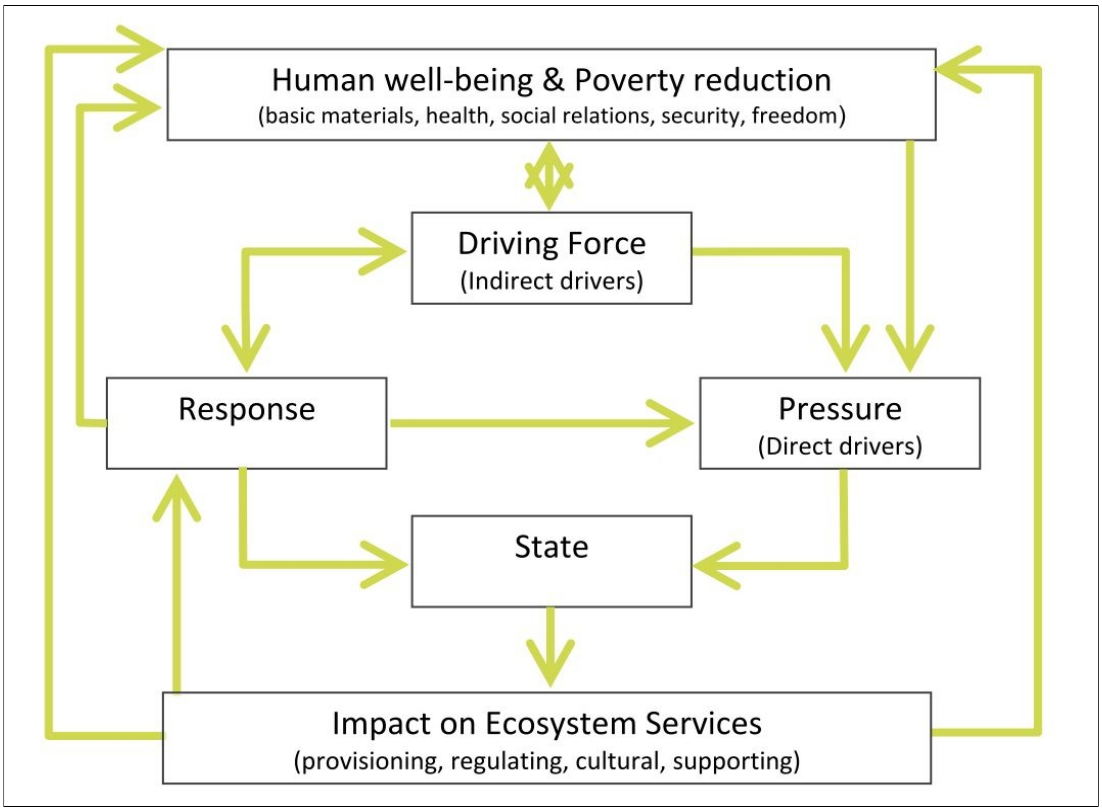

Figure 4: The hybrid SLM framework including the DPSIR and the Millennium Ecosystem Assessment frameworks. Source: GEF 2010.

The state block represents the current condition in the research area. In case of this thesis unsustainable land management lead to soil degradation, with its extreme form of gully formation, representing a negative impact on the ecosystem services: Supporting services (primary production and soil formation) are therefore hindered or in case of a gully not possible to be fulfilled any more. If primary production is lowered or stopped and the soils are not able to recover, the provisioning services (e.g. food and water) are not fully accessible in needed quality and quantity as well. As a response, local communities started to mitigate and rehabilitate gullies with different technologies and with different results influencing pressures and driving forces (according to MA 2005).

After seeing this cycle one may ask what the causes of an unsustainable land management were? This is answered by the driving forces (indirect drivers) and the pressures (direct drivers). Driving forces for overusing the land in the specific area may be the relatively high population density or other forces that need to be identified (could be: demographic, economic, sociopolitical, science and technology or cultural and religious). These driving forces lead to certain pressures (e.g. changes in local land use and land cover, climate change, technology adaptation and use etc.) which then lead to a specific state again (MA 2005).

Above the before mentioned cycles stands the human well-being and poverty reduction. It represents the individual or collective rights of freedom, health, security, social relations and the basic materials for a good life. Rather than influencing other factors it is very much dependent on the state of the other factors. But it influences the driving forces and therefore demography, economy and so on (MA 2005). The whole framework is, as clearly visible, dominated by interrelations in one way or another or in both ways and between one or more factors. It is therefore not a linear concept which raises complexity.

4. Methodology

The methodology of this thesis was designed in order to answer the 3 above stated specific objectives. Each method had its strengths and weaknesses and was therefore contributing differently to each specific objective (see figure 5). The methods chapters as well as the results were structured according to following figure:

Specific objective / Method	Identify and assess gully rehabilitation technologies in the research area	Describe, valuate and compare identified technologies	Estimate potentials and limitations of Jatropha as an energy crop in the local context
4.1 Research area assessment			
4.1.1 Field work preparations/finding research sites	++		
4.1.2 Mapping of research areas	++		
4.1.3 Measuring gully dimensions	++		
4.1.4 Computing vertical profiles	++		
4.1.5 Conducting a spade analysis	+		
4.2 Technology evaluation with WOCAT			
WOCAT questionnaires		++	
4.3 Analysis of Jatropha as an energy crop			
Informal Interview			++
Literature reviews			++

Assess the potentials and limitations of Jatropha as a multipurpose crop for soil and water conservation and sustainable energy supply in Bati, Ethiopia

Contribution: ++ important, + useful

Figure 5: Methodology flowchart (S.Bach 2012).

4.1. Research area assessment

To be able to make an assessment of different SWC technologies it was crucial to find adequate watersheds with different SWC technologies at first.

4.1.1. Field work preparations and finding adequate research sites

Reconnaissance trips by foot, motorcycle and car were conducted at the beginning of the field work in order to gain a good overview over the Bati area. Goal of this field trips was to see what SWC technologies are used in the local context and where the actual field work should take place.

To be able to compare different SWC technologies it was crucial to distinguish case study sites where different technologies were already implemented. The most important factor for finding adequate case study sites was the accessibility. In areas like the surrounding hills of Bati transport was a crucial cost and time factor. It was possible to get to these sites with local auto ricksha (or Tuk-Tuk) taxis. This factor had a influence in the decision-making process of which study sites to take, since the study sites had to be visited on several days and not only on one day.

Additionally to the mapping of the watersheds and the technologies and measuring of the gully, taking photos was important in all steps of the documentation procedure. With the photos it was later possible to illustrate different phenomena found in the two watersheds.

It was very important to have a field assistant since I was not able to speak the local languages and to behave appropriate in the given cultural context. Habtamu Ayele assisted and helped my during the time of field work. He conducted his master thesis (Ayele 2011) in the same area and was therefore familiar with it.

4.1.2. Mapping of research areas and their SWC technologies

Because different SWC technologies were compared in this thesis it was important to have similar conditions in which these technologies were found. If that was the case one is really comparing the technologies and not the land use systems for example. So, first of all it was important to find different watersheds with comparable size and land use systems but different SWC technologies.

For the purpose of this research two different watersheds had to be identified, which were comparable pertaining to: Area, Distance between each, soil types, slope, vegetation cover and land management (according to Herweg 1996).

After the two different sites were chosen, the watershed boundaries were delineated by Global Positioning System (GPS). The delineation line represented the actual study-sites. The watershed's output point was freely defined in the depression in order to receive similar watersheds in size.

The watershed boundaries were mapped by simply walking along the highest contour with the GPS turned on. The GPS automatically saved the location points (including coordinates and elevation) every few seconds. The farming land was mapped in the same way, by walking at the boarder of each field plot. Afterward, the village area had been mapped by hand in a geographic information system (GIS) with use of the satellite images. The total watershed minus the village area and minus the farming land led to the land use category called “degraded bushy grazing land”.

The soil and water conservation technologies were also mapped by GPS. A point was taken at each end of the technology and several points in between if it was a large technology. Four different technology types were distinguished: Stone wall and Jatropha in combination, Jatropha hedge, stone wall, and Eucalyptus.

4.1.3. Measuring gully dimensions

To have an impression what an actual gully may look like in the region, an active gully was measured. At the starting point and approximately at every 50 – 100 m of the gully a GPS point was marked and the gully's depth and width were measured (or estimated where it was large). Additionally, the slope angle to the next point was measured by inclinometer and the top soil type as well as its depth were estimated (see figure 6). Finally, also the main land use type at the marked point was noted. The measurements were then used to calculate the gully dimensions.

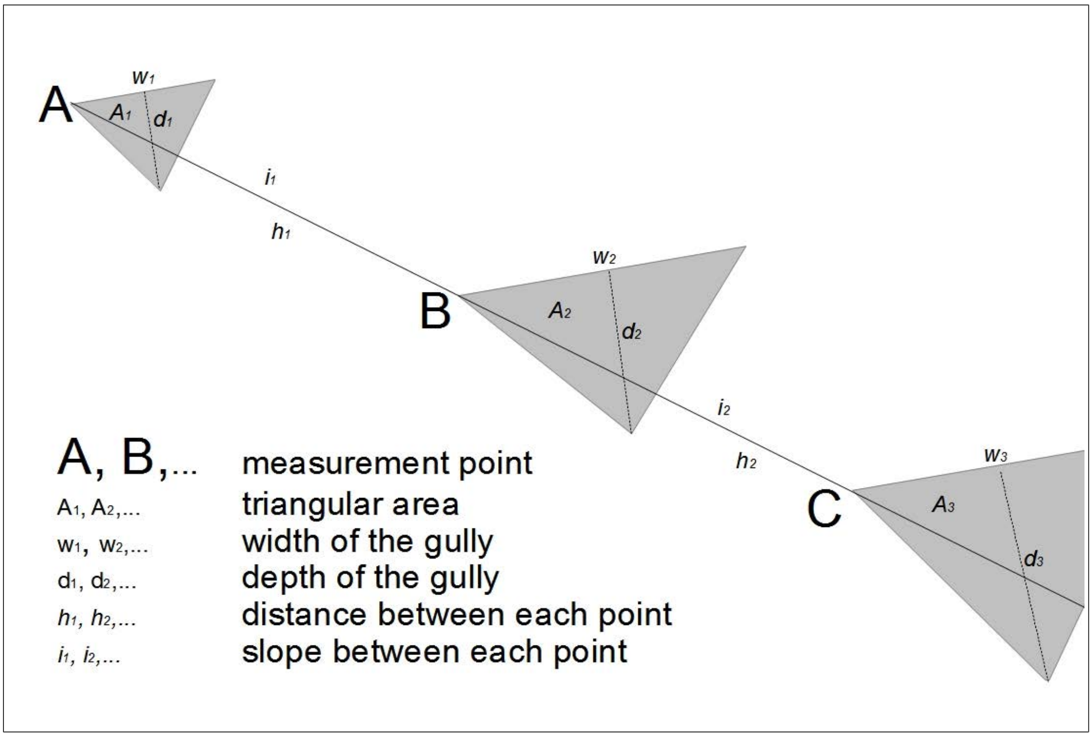

Figure 6: A sketch of the gully measurements (S.Bach 2012).

4.1.4. Computing vertical profiles

A vertical profile was computed to be able to compare the drainage lines of both watersheds with each other. A lot of GPS-points (mostly from the technology mapping) were available in each watershed containing elevation information. On the map a line from point to point was drawn and then, since for each point the altitude was known, a vertical profile could be computed. Unfortunately not too much points without any technology were mapped but a long uninterrupted line in the graph represents an uninterrupted drainage line as well (meaning no technology is blocking the line).

4.1.5. Conducting an adapted spade analysis

Soil samples were taken to assess the impact of SWC technologies on soil quality. A spade diagnosis adapted from Hasinger 1993 was used. In the original approach, a portion of soil of approximate 45 cm x 10 cm is cut out of the ground using a spade. The soil is further investigated for its humidity, smell, color, particles, fragments layers and more.

Because the soil was sandy and loamy as well as very dry it did not make any sense to try to take spades of soil out of the ground - therefore holes of approximately 30 cm of depth were made and characteristics of the soil in these holes were then described. Three such samples were taken downstream and three samples upstream the Jatropha technology. Whereas two samples (because the technology was small) were taken downstream and three soil samples upstream the stone technology. Additionally, there were soil samples taken randomly in the watershed not too far away from the technologies but outside the depression to have an idea of the “normal” soil conditions without alluvial soil. The spade analysis revealed that soil accumulated behind SWC structures was mainly unstructured sand that could not be differentiated from one place to the other.

The soil samples taken in the field were characterized after the idea of the standard form provided by spade diagnosis approach by Hasinger 1993. Characteristics described in this thesis were:

- Soil type: Describes if the soil is sandy, loam or even clay or stones (by the size of the particles).
- Particles: Describes different types of particles - crumbs, nuggets, polyhedrons or fragments.
- Structure: Describes how the particles are structured. Crumbly structure stands for a loose structure of all particles. The particles can also be clogged together in smaller pieces (polyhedrons) or bigger pieces (prisms)
- Surface cover: Describes the cover of the soil for example if there is grass and to what amount.
- Top Layer: Describes approximately the upper 5 cm of the soil. For example is there a crust or are there any roots?

- Color: Describes the color of the 30 cm of soil that is investigated.

After discovering that in gullies the main soil was alluvial soil and did not tell too much about each technologies effects on the soil itself, another spade diagnosis was implemented at a Jatropha hedge in a flat area. To see the effects of the plant two samples were conducted in a distance of 1 m and 2 m away of the hedge. The third sample was taken beneath the hedge's canopy.

4.2. Technology evaluation with WOCAT

To have a well founded view of the different observed soil and water conservation technologies in technical as well as in social contexts, the World Overview of Conservation Approaches and Technologies WOCAT (WOCAT 2011) questionnaires were used in the field. The questionnaires help to investigate the different SWC technologies and in the end support a comparison between them. Finally the results are available for decision support through the global WOCAT database for the different stakeholders (e.g. agricultural advisers). These questionnaires were developed by WOCAT to analyze and evaluate sustainable land management at a local level:

- Questionnaires on SLM Technologies (QT): addresses the following questions: what are the specifications of the technology, and where is it used (natural and human environment), what impact does it have.
- Questionnaires on SLM Approaches (QA): addresses the questions of how the implementation was achieved and who achieved it.

WOCAT questionnaires include stakeholder interviews as well as observations in the field and descriptions of the technologies (WOCAT 2008a,WOCAT 2008b). For this thesis the focus was laid on the QT questionnaires since the technologies and their functions are central for this thesis.

Since Habtamu Ayele was quite familiar with the region, both of us tried to fill out the technologies questionnaires as far as possible ourselves an in a dialog with each other (e.g. the environmental conditions, administrative questions etc.) and by taking a look at the reality in the field. In that case we did not have to bother our later identified interview partners, the farmers, with questions that were not in their possibilities to answer and we could focus on asking them questions about the actual technologies they built on their land.

After finding out who had implemented the technologies in each watershed these farmers were invited for an interview with the WOCAT questionnaire on the technologies. The interview took place in a hotel in Bati, a place where the farmers were not distracted by their household or by their work.

For each watershed two farmers that were active during the implementation of the technologies or were still active to build or maintain technologies at the present time were invited for the WOCAT interview. The interview was lead by Habtamu Ayele in the Oromic language, in which both parties, Habtamu Ayele as well as the farmers, were native speakers. We focused on questioning the farmers on the actual technologies they built. .

4.3. Analysis of Jatropha's potential as an energy crop

To see how Jatropha was used at the time of the field work, an unstructured interview with the local agricultural adviser of the Agricultural Office in Bati was held. The interview was more like an open talk rather than questions and answers. Main topic of the talk was the actual and future general use of Jatropha in Bati. The answers widely range from Jatropha used for fencing or for medical use to possible energy supply by Jatropha in Bati.

In addition to the above mentioned interview with the local agricultural adviser this thesis was connected to other research done in the BIA project so far. This was done by consulting articles and other literature published within the BIA.

4.4. Additional data

The data used in this thesis is gained by applying the above mentioned methods. To illustrate field-data google.maps.com (DigitalGlobe, GeoEye) satellite images of the year 2006 with a spatial resolution of 0.5 m were used.

5. Results and discussions

5.1. Soil and water conservation technologies in two different watersheds

5.1.1. Research area overview

The reconnaissance trips show that farmers are using a lot of different soil and water conservation technologies in Bati area. These technologies are locally developed by farmers (e.g. Jatropha hedges used as dams), or commonly known technologies (e.g. gabions or stone walls). The local Agricultural Office introduced the latter to farmers in order to improve soil and water management in entire watersheds and not only on farm plots as local farmers sometimes tend to do. But the Agricultural Office also supports farmers from time to time with food for work programs or with tools or other material to encourage them to take care of their land in a sustainable way.

Farmers around Bati are organized in watershed groups. Each group has a leader, who is responsible for organizing and managing SWC in the watershed, and who is the person of contact between farmers in the watershed and advisers from the Agricultural Office. The other farmers of the group are responsible to establish and maintain SWC technologies in specific areas (mostly on their plots). An average watershed in the Bati area has an approximate size of 250 – 500 ha.

According to watershed leaders the watershed groups around Bati have treated already 3'000 ha of communal land with Jatropha cuttings to prevent soil loss (together with other technologies). One watershed leader explained that he sees no alternative to Jatropha since he appraises it as a tolerant and drought resistant plant.

According to a local watershed leader, the area around Bati was covered with forest 30 years ago. This forest disappeared due to overuse and deforestation and what remained is bare land with little grass cover, some shrubs and only few trees. The watershed leaders are aware that a lot of fertile soil was lost due to land degradation. With that background and additional support of the Agricultural Office, farmers are willingly taking part in watershed treatment by SWC technologies in the area.

Farmers' will to take care of the land is also shown by their behavior. After visiting and talking to some farmers during the reconnaissance trips, other farmers recognized that there seems to be an interest from outside in SWC technologies in general and Jatropha hedges in particular. So farmers started using Jatropha more often only because of someone from outside was taking interest in it.

To prevent present-day deforestation local communities have established their own protection rules. For example, if someone cuts a shrub on the communal land, this person has to pay a fee of 50 Birr (approximately 2.90$). The fine keeps on doubling with each new violation. This regulation system should avoid further deforestation and should lead to a reforestation of the area.

During the research area overview process two research areas were selected as described in the methods chapter of this thesis. The two different research areas near Bati town are visualized on a map (see figure 7).

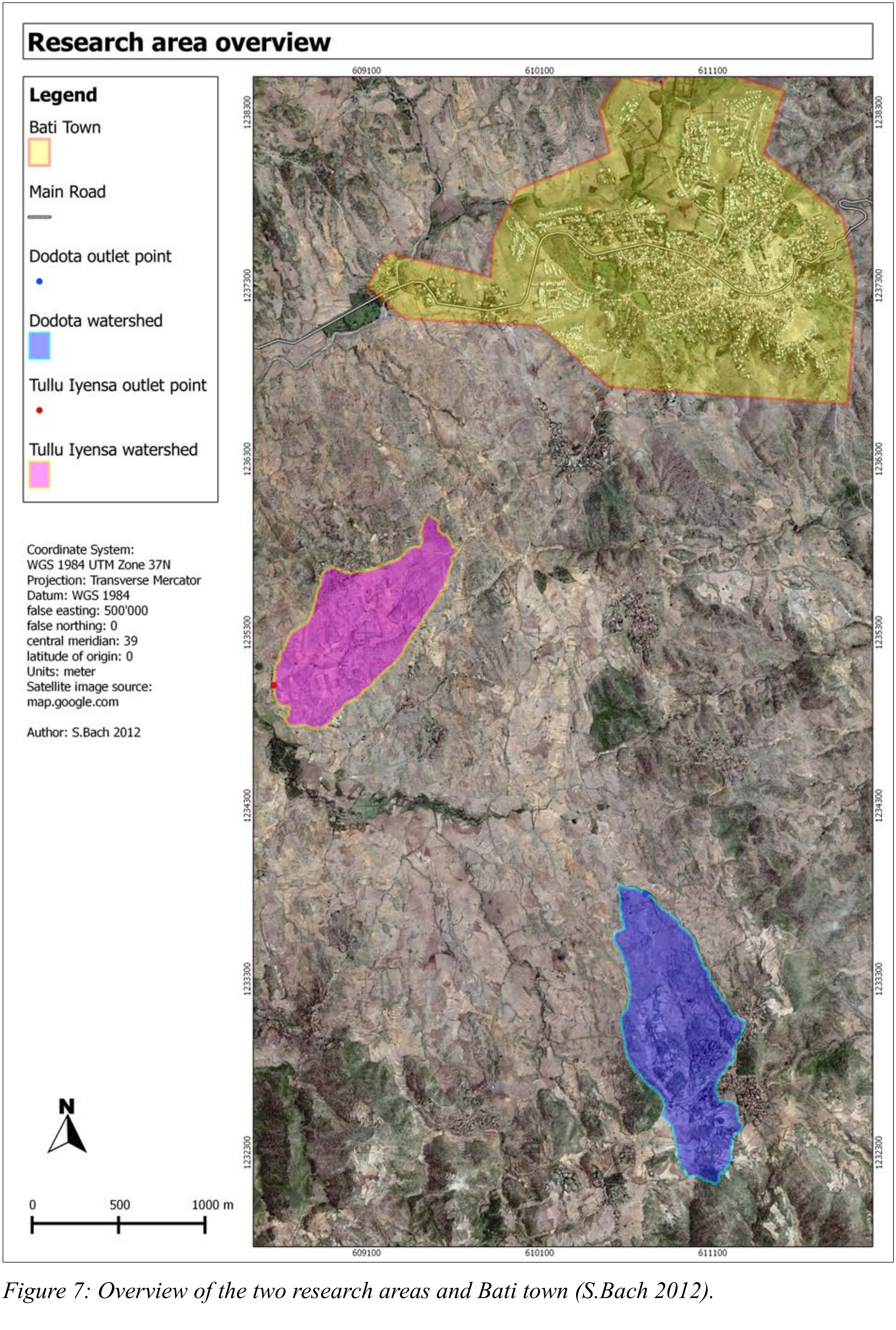

Figure 7: Overview of the two research areas and Bati town (S.Bach 2012).

Discussion of the research area overview

The reconnaissance trips show that there is already an awareness for soil and water conservation at farmer or watershed level in the area. SWC is conducted with different methods, some introduced by the Agricultural Office (stone walls, gabions etc.) others locally invented by farmers (e.g. Jatropha hedges for SWC).

Due to the support by the Agricultural Office (in earlier times and also sporadically today), farmers are somewhat used to that support and therefore still searching for it, no matter if monetary or food for work programs, although there are not always such programs available. This could hinder poorer farmers in adopting SWC technologies if they are waiting for another program to start. However the watershed groups seem to have their own regulation systems concerning land use and SWC and therefore also the power to supervise or to support each other in the watershed to a certain degree.

The watershed leader sees no alternative to Jatropha when rehabilitating degraded land. It seems not the best solution to focus on a single species since a possible pest has a bigger effect on such a system than a system with different species all vulnerable to different pests. Here it seems wise to improve farmer's knowledge and to introduce different solutions to them and not only one.

5.1.2. Land use, SWC technologies and the drainage line in the watersheds

As described in chapter 4, the soil and water conservation technologies, the drainage lines and the land use types are systematically mapped in the Tullu Iyensa (South-West of Bati) and the Dodota (South of Bati) watershed by GPS and categorized as Jatropha hedge, stone wall, stone wall and Jatropha (= Jatropha is planted in front of a stone wall technology) and Eucalyptus forest. The mapping focuses on technologies aiming to prevent or rehabilitate gully erosion, which occurs along drainage lines. These lines are defined as the lowest elevation paths within a watershed, where surface water runoff is most important. In some places in the selected watersheds, the drainage lines, are an active gully, and in other places

SWC technologies are hindering gully development, or have helped to rehabilitate gullies. Three categories are used to describe this drainage line or the gully (see table 1):

Drainage line type	Definition	Picture
Rehabilitated	No gully detectable in the drainage line. In some places remains of a gully are visible and in other places it is unknown if actually there was a gully once. The area of the drainage line is rather flat due to the alluvial soil behind the technologies and is interrupted with SWC technologies. Crop fields are common on the flat areas.	
Inactive	A gully is visible in the drainage line but its ground and sides are covered with vegetation, indicating no recent erosion processes. Additionally, SWC technologies might be implemented which hinder gully erosion.	
Active	A rill deeper than 50 cm. Clearly visible side and ground erosion. Bare soil and loose rocks visible, no vegetation cover either on the gully ground or on its sides. Fresh signs of side erosion are visible as well.	

Table 1: Definitions of the different types of drainage lines.

Additionally to the drainage line, land use types were mapped in both watersheds for comparative purposes, and in order to explain gully formation. Not only technologies and the drainage line play an important role but also the surrounding land use types. It seems more likely for a gully to develop on bare soil than in a forest with dense vegetation for example. And since people are involved in the research area not only land cover but land use types are mapped. Three different types of land use types are defined and mapped (see table 2):

Land use type	Definition	Picture
Cropland	As defined by WOCAT glossary 2012: an area used for growing crops. It is annually plowed. Crop residues are collected and stored off field for livestock feeding. The little residues remaining on the fields are eaten by livestock herds.	
Degraded bushy grazing land	According to the WOCAT glossary 2012 grazing land is used for grazing animals. Herds are often supervised by children. The livestock eats what ever possible: grass, shrubs etc. Therefore the area is overused, bare soil is visible at some places, interrupted vegetation cover. Little shrubs from time to time. Seldom trees.	
Village	A village is an accumulation of inhabited houses. Rural character with round houses and stables. Often hedges are protecting the direct area around the houses. Threes can be found around the houses.	

Table 2: Important land use types for this thesis.

A comparison of the two watersheds

Two watersheds were identified and mapped; one to the South of Bati named Dodota and the other to the South-West of Bati named Tullu Iyensa. (see table 3):

Area type	Dodota size [ha]	Dodota ratio [%]	Tullu Iyensa size [ha]	Tullu Iyensa ratio [%]
Total watershed	71.9	100	60.7	100
Cropland	42.4	59	31.4	52
Degraded bushy grazing land	24.3	34	28.3	46
Village area inside the watershed	5.2	7	1	2

Table 3: Area and land use statistics of the watersheds.

As shown in table 3, both watersheds are comparable in size, which was a precondition defined in chapter 4.1.2. The ratios of land use types are also comparable.

In order to see where possible gully erosion may occur, the drainage line is mapped and categorized according to the three above mentioned classes (see table 1):

Drainage line class	Dodota length [m]	Tullu Iyensa length [m]
Rehabilitated	1'597	524
Inactive	863	282
Active	0	987
Total length	**2'460**	**1'793**

Table 4: Drainage line classification of each watershed.

Table 4 shows the drainage line classification recorded through GPS survey. Tullu Iyensa has a large active gully, which will be described in detail in chapter 5.1.3. Dodota watershed has a lot of rehabilitated or even inactive drainage lines. The two watersheds have similar land use types but very different types of drainage lines, which increases the interest of comparison.

Technology type	**Dodota technology length [m]**	**Tullu Iyensa technology length [m]**
Jatropha hedge	97	4
Stone wall	1'200	476
Stone wall and Jatropha	313	38
Eucalyptus	40	0
Total length	**1'650**	**518**

Table 5: Type and total length of the technologies crossing the drainage line in Dodota and Tullu Iyensa watershed.

Dodota watershed was chosen because of its long Jatropha hedges crossing the drainage line and also because a lot of Jatropha is used in combination with stone walls (see table 5) On the other hand it is of interest what effect a low amount of technologies has on gully development like in the Tullu Iyensa watershed.

The two following pages show the end product of the mapping procedure - the Dodota watershed's- (see figure 8) and the Tullu Iyensa watershed's (see figure 9) overview map.

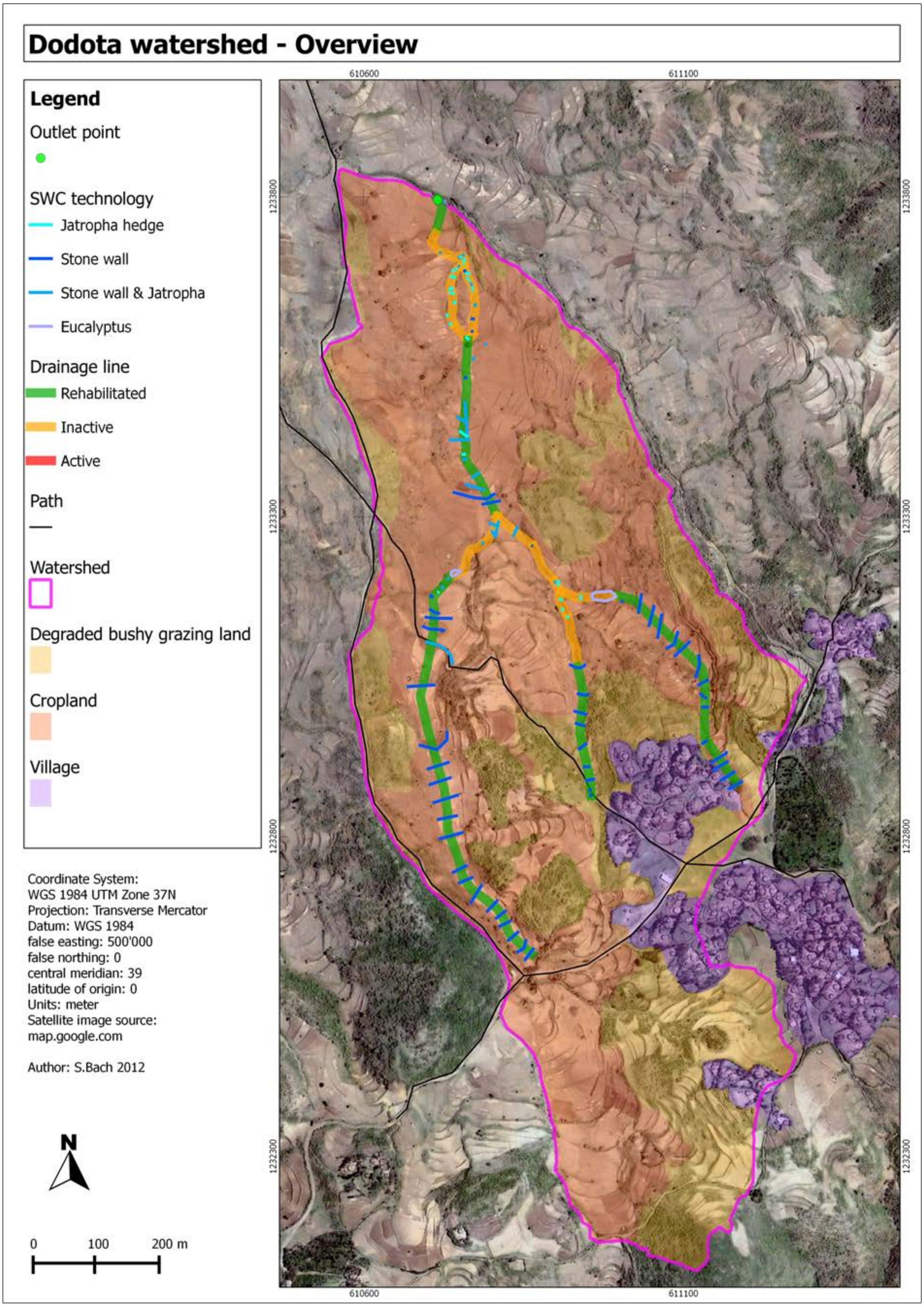

Figure 8: Technologies, drainage lines and land use types in the Dodota watershed (S.Bach 2012).

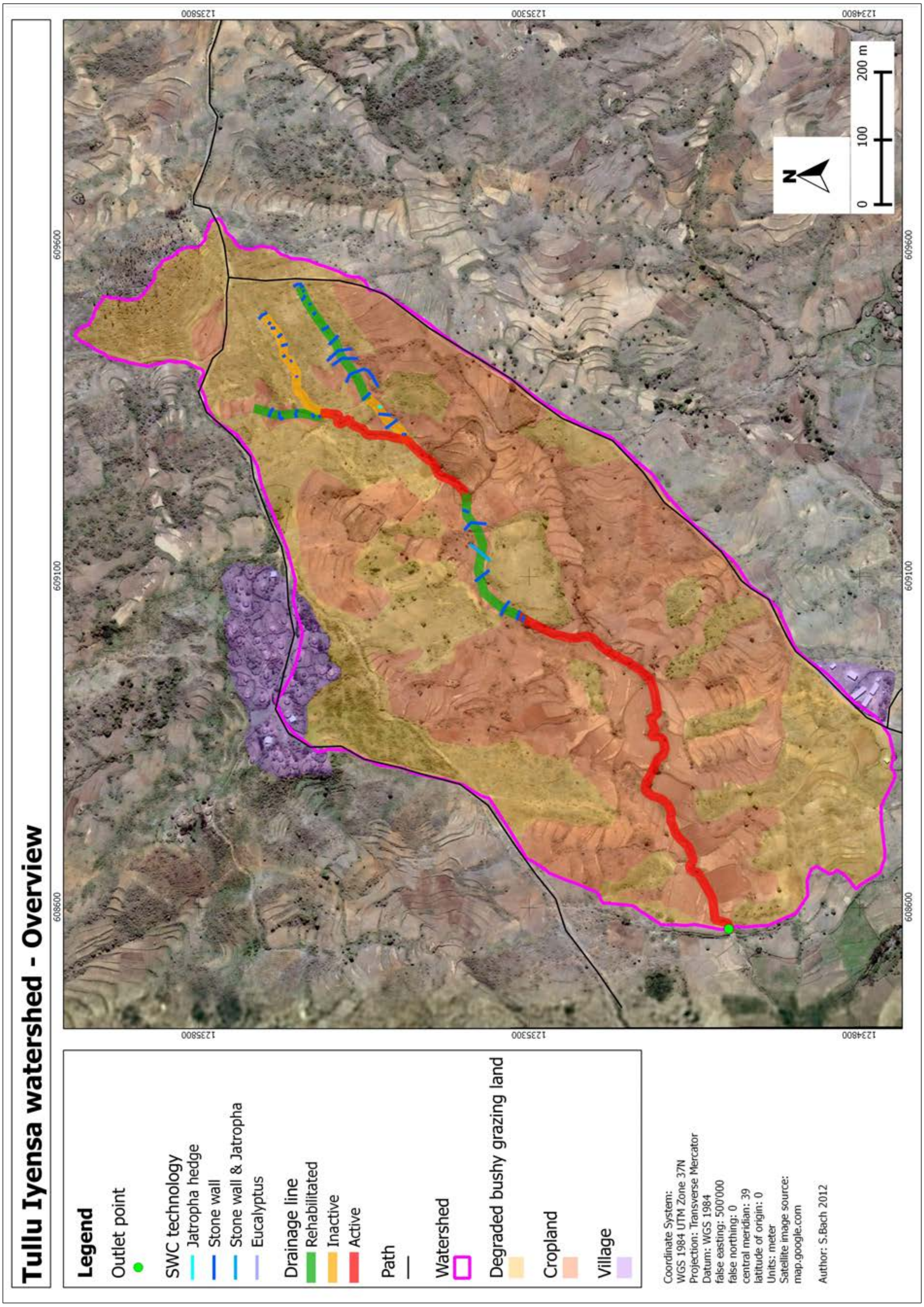

Figure 9: Technologies, drainage line and land use types in the Tullu Iyensa watershed (S.Bach 2012).

Discussion of the Land use types, SWC technologies and the drainage lines

The mapping of both watersheds shows the effects of barriers inside a gully. In the Dodota watershed, where a lot of technologies are implemented, the total drainage line is classified as inactive or even as rehabilitated. When no technologies hinder intensive runoff, gully formation is accelerated as shown on the Tullu Iyensa map.

In the two investigated cases the surrounding land use types do not seem to have a positive or negative effect on gully formation. Gullies can be found on cropland or on degraded bushy grazing land as the Tullu Iyensa map shows. Since both land use types do not have dense soil cover, it can be assumed that for example forests would perform differently. Also, the land use type does nod seem to affect the farmer's decision to implement technologies or not since technologies can be found on either land use type.

No functional difference between different technologies is visible if comparing the structures on the map Stone walls, Jatropha hedges, a combination of both or Eucalyptus forests perform equally well in hindering or stopping gully formation.

The Dodota village is bigger than the Tullu Iyensa village. It could be that since more people live in the surrounding area of the Dodota watershed, the pressure on land is stronger than in Tullu Iyensa watershed. Therefore it is necessary for people to manage the fields and soils as best as possible and therefore to invest in SWC technologies. On the other hand, for the smaller Tullu Iyensa village, the cropland area might be sufficient so they do not have to care too much for SWC technologies. But since demographic pressure on agricultural land is high in all Ethiopia, this conclusion is hypothetical.

5.1.3. The active gully in the Tullu Iyensa watershed

The large active gully in the Tullu Iyensa watershed is measured as described in chapter 4.1.3. At several points along the drainage line where it is classified as an active gully, measurements are taken (see figure 10). At each measurement point the elevation (from GPS reading), the width (w) and the depth (d) and the inclination to the next point are noted and the real length between each point (h) can be calculated through Pythagorean theorem (map length is measured on the map). It is then possible to calculate an approximate volume of the total soil loss due to that gully.

First the triangular area (A) at each point (the triangular cross section of the gully) is calculated by:

$$A_1 = \frac{w_1 * d_1}{2}$$

A_1 = triangle area at point 1, w = width of the gully at point 1, d = depth of the gully at point 1

The gully can be approximated as a pyramidal frustum with triangular areas. The volume (V) of a pyramidal frustum between two triangular areas (A_1 and A_2) with a given distance (h_1) is calculated with:

$$V_1 = \frac{1}{3} h_1 \left(A_1 + A_2 + \sqrt{A_1 A_2} \right)$$

V_1 = volume of the pyramidal frustum between point 1 and 2, h_1 = distance between point 1 and 2, A_1 and A_2 = triangular area at point 1 and 2

The real distance between two points is calculated with Pythagorean theorem:

$$h = \sqrt{l^2 + z^2}$$

h = real distance between two points, l = distance between two points on the map, z = elevation difference between two points

For each segment and the total gully the pyramidal frustum is calculated (see table 6 and figure 10):

Point alias	Depth (d) [m]	Width (w)[m]	Area (A) of triangle [m²]	Segment	Real length (h) of segment [m]	Segment gradient [%]	Volume (V) of pyramidal frustum [m³]
A	2.1	4.2	4.41	AB	26.7	15	70.6
B	1.1	2.2	1.21	BC	99.5	6	486.1
C	4	5	10	CD	35.5	15	520.1
D	4	10	20	DE	93.7	8	1'143.9
E	2.25	5.2	5.85	EF	233.8	5	6'586.4
F	6	20	60	FG	176.6	9	6'174.0
G	5	6	15	GH	162.4	4	2'433.0
H	3	10	15	HI	202.1	5	2'397.2
I	3	6	9	IK	155.4	4	1'279.5
K	3	5	7.5	KL	70.0	3	386.1
L	1.5	5	3.75			0	
						Subtotal	**21'477**
						Without segment EF	**14'890**
I	3	6	9	I OutletP	80.2	4	661.1
Outletpoint	3	5	7.5				
						From A to Outlet point without segment EF	**13'886**

Table 6: Dimensions of the active gully in the Tullu Iyensa watershed.

The calculated subtotal (all the gully line on the map, see figure 10) of lost soil is 21'477 m^3. Segment EF must be subtracted as it is classified as inactive. Therefore, a total of 14'890 m^3 of soil was lost between points A and L. However this number still includes measurements outside the actual research area (the delineated watershed). If in addition segment KL is subtracted and a new pyramidal frustum from point I to the outlet point is calculated, a total amount of 13'886 m^3 of soil is lost due to the active gully inside the research area. Approximating a soil density of 1kg/dm^3 this amount equals 13'886 tons of lost soil on a gully distance of 987 m.

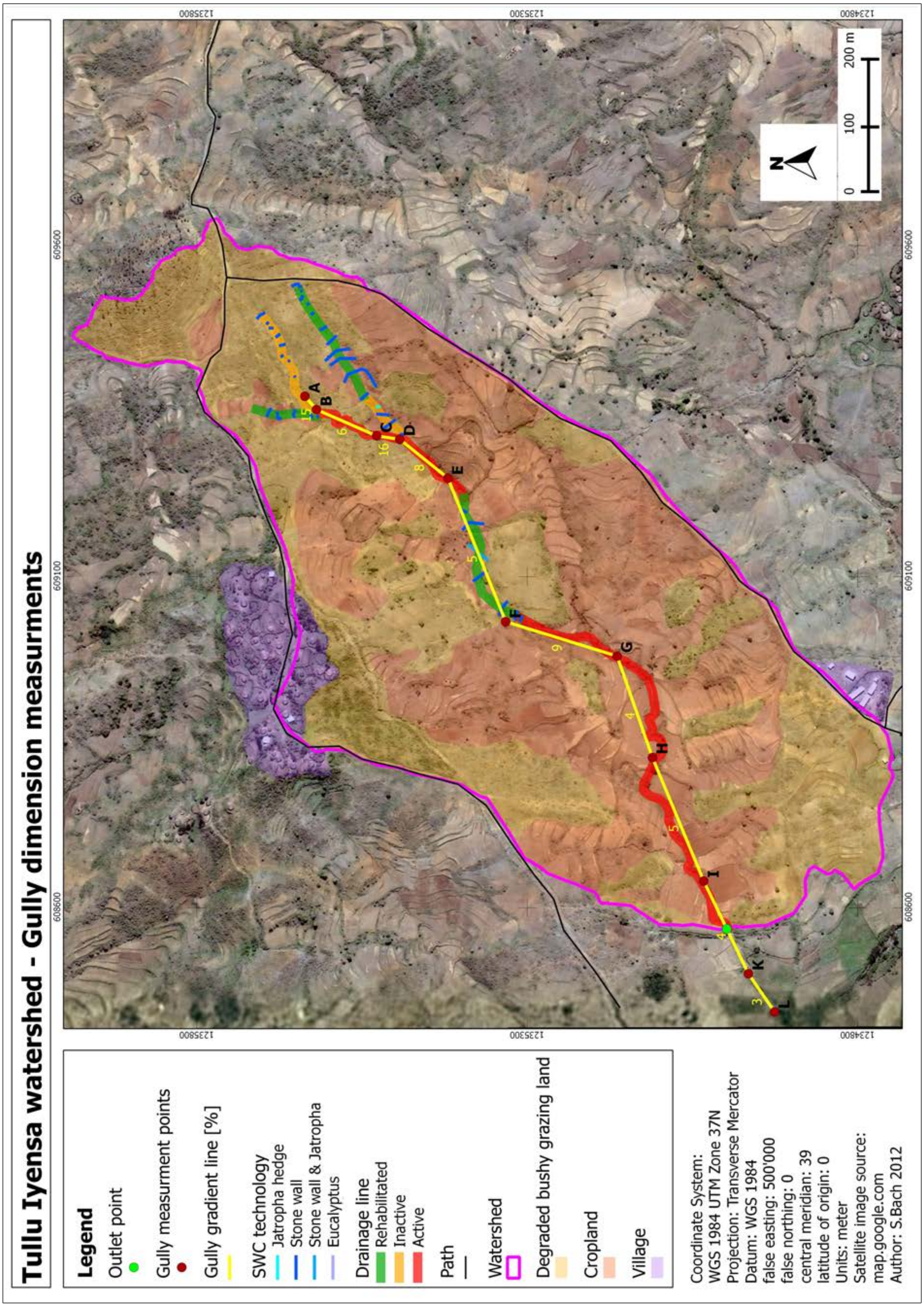

Figure 10: The gully dimension measured at each point. The yellow numbers are indicating the slope gradient measured from A to B etc. (S.Bach 2012).

Discussion of the active gully

A big amount of soil is lost due to the measured gully. However, farmers in the Tullu Iyensa watershed do not treat a large part of the gully. Maybe the gully is already too big to treat adequately. The bigger the gully gets the more work the technologies need to establish. Therefore it is crucial to treat gullies or rills right from the start since with little work input a very positive effect can be achieved.

Unfortunately it is not known how old the surveyed gully is, so bullet proof conclusions can not be made. But if farmers had treated it 10 years ago it can be assumed that far less work would have been needed to rehabilitate or mitigate it than today. At this point the advantages of Jatropha comes in to play. As shown in chapter 5.2. thanks to the the WOCAT results, Jatropha hedges need very little work and time input for establishment and maintenance. And since Jatropha hedges are not able to rehabilitate very deep gullies, they are most effective at the time of gully formation in earlier stages. In other words Jatropha should be used to prevent gully formation or to mitigate it at the beginning of the process. Therefore it is advisable as soon as rills establish on the fields to block surface runoff with a Jatropha hedge or with another barrier.

5.1.4. Vertical profiles of both watersheds

A vertical profile was computed for both watersheds. Elevation information is available from GPS mapping. There are not too much points available without any technology, but long distances of an uninterrupted line on the vertical profile also represent long distances of uninterrupted drainage line. Tullu Iyensa watershed contains 24 points of known altitude at structures or in the drainage line. Figure 11 shows the drainage line's vertical profile, whereas figure 12 shows the profile line on the map.

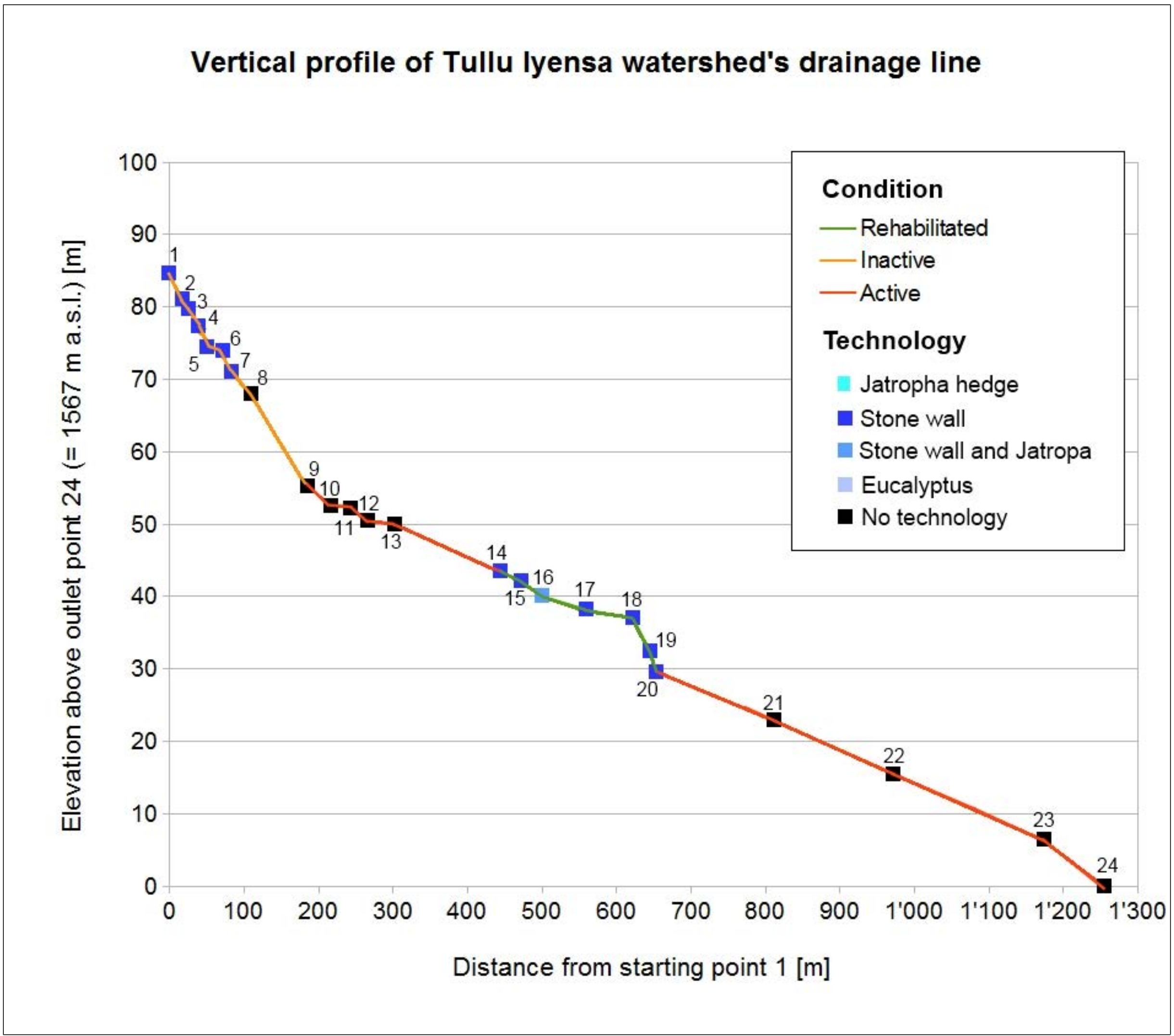

Figure 11: Tullu Iyensa watershed's vertical profile (S.Bach 2012).

The horizontal distance of the drainage line between starting point and outlet point is 1253 m. The vertical distance between outlet and starting point is 84 m. Totally 24 points are measured inside the drainage line and in average, between each of the existing 14 technologies a distance of 90 m is calculated.

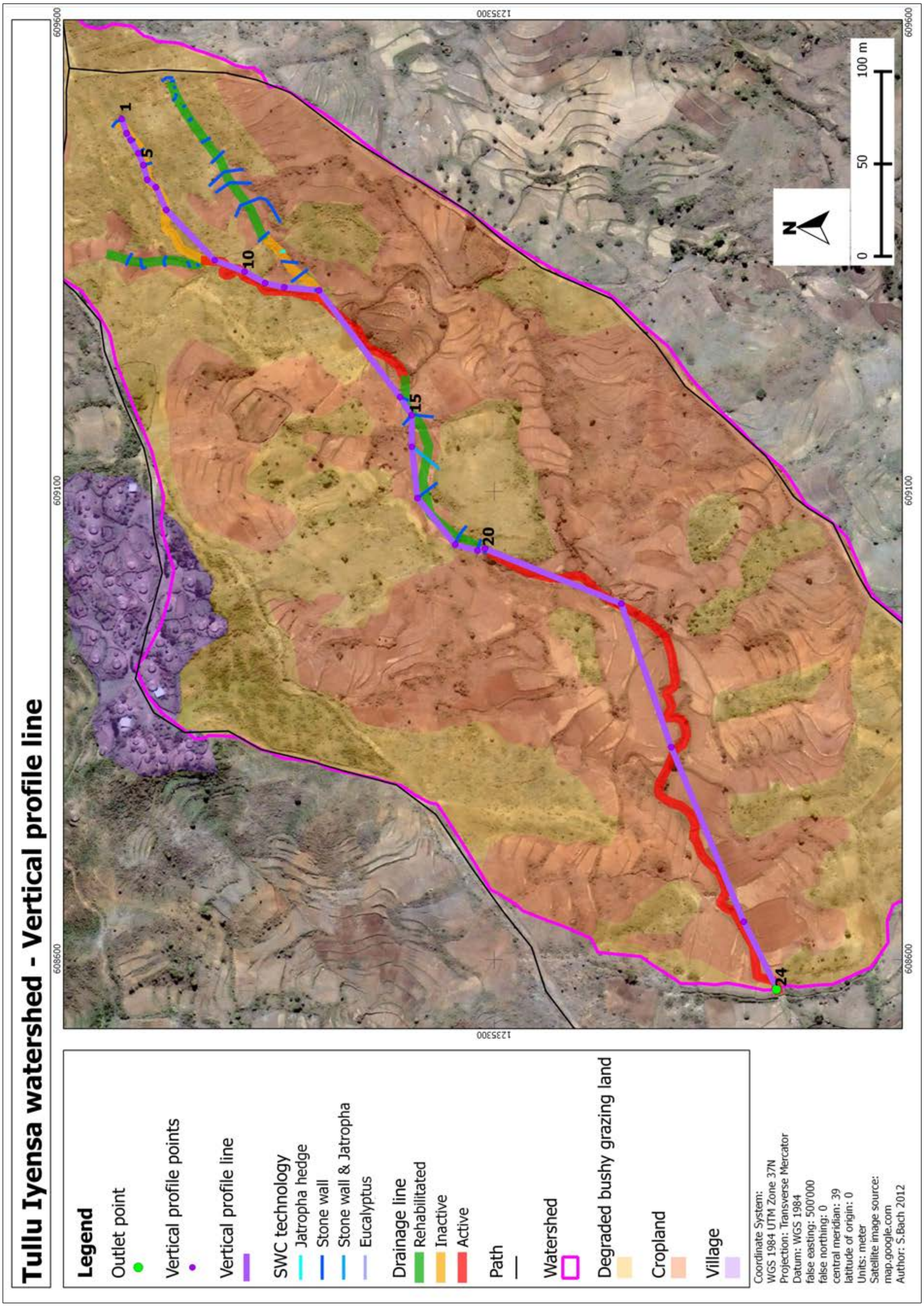

Figure 12: Tullu Iyensa watershed's vertical profile line on the map (S.Bach 2012).

The Dodota watershed's vertical profile was computed with 48 points of known altitude, mostly at structures. Figure 13 shows the drainage line's vertical profile, whereas figure 14 shows the profile line on the map.

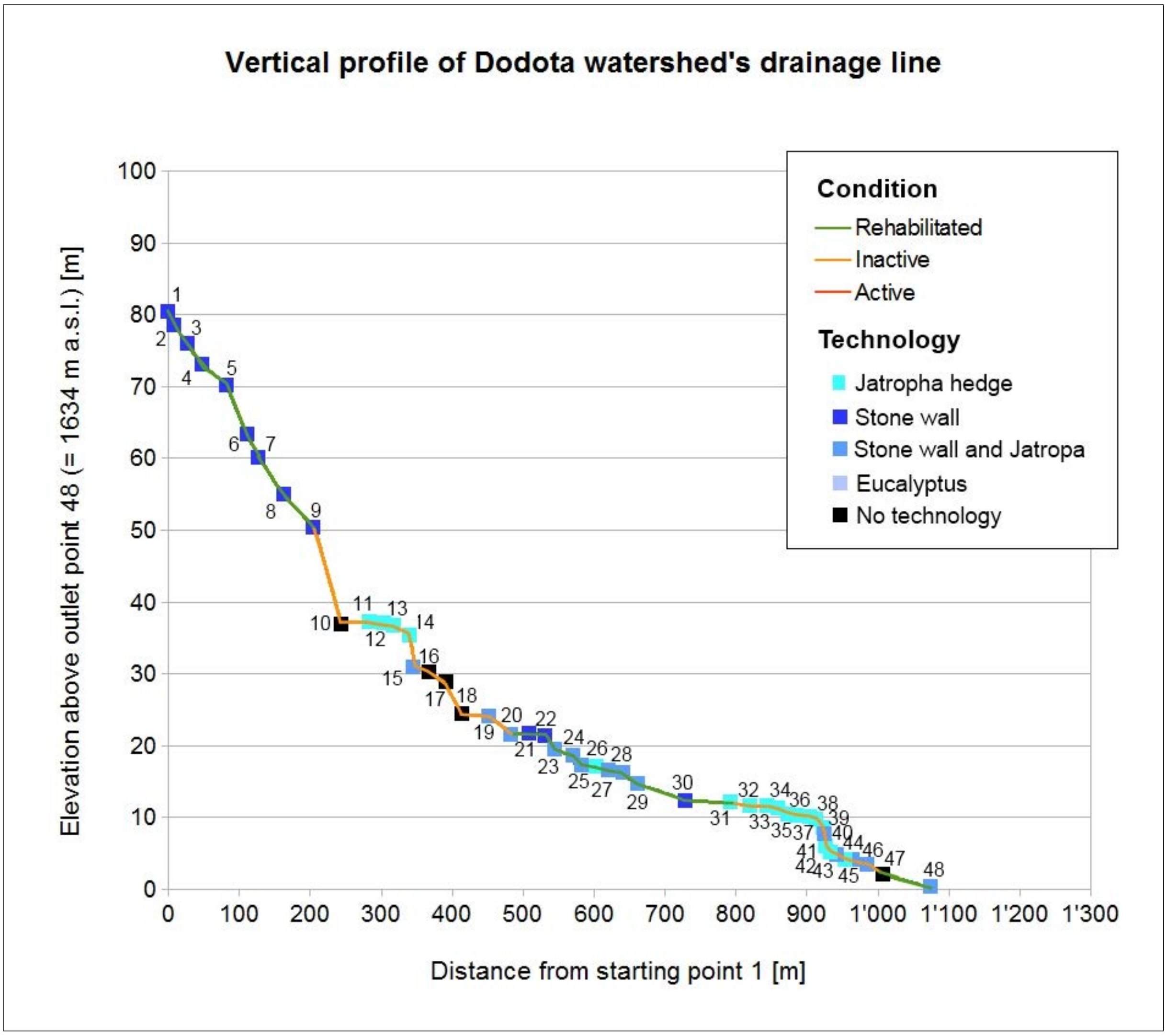

Figure 13: Dodota watershed's vertical profile (S.Bach 2012).

The total horizontal distance between starting point and outlet point is 1073 m with a vertical distance of 80 m with total number of 48 measurement points and 43 soil and water conservation technologies. So in average, every 25 m a technology is implemented.

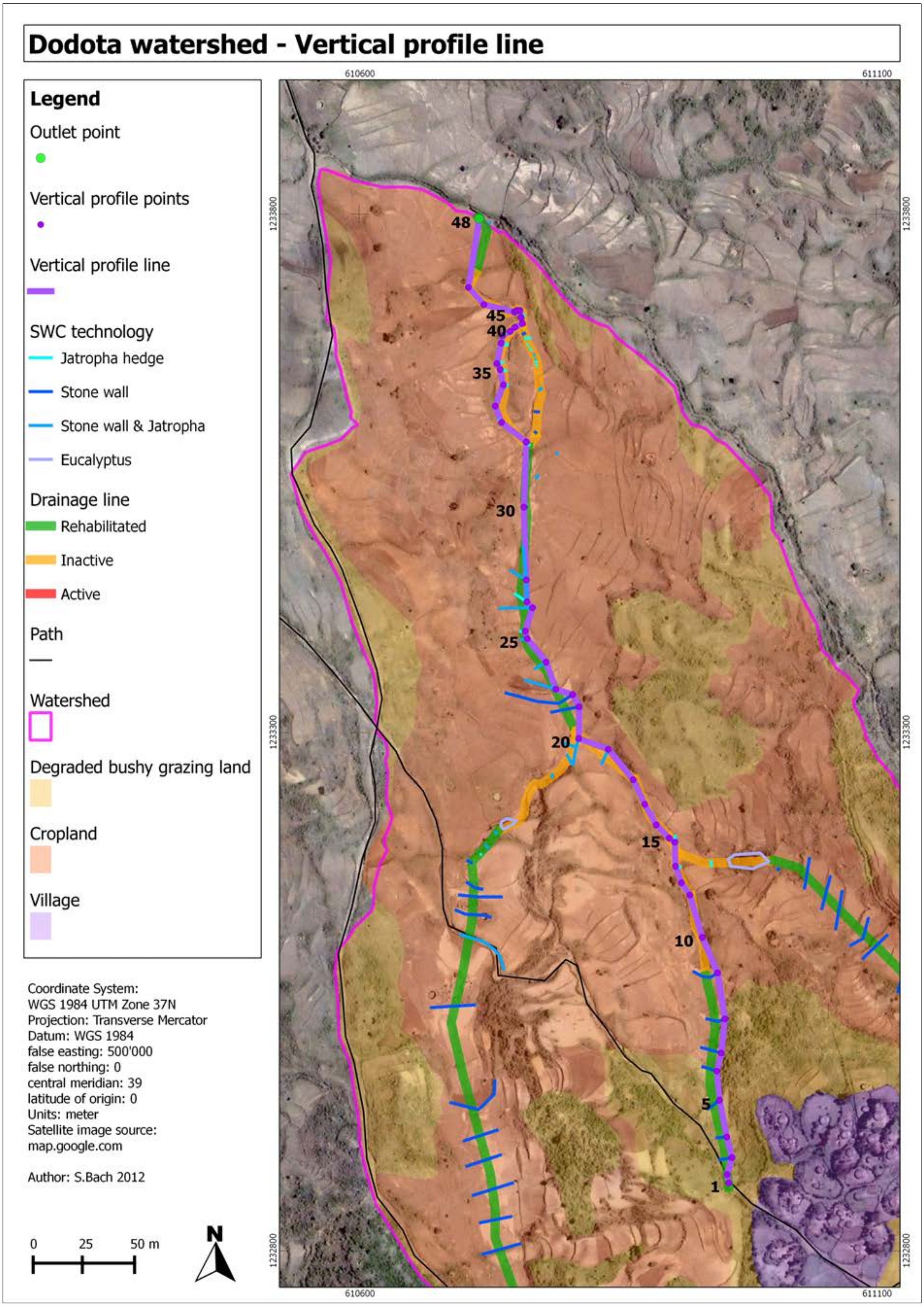

Figure 14: Dodota watershed's vertical profile line on the map (S.Bach 2012).

Discussion of the vertical profiles

The mapping has shown that both watersheds are quite similar in their land use types as well as their size. Therefore also a comparison of each drainage line with its vertical profile should be possible.

The horizontal distance from the starting point to the output point in Tullu Iyensa is approximately 200 m longer than in Dodota watershed but with almost the same elevation differences (4 m more). Therefore the vertical profile in the Tullu Iyensa watershed is flatter. But still more drainage line is categorized as active gully in that watershed. If the figures of both watersheds' profiles are compared the reason for that is visible - in Dodota watershed more SWC technologies are implemented in the drainage line than in Tullu Iyensa watershed (43 against 14 structures). As soon as technologies are implemented, the gully erosion inside the drainage line becomes inactive or the gully may even rehabilitate no matter in which watershed and in which slope gradient.

More technologies result in fewer space for farming activities. Whereas in Tullu Iyensa technologies have been put in place in average at every 90 m of horizontal distance, in Dodota watershed this value shrinks to 25 m. This value may be important to be optimized; at what point or what slope with what vertical distance technologies should be implemented? What distance is the most comfortable for farmers? Where can the best cost-income ratio be achieved? Further research is needed to answer these questions in detail, but generally it can be said that it seems wiser to implement too much technologies rather than risking the creation of a large gully like in Tullu Iyensa watershed.

5.1.5. Adapted spade analysis

At a Jatropha hedge across a gully and at a stone wall across a gully, soil samples were taken up- and downstream of each technology. This was done in both Dodota (table 7 and on the map in figure 16) and Tullu Iyensa (table 8 and on the map in figure 15) watershed. In addition, at a Jatropha hedge outside of a gully, soil was sampled as well (table 9).

Point	Location	Soil type	Particles	Structure	Surface cover	Top layer	Color
V1	downstream stone	sand+few stones	crumbs	crumbly	10%grass/90%bare	some roots/no crust	gray brown
V2	downstream stone	sand+stones	crumbs	crumbly	10%grass/90%bare	some roots/no crust	brown gray
W1	upstream stone	sand+gravel	crumbs	crumbly	30%grass/70%bare	some roots/no crust	gray brown
W2	upstream stone	sand	crumbs	crumbly	50%grass/50%bare	some roots/no crust	gray brown
W3	upstream stone	sand+gravel	crumbs	crumbly	50%grass/50%bare	some roots/no crust	brown
X1	downstream Jatropha	sand	crumbs	crumbly	50%grass/50%bare	grass roots/no crust	gray brown
X2	downstream Jatropha	sand	crumbs	crumbly	50%grass/50%bare	grass roots/no crust	gray brown
X3	downstream Jatropha	sand	crumbs	crumbly	50%grass/50%bare	grass roots/no crust	gray brown
Y1	upstream Jatropha	sand	crumbs	crumbly	70%grass/30%bare	grass roots/no crust	gray brown
Y2	upstream Jatropha	sand	crumbs	crumbly	70%grass/30%bare	grass roots/no crust	gray brown
Y3	upstream Jatropha	sand	crumbs	crumbly	70%grass/30%bare	grass roots/no crust	gray brown
Z1	DBGL	sand+gravel	crumbs	crumbly+stones	10%grass/90%bare	grass roots/no crust/stones	gray brown
Z2	DBGL	sand+loam	crumbs	crumbly	40%grass/60%bare	grass roots/no crust/stones	brown gray

Table 7: Soil samples taken in Dodota watershed.

Table 7 for Dodota watershed shows that for soil type, particles, structure, top layer and color it does not matter where the samples are taken. These characteristics are almost the same in all samples no matter if taken up- or downstream or at a distance from the technology. However, surface cover seems to be slightly affected by the technology since at the Jatropha technology there is more grass cover than at the stone technology or outside a technology on the degraded bushy grazing land. Surface cover also seems influenced whether the sample is taken up- or downstream of the technology - upstream samples show more grass cover than downstream samples. The degraded bushy grazing land samples are similar to the other samples but the surface cover seems to vary more than in the other samples.

Point	Location	Soil type	Particles	Structure	Surface cover	Top layer	Color
A1	upstream stone	sand	crumbs	crumbly	no cover/no crust	plowed	gray brown
A2	upstream stone	sand	crumbs	crumbly	no cover/no crust	plowed	gray brown
B1	downstream stone	sand	crumbs	crumbly	no cover/no crust	plowed	gray brown
B2	downstream stone	sand	crumbs	crumbly	no cover/no crust	plowed	gray brown
C1	DBGL	sand+stones	crumbs	crumbly	5%grass/bushes	5cm topsoil,rock	gray brown
C2	DBGL	sandy loam	crumbs	crumbly	50%grass/50%bare	grass roots	gray brown

Table 8: Soil samples taken in Tullu Iyensa watershed.

Table 8 for Tullu Iyensa watershed shows a similar result as table 7. Again, all factors are very similar including surface cover. The A and the B samples were taken at a technology in the middle of freshly plowed crop land and therefore the results are alike. The variation of surface cover seems highest on the degraded bushy grazing land.

Point	Location	Soil type	Particles	Structure	Surface cover	Top layer	Color
H	sub canopy Jatropha	sandy loam	crumbs	crumbly	sub canopy/up to 100%grass	lot of roots	light brown
H1	1m distance Jatropha	sandy loam	crumbs/blocks	crumbly	60%grass/40%bare	roots	light brown
H2	2 m distance Jatropha	sandy loam	crumbs/blocks	crumbly	40%grass/60%bare	roots+gravel	light brown

Table 9: Soil samples taken from outside the watersheds at a Jatropha hedge south of Tullu Iyensa.

In table 9, soil samples at a Jatropha hedge are shown. In these samples the surface cover seems the most varying factor. Grass cover seems to reduce the bigger the distance from the hedge gets. Further away from the hedge, approximately in 4 m distance, there is a plowed field that might influence the sample as well.

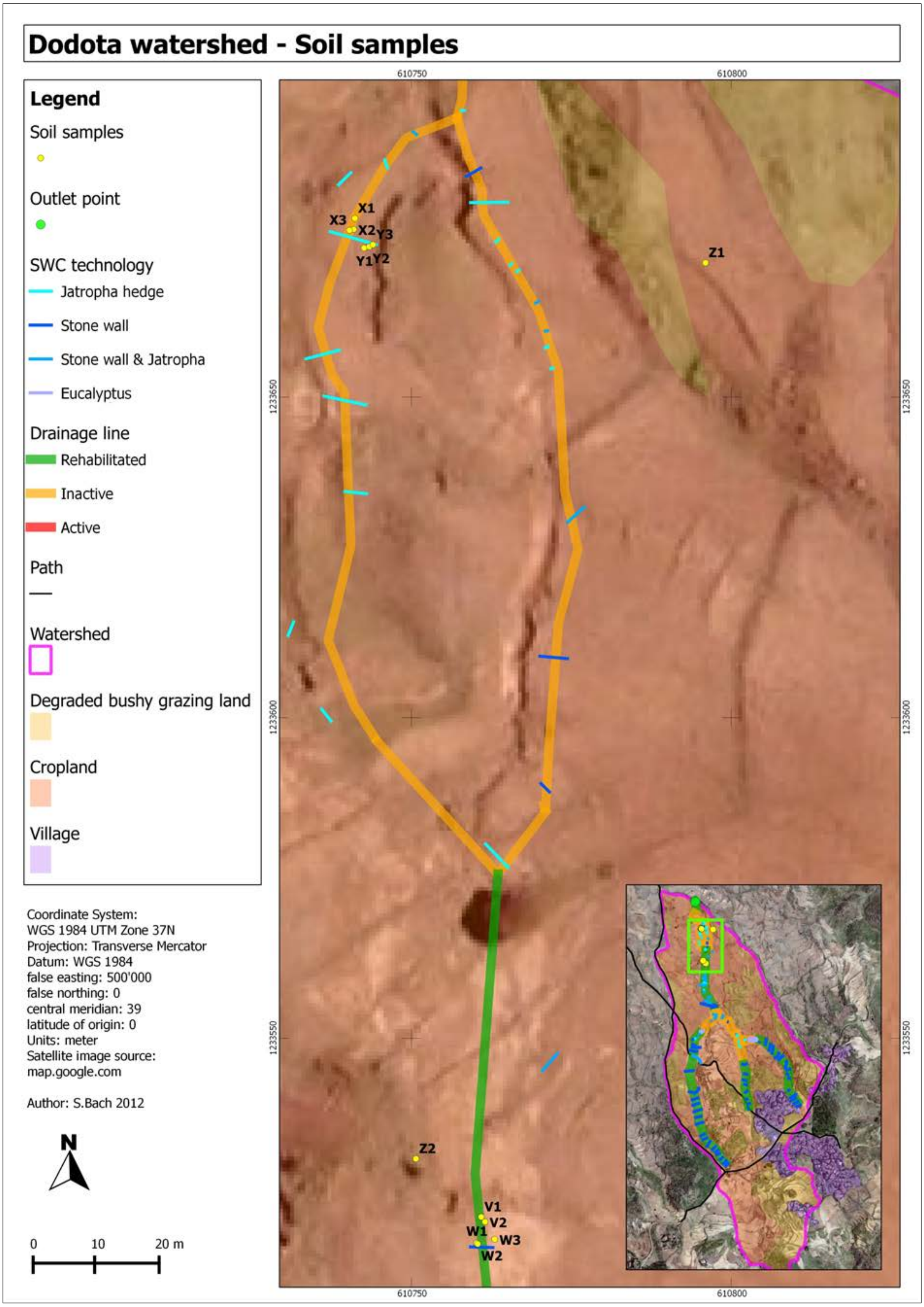

Figure 15: Locations of the soil samples in Dodota watershed (S.Bach 2012).

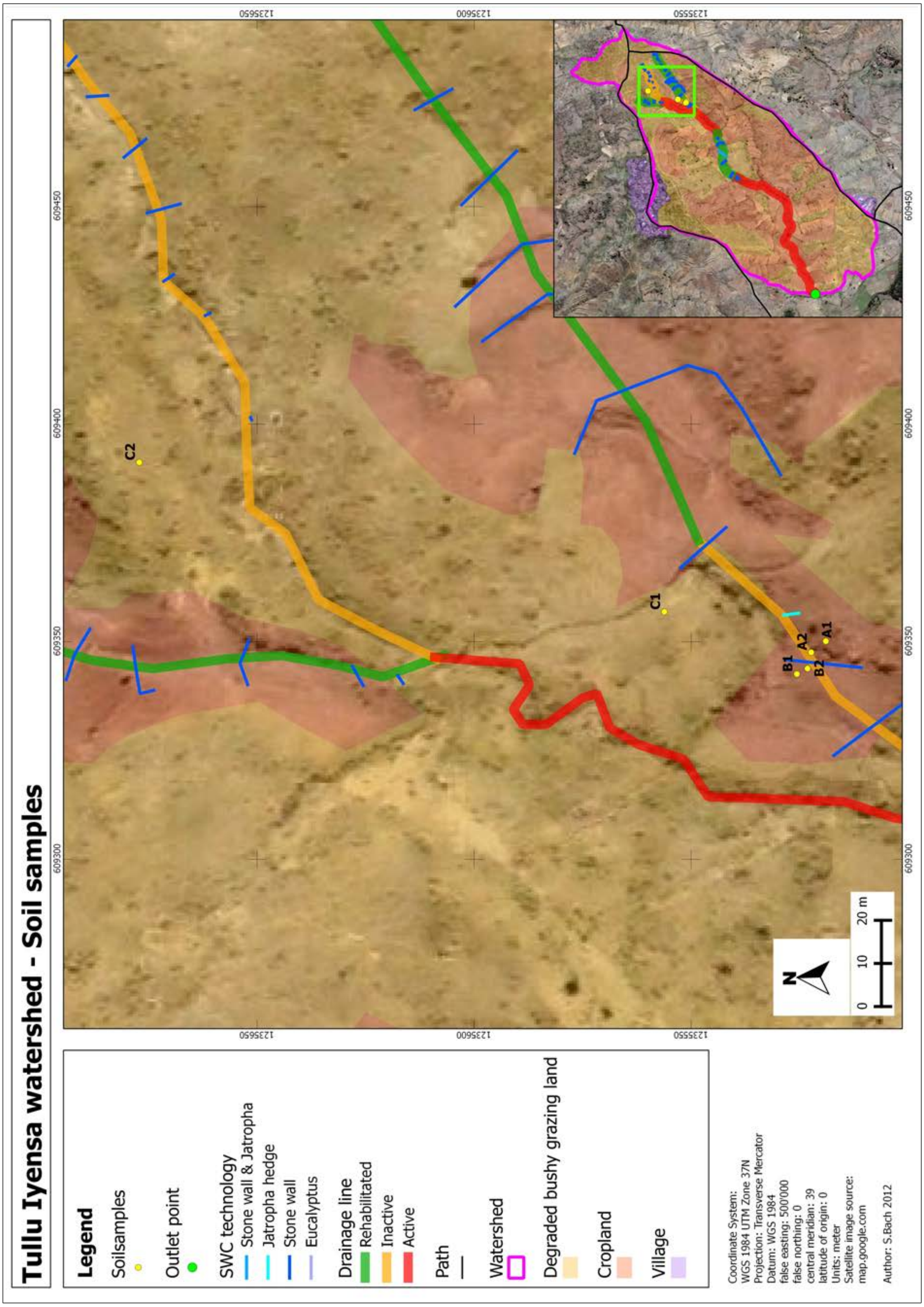

Figure 16: Locations of the soil samples in Tullu Iyensa watershed (S.Bach 2012).

Discussion of the adapted spade analysis

The adapted spade analysis shows that behind or in front of SWC technologies in the drainage line no significant difference can be found concerning the soil. Soil cover seems slightly influenced by the technologies, since upstream samples show denser grass cover than downstream samples. This could indicate a possible storage of water behind technologies. One has to be aware that only a few samples were taken. And it could be that farmers tend to plow near structures on the downstream side, and leave some space at the upstream side since the border of the technology is covered by soil (at least at stone walls).

The Jatropha hedge samples are not too meaningful since only three samples were taken. The sub-canopy sample shows a dense soil cover whereas further away from the hedge the grass density is more and more reduced. This is no proof for a possible effect of the Jatropha plant on soil cover since it could as well indicate how close to the technology the farmers plow the fields nearby. But under the Jatropha canopy a lot of litter can be found which likely has a positive effect on the soil.

5.1.6. Discussion of soil and water conservation technologies and the watersheds

The watershed assessment shows that in both watersheds the problem of gully erosion occurs. The investigations also show that the land use types of cropland or degraded bushy grazing land surrounding the drainage line do not seem to influence gully formation differently. In the Dodota watershed, the drainage line is more intensively treated than in the Tullu Iyensa watershed. Because of that, the Dodota drainage line is never classified as active whereas in Tullu Iyensa watershed a large active gully can be found. It is unknown why some farmers decide to implement SWC technologies and others not. This topic needs additional research in order to be answered. The vertical profiles computed for both drainage lines show a strong effect of SCW technologies on hindering gully formation. Slope gradients do not seem to play a very dominant role since the biggest active gully is found in a rather flat area in the Tullu Iyensa watershed. Due to this active gully, a lot of fertile soil is lost that is missing on the fields. The SWC technologies do not seem to have a dominant effect on the physical soil structure but since they are an obstacle in the farming fields grass may grow more easily because plowing is not possible.

The watershed assessment shows that it does not matter how rills and later gullies are treated but it shows the importance of a treatment. Although farmers need to establish and maintain SWC technologies, the benefits of higher soil fertility are very important. If farmers leave gullies erode, the bigger the gully gets the harder it becomes to rehabilitate and the more work is needed. Already simple techniques like putting some Jatropha sticks in the ground and creating a fence-like barrier help to stop gully erosion as seen in the Dodota watershed. It is therefore important so sensitize farmers to combat rill and gully erosion right from the start and not when it is too late and heavy work inputs are needed.

On the maps and also on the vertical profiles it is clearly visible that Jatropha hedges and stone wall SWC technologies are implemented rather chaotically wherever it seems right. Here a scientific approach to find best spacing between each structure might be helpful to improve the effect at watershed level. Farmers want to use as much land as possible and to lose as little land as necessary to such structures. Therefore it is important to optimize this tradeoff for the farmers needs. Through the network of the Agricultural Office the gained knowledge could then be distributed to the farmers. It is not likely and also not wise that already established structures are rebuilt in perfect spacing. But farmers could use that knowledge if new SWC structures should be constructed.

5.2. The technology assessment with WOCAT

To see how the different SWC technologies perform, it is important do describe them. To evaluate the technologies, the WOCAT questionnaires on technologies (WOCAT QT) were used in this thesis (the final WOCAT sheets can be found in the appendix). At the end, the findings from these questionnaires could be used to compare the technologies and to valuate them against each other in sake of their possibilities and their restraints.

5.2.1. Stone walls

The most prominent technology found in Bati region are stone walls. The walls are used as hill stabilization as well as gully rehabilitation technology. In this thesis the focus is on the latter.

To rehabilitate gully erosion, stone walls are built across the gully (see figure 17). The walls are built with two rows of larger stones approximately one meter apart from each other. The lowest line is established in the top 30 cm of the ground. The gap between these two larger stone rows is filled up with gravel and smaller stones or soil (whatever is at hand). After one layer is finished another layer is added on top of the previous one until the wall is high enough (often a few rows) to collect alluvial soil but not as high as to collapse. The wall itself is bent against the water flow up the hill.

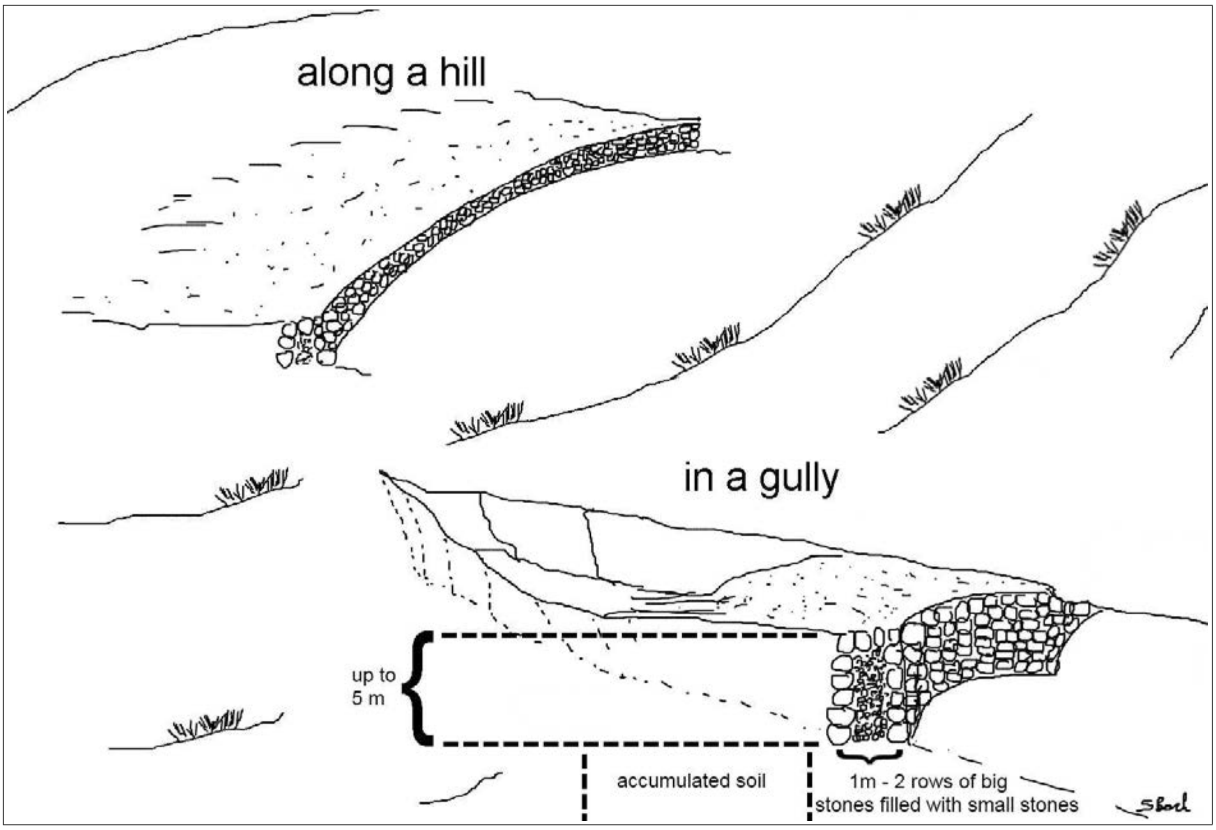

Figure 17: Sketch of gully rehabilitation with stone walls (S.Bach 2012).

As soon as the stone wall has silted up due to alluvial soil accumulation, new layers of stones are added on top of the previous layers. This procedure continues until the gully is fully rehabilitated or until the farmer decides that no more soil has to be accumulated.

Discussion of the stone wall technology

Stone walls are widely used in the research areas not only for gully rehabilitation but also for hill stabilization. Once established the walls are stable and need maintenance only after heavy rainstorms if the wall is partly damaged. Deep gullies can be rehabilitated with stone walls since it is only a matter of work and time to construct the wall in desired height.

To establish the walls a lot of work and time is needed which hinders people from pursuing farming activities. Maintenance of the walls is also time consuming. Since the gully silts up over time, also the wall has to increase until the gully is totally rehabilitated. After every rainy season farmers need to increase the wall's height. Know-how is needed on how to construct the walls stable enough so they do not collapse in the first rain storm with a lot of runoff. In the research area, this point seems less important since almost on every farmer's plots stone walls can be found and knowledge seems to be available within the communities.

5.2.2. Jatropha hedges

One technology mainly found in the Dodota watershed are Jatropha hedges planted across gullies to prevent gully erosion. The hedges are also used in combination with stone walls where Jatropha is planted in front of the wall or on the wall itself. Since this thesis is focusing on gully erosion, the following evaluations are as well focusing on Jatropha hedges used for gully prevention and mitigation (see figure 18).

The most prominent form of Jatropha propagation in Bati is by cuttings. Jatropha cuttings can easily be accessed since hedges or single plants are scattered throughout the countryside. Therefore access to Jatropha is considered free (after one time initial sawing or planting 30 years ago). After cuttings are collected the farmer puts them in to the ground across the gully (both actions are taking place in dry season). Each cutting is planted as near to the next one as possible to reduce the gaps in between. The gaps are further filled up with small stones or branches or other litter found in the surrounding area. No further inputs are needed. Once the plant has rooted it is able to collect alluvial soil during wet season. In the event of a large water flow, the freshly rooted cuttings are thin enough to resist the flood and flexible enough to bend in the water.

If the plant barrier has silted up, the gaps between the stems further up the plant are closed with additional litter. With this method a soil collection up to 1 m is possible since that is the approximate stem height (where it is still thick and stable enough). To avoid shading on their fields next to the Jatropha technologies, farmers prune the plants each year before the wet season starts.

According to the farmers, up to 0.5 kg of Jatropha seeds can be collected for every meter of hedge. Up to now, the seeds are sold on the local market. But farmers stated that if the seeds are crushed, the resulting paste is used to smooth the clay plate for Injera baking.

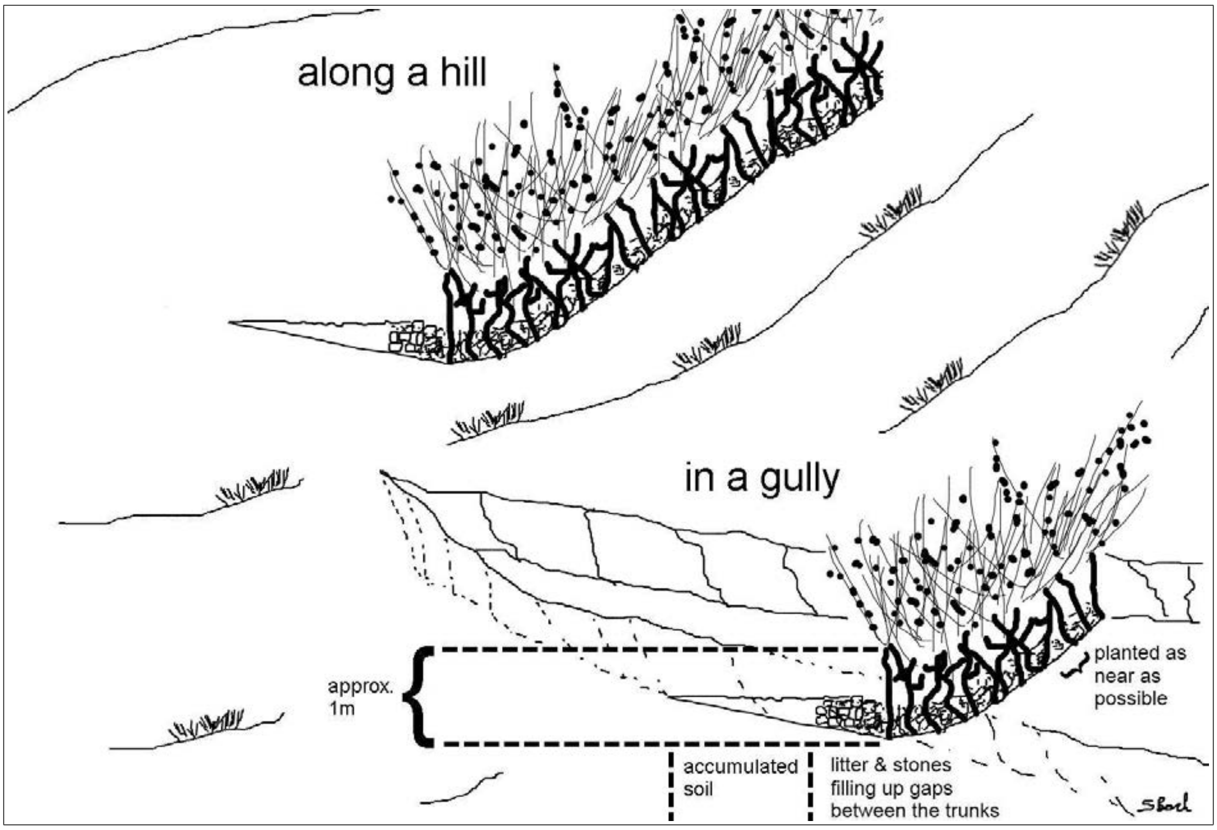

Figure 18: Sketch of gully rehabilitation with Jatropha hedges (S.Bach 2012).

Discussion of the Jatropha hedges technology

The Jatropha hedge SWC technology is not too widely spread in the Bati area. However, the plant is commonly known as a good life fence and some farmers started using Jatropha also as SWC technologies in recent years. This type of SWC technology is very effective in early stages of gully or rill erosion (as a prevention or mitigation technology) since it does need little input to achieve good results. The Jatropha cuttings just have to be cut somewhere and stick into the ground. Once rooted, the plants are flexible enough to survive even heavy runoff. But if not yet rooted, the cuttings might be washed away during heavy runoff.

A possible drawback of the technology is that it is not scalable. If the gully has silted up in height of the main stem the technology's height can not be increased without adding a new row of plants on the newly established higher ground. If this method is conducted the farmer also loses more land than with the stone wall technology.

Since the farmers prune the plant to avoid shading and water competition, they also minimize Jatropha seed yield. Further research is needed to optimize Jatropha seed yields and also minimize negative effects of the plant to the food crops on the plots next to the technologies.

5.2.3. Jatropha hedges and stone walls in combination

In the Dodota watershed Jatropha hedges are sometimes combined with stone walls. Farmers are trying to enhance the stability of stone walls by planting Jatropha hedges in front of the walls. At some places the plants are as well planted on the stone wall itself (see figure 19).

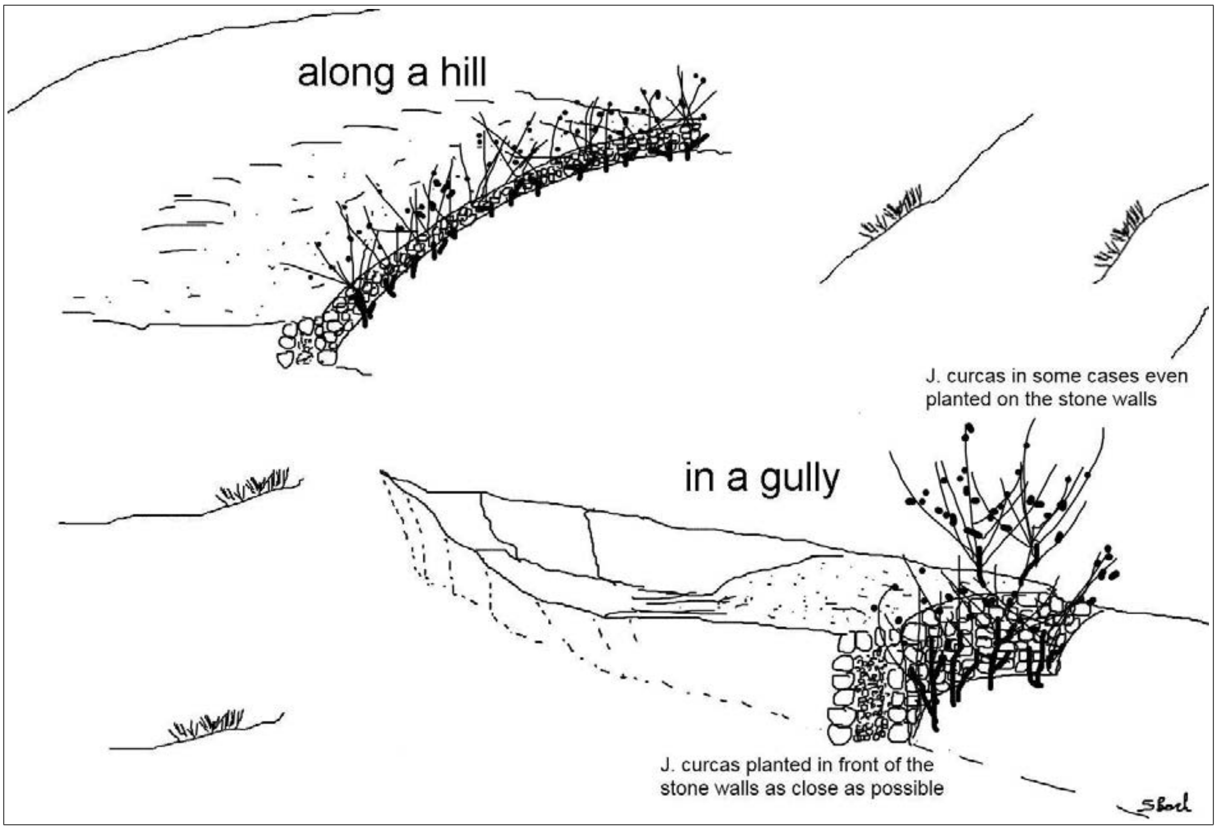

Figure 19: Sketch of Jatropha hedges in combination with stone walls (S.Bach 2012).

Discussion of a combined Jatropha and stone wall technology

Sometimes a combination of the two aforementioned technologies can be found in the research area. However it remains questionable if planting Jatropha on stone walls is not damaging them rather than being useful. But if Jatropha is planted in front of the stone wall it might work like a gabion net and holding the stone wall in its place during a heavy rain storm for example. But since the main stem of the plant is not too thick it remains unknown to what degree of pressure the plant is able to fulfill this “gabion function”. Additional research is needed to answer these questions.

5.2.4. Economic comparison of both technologies

Since Jatropha as well as the stones are collected for free by the farmers, construction time is the dominant cost driver. According to farmers the local daily rate payed by the Agricultural Office in their work program is 1$ (16 Birr) or the equivalent amount of food. This daily rate is thus used for the further calculations.

Calculations in table 10 are made for 1 ha of treated land by each technology. It is assumed that the hedges or the walls are 100 m long and the spacing between each row is 20 m. The total technology length is therefore 500 m for 1 ha (5 rows x 100 m length). For stone walls it is assumed that the wall is 500 m long, 1 m high and 1 m wide.

For establishing stone walls, farmers experienced some support in recent times (food or cash for work) by the Agricultural Office. Farmers implement the structures by themselves as well but are still seeking support. In the field it is difficult to tell which farmer is supported or not. The interviewed farmers are not supported at the current time.

Economic comparison shows that Jatropha hedges are much cheaper than stone walls (see table 10). The main cost driver for both technologies are labor costs per day, so indirectly the time needed to establish the technology. It is calculated that where 500 m of Jatropha hedge can be established within 30 person days 500 m of stone wall structure need 1166.5 person days. As logical consequence the stone walls are therefore much more expensive than the Jatropha hedges.

Jatropha hedge activity	**Quantity per person**	**Required person days for 1 ha (500m)**	**Stone wall activity**	**Quantity per person**	**Required person days for 1 ha (500m)**
Cutting (500m)	40 m/d	12.5 d	Preparation of stones (500m^3)	1 m3/d	500 d
Planting (500m)	40 m/d	12.5 d	Digging of foundation (500m)	3 m/d	166.5 d
Filling the gaps with litter	100 m/d	5	Building of stone wall (500m)	1 m3/d	500
Total person days for 1 ha		30 d	Total person days for 1 ha		1'166.5 d
Total costs (1$ daily rate)		**30 $**	**Total costs (1$ daily rate)**		**1'166.5 $**

Table 10: Comparative calculation of establishment costs for Jatropha hedges and stone walls for a total length of 500 m.

Discussion of the economic comparison

It is clearly visible that Jatropha hedges outperform the stone wall technology in economic terms due to the easy way of establishment. It is depending on the actual situation whether Jatropha structures are actually the better solution than stone walls. If a large gully has to be rehabilitated it is wiser to use stone walls since they can be built up on a rather small area of land whereas Jatropha hedges do not perform well if rehabilitating deep gullies. In that case several rows of Jatropha hedges have to be planted with a bigger area of lost land that is not available for agriculture anymore.

It remains questionable if directly comparing both technologies like done above, is adequate, since in earlier times farmers received support through food for work programs to establish stone wall technologies or other SWC technologies. During a food for work program the more expensive stone walls might be cheaper for a farmer to establish than the Jatropha hedge which is not supported through the program. Here additional research is needed that takes an in-depth look of the costs and benefits of these technologies. For this thesis however, the Jatropha hedges are the cheaper technology for the farmers and also the easier one to implement if no support is available.

5.2.5. Integrated analysis of the SWC technologies according to WOCAT

Following chapters summarize the WOCAT QT within the three dimensions of sustainability. The WOCAT questionnaire data outputs can be found in the appendix of this thesis.

Production and socio-economic benefits and drawbacks

Due to reclamation of land, both Jatropha and stone wall technologies create space for new fields and are therefore contributing to farmer's income (in form of crops and cash). Because of these additional plots of land farmers are less vulnerable to yield failures.

Jatropha hedges lead to diversification of farm income. Cuttings can be sold or used by farmers themselves. The leaves and seeds are used for different purposes (medical application, smoothing of the clay plate for Injera baking) and can be sold on local markets. A market for Jatropha seeds as a biofuel source would also benefit farmers since they could sell seeds in bigger quantities to biofuel factories.

A possible drawback is that although both technologies enable the access to new land they also require land. In addition Jatropha hedges compete for water and sunlight with nearby crops.

Since both technologies need labor inputs they may also compete with other farming activities. However, Jatropha hedges seem to need less labor input than stone walls for both, establishment and maintenance work.

Socio-cultural benefits and drawbacks

Both, Jatropha hedges and stone walls are used in the Bati area. Farmers have realized that these technologies their functions work in terms of soil and water conservation. Therefore knowledge about erosion control and SWC may spread through positive examples throughout the community.

If the plant gets more attention world wide, farmers focus production on this plant and loose their multi-strategies in growing different products and keeping livestock. This must be seen as a negative impact of Jatropha cultivation since multi-strategies are very important to sustain farmers livelihood.

Ecological benefits and drawbacks

Because Jatropha hedges and stone walls are both able to accumulate water, they increase soil moisture which may lead to better yields. Because the fields behind the barriers are silted up soil, they are quite flat and are less vulnerable to surface runoff and soil loss, which may lead to even higher water availability behind the technologies.

In the case of Jatropha hedges the shading may help to reduce evaporation. The plant's litter could be used for mulching that reduces evaporation as well. Again more water is available on the field. In addition, Jatropha hedges are a windshield, create additional biomass and even help reducing atmospheric emissions or greenhouse gases.

Disadvantages of both technologies are mainly created by the barrier effect. Since water is captured or even stored, water logging becomes more likely. Both technologies are as well creating new habitat for rodents or other pests. As already mentioned, Jatropha hedges compete for water and sunlight with the surrounding plants. Since Jatropha may grow up to approximately 4 m, crops do not outgrow it.

Off-site advantages and drawbacks

Because both technologies are barrier structures they hold back water. This can lead to ground water recharge or even spring development further away from the technologies. Down-stream population benefits from cleaner water containing less sediments. Because water flows slower through the ground than on the surface, the technologies buffer water flow and enhance water filtering. Surface runoff is reduced or even prevented and therefore there is less damage on neighboring fields or infrastructure.

Because soil siltation through runoff is hindered, down stream farmers may not be able to rehabilitate their gullies or plots of land as well through alluvial soil. Also water is held back by the structures and is therefore at first available for the farmer with plots behind the technology. Downstream farmers might become dependent on this farmer's behavior to get enough water for themselves.

Discussion of the integrated analysis of the SWC technologies

As seen in the previous chapters Jatropha hedges as well as stone walls have potential advantages and drawbacks on-site as well as off-site and in all three dimensions of sustainability. Therefore it is important that farmers have clear indication on how to choose the most appropriate technology.

It is advisable to use Jatropha hedges in early stages of rill and gully erosion since the plant is capable of mitigating these soil erosion effects quite easily or even prevent erosion at all. Stone walls are more suitable in deeper gullies as a rehabilitation technology.

Jatropha hedges have the advantage of a secondary use of the plant's seeds and of other byproducts. Since farmers prune the plant to avoid sunlight and water competition with crops, this secondary use is not yet fully exploited. Here a balance between a good Jatropha seed yield and low competition with other plants has to be found. Other parts of the plant are used as well for example the leaves for medication purposes. Considering the plant's potential, additional research is needed: can the oil be used as lubricant, what are medicinal potentials of all the plant's parts, is it really harmless to use Jatropha oil for smoothing the clay plate for

Injera baking since it is a toxic plant etc.

If the selling of Jatropha seeds should once become lucrative, a system to avoid inequality has to be implemented. One solution could be that farmers work in cooperatives so poor farmers can also profit from Jatropha although they may only provide small yields. It should be avoided that farmers focus on Jatropha seed production only since that would make them more vulnerable to global markets and prices and their fluctuations. Best solution is, if farmers take up Jatropha as an additional possibility in their multi-strategy.

On the ecological side it is important to have profound knowledge on Jatropha to avoid pests or diseases in the region since the plant is not domestic in that area and long term effects of growing and using it are unknown. Jatropha's chemical effects on the soil are little known no matter if in form of litter on the ground or the plant itself.

The effects of water logging behind each type of structure was not looked at in this thesis. But since Jatropha structures have bigger gaps between each plant than the stones have between each other, it is possible that Jatropha hedges are less prone to water logging than stone walls. But additional research may be done to investigate sub-soil effects on water flow of Jatropha SWC technologies.

5.2.6. Discussion of the technology assessment by WOCAT

The WOCAT assessment shows that both technologies, Jatropha hedges and stone walls, have advantages and disadvantages, which also depend on the environment in which each technology is implemented (e.g. prevention technology, rill erosion or deep gully erosion). Due to the fact that the WOCAT questionnaires are a standardized tool these findings are now available through an online database to whoever searches for gully mitigation and rehabilitation technologies. With that database, users can estimate if one of the two investigated technologies also fit in their specific context. If so, they now can easily adopt it. In the case of the Jatropha hedges, locally invented SWC technologies are then available to a global community.

As already mentioned, the surveyed technologies mainly base on farmer's initiative (especially the Jatropha hedges) and may not yet be perfect in some aspects. Here science may play an important role in trying to optimize these technologies. In the research areas the technologies are implemented quite chaotically wherever needed. A perfect spacing between each structure may be established through additional research to optimize the tradeoff between soil and water conservation and the loss of cropland due to these SWC technologies.

5.3. Jatropha as an energy crop at local scale

Although farmers of the above mentioned watershed groups plant Jatropha mainly for the purpose of soil and water conservation, some are aware of the extractor to be built in the near future by the CHF (Canadian Hunger Foundation) mentioned in the informal interview with the local expert. The watershed groups want to sell seeds to the people running the extractor as soon as it starts working.

5.3.1. The informal interview with a local Expert

A talk was conducted with the local soil and water conservation expert of the Agricultural Office to assess the current usage of Jatropha in the research area. At the moment of the interview his team was traveling throughout the countrysides to sensitize farmers to carry out the so called “watershed approach”: It is important to sensitize farmers not only to protect their own plots of land but to encourage them to organize themselves in groups to take care of entire watersheds from the highest point to the outlet to reach a sustainable soil and water management in all plots of land. The Agricultural Office shows farmers with what kind of inputs they can protect the soil.

The questions for the interview came up during the field work. The talk itself took place at the end of the fieldwork in Mai 2011 and was not recorded electronically.

How is Jatropha currently used in the Bati area?

It is used as a biological conservation measure and - most importantly - for fencing. All fences in the Amhara Region would reach a price of 10 million Birr [0.58 mil.$ 30.08.2011, *author's note] if built with conventional material. Fences build with Jatropha are for free so they help to reduce these amount of 10 mil. Birr in the moist deficit areas of the Amhara Region.*

Jatropha seeds are sold on the local market for a price of six to eight Birr per kilogram [one Birr = 0.06$ 30.08.2011, author's note]. From one hectare of land it is possible to gain 600 kg of seeds per year. People use the seeds for different purposes:

The seeds are crushed and the residual substance containing oil and crushed hull is used for treating animal hides. Another use is to string seeds on a wire and use them as a light: The top seed can be lit with fire and it then slowly burns down and lights the lower seed again and the light continues burning until the last seed. After crushing the seeds the remaining substance is also used for smoothing the clay plate for Injera baking or for treating wounds of animals. The seeds are also propagated in their original form to be used as seeds for direct sowing.

The leaves of Jatropha are crushed to a paste, which is used for wound treatment of animals and humans, especially for treating burnings. The leaves are also used as a pesticide: After crushing them some water is added and the mixture is left for some time. After the liquid has fermented it can be filled in a spray and used as a pesticide in the field. The leaves can also be used as fertilizer or mulch when littering them on the fields.

The stem and branches of the Jatropha plant can be used for propagating the plant by cuttings. The wood is not a good firewood because of its low caloric value . Also the wood is not useful for construction. The cuttings are sold on a regional market (approx. 400 km away) for an approximate price of 0.25 Birr per cutting.

Is there currently any Jatropha oil or bio-diesel production in the Bati area?

Not at the moment In August 2011 an oil-extractor funded by the Canadian Hunger Foundation (CHF) will be installed. The goal is, that 300 people from different watersheds form an association that will own the oil-extractor. These people (mostly farmers) then sell Jatropha seeds to their own association. The machine will cost around 1.3 mil. Birr. The oil will be blended with normal gasoline (10 liters of gasoline + 1 kg of Jatropha oil) and should then run in normal gasoline engines without adaptation. The goal is to then sell the blended *gasoline locally in Bati.*

The by-products of the oil production should be used in the Bati area as well. After treating it, the seed cake can be used as fodder for animals or as fertilizer. The oil residues can be used to make soap, oral drops against stomach problems, pesticides, candles or for drops that can be taken by pregnant women to start childbirth.

Discussion of the informal interview

The Agricultural Officer emphasizes the potential of Jatropha as a live fence to replace dead wood fences. For him it is clear that Jatropha fences need less work and money input than dead wood fences. The Agricultural Officer as well points out a lot of ways to use Jatropha and its by products. No additional information could be found about Jatropha's medicinal potentials to back up the claims of the Agricultural Officer - additional research is needed to close this knowledge gap.

It is still unknown if the oil extractor was actually put in place in Bati one year after the interview. The farmers as well as the Agricultural Officer seemed to be waiting for the extractor so they could start producing Jatropha oil. Exaggerated expectations may be present. According to literature it is not possible to blend Jatropha oil with gasoline like the Officer claims, but only with diesel. A big consumer group in Bati for petroleum based energy are the auto ricksha taxis. But unfortunately they run with gasoline and not with diesel. Somehow this gap between product and big consumer group should be closed in order to establish a Jatropha oil business in the region. Further research for technologies or methods are needed for that.

5.3.2. BIA Literature review on Jatropha as an energy crop

A Life Cycle Assessment (LCA) conducted by Gmünder et al. 2010 in a remote rural village in India shows that electrification of a small village by a Jatropha oil run generator is environmentally friendly compared to the usage of fossil diesel. Even a possible connection to the Indian power grid is seen less environmentally friendly than a Jatropha generator, mainly because 95% of India's power is produced by coal power plants. However, photovoltaic energy generation outperforms energy generation by generator with Jatropha or diesel as well as connection the the power grid. Beside its positive environmental characteristics burning Jatropha produces aerosols that may harm human health.

Since Bati town is already connected to the Ethiopian power grid and 99% of Ethiopia's electricity is produced by hydro power (RECIPES 2006) a connection to the electrical grid may perform better in a LCA designed for Bati district in Ethiopia than the one conducted in India. However, for India Gmünder et al. 2010:354 conclude that environmental benefits can only be achieved if Jatropha is cultivated on marginal land and therefore is not competing with plants and crops that need fertile soil such as a wide variety of food crops. In that case they see Jatropha based electricity production as "a useful alternative to other renewable electrification options, as the technology is very sturdy and can be maintained even in remote and highly under-developed regions".

In addition to the interview above, different types of Jatropha utilization in Bati can be found in the BIA literature: Feto 2011:44 states that Jatropha is mainly used in the Bati area for fencing purposes and that farmers plan to use the seeds for a possible oil extractor in future. Nezir 2010:4 sees the major use of Jatropha in the Bati district as a hedge for garden and home protection as well as for soil erosion control. The seeds are sold on the market or crushed to an oily paste that can be used to smooth the clay plate for Injera baking so the bread does not stick to the plate Nezir 2010:32.

Discussion of the BIA literature review

The literature review supports the Agricultural Officers claims about the variety of utilization purposes for Jatropha in the Bati region. Since Bati is connected to the national power grid it does not seem to make sense to locally produce energy by generators run by Jatropha based biodiesel. This method could be a solution for remote, larger villages in the area that are not yet connected to the power grid. Without additional support it does not seem possible for these villages to gain access to the needed technologies to start this decentralized production since not even Bati has a oil extractor yet.

5.3.3. Discussion of of Jatropha as an energy crop at a local scale

As seen in the previous chapters, Jatropha seeds are not yet used for oil production in Bati district. It remains questionable if an oil extractor makes sense since Bati is located on an internationally connected road and is as well connected to the national electricity grid and oil, diesel and gasoline are therefore available in the town. However, like Gmünder et al. 2010 shows, there might be potential for larger remote villages in the area not connected to the electricity grid to have opportunities to produce electricity with generators using Jatropha oil in decentralized manner. But since generators and oil extractors are expensive this is not possible for these remote villages unless there is support from the government or a NGO. As long as there are no such opportunities for Jatropha oil production, the plant and its seeds will be used as before - as a fence, pan oil, soil erosion control, medicinal plant and so on. If somehow Jatropha could be used to deliver the ricksha taxis in Bati, a local market for Jatropha seeds would establish. However, it is not known if this gap can be closed - further research is needed to answer this question.

Rather than expensive generators and oil extractors for electricity production there might be potential for Jatropha on a smaller scale: Chapter 3.2 showed that Jatropha has potential to substitute fire wood or other traditional energy sources. Stoves fired with crushed Jatropha seeds already exist as well as lamps run with Jatropha oil. Non of these technologies could be found in the Bati region. Since it seems unlikely that remote areas are able to produce their own generator based electricity in near future, the local Agricultural Office might support these smaller and cheaper technologies to promote Jatropha oil as a substitute for traditional energy forms. This would contribute to sustainable land management.

6. Synthesis

6.1. Conclusion

6.1.1. Different technologies in different watersheds

Stone walls are the dominant soil and water conservation technology to rehabilitate gullies in Dodota and in Tullu Iyensa watershed. In the Dodota watershed a number of Jatropha hedges used as SWC technologies can be found. The mapping of drainage lines in each watershed shows that both technologies are equally efficient in slowing down runoff and hindering further gully erosion.

Measurements of an active gully show what happens if no SWC technology is hindering gully erosion: nearly 14'000 m^3 of soil are lost only due to a gully of 1030 m of length. This number only indicates the actual gully erosion and not all the other erosion processes going on in the watershed especially during times of heavy rainfall and runoff.

The computed vertical profiles of both watersheds show that SWC technologies have a positive effect on gully mitigation and rehabilitation. Segments with many SWC technologies, are classified as inactive or rehabilitated, and active gullies develop in segments without technologies. The vertical profile of the Tullu Iyensa watershed shows that farmers take care of the steeper slopes by implementing SWC technologies and therefore hindering gully erosion. However, in the case of the Tullu Iyensa watershed shows that active gullies can also develop on gentler slopes.

The adapted spade analysis shows that the grass cover on the upper side of the technology seems slightly denser than on the lower side. This could indicate a positive effect of the technology on the sub surface water storage. It could as well represent farmers plowing behavior meaning they do not plow too near to the technologies.

6.1.2. Technology description and comparison

WOCAT analysis shows that each technology has its strengths and weaknesses. Jatropha hedges need little work input for establishment and maintenance. However the plant is not very tall an thick and thus not ideal for deep gully rehabilitation. Jatropha hedges therefore seem best suited for gully erosion prevention or erosion mitigation at an early stage. Additionally the plant is flexible and can therefore cope with heavy runoff. Because farmers want to minimize competition between Jatropha and crops, they prune Jatropha hedges every year, which drastically reduces Jatropha seed yields.

Stone walls are able to rehabilitate even larger gullies since once silted up, the wall can be increased with another row of stones. However a lot of work is needed to establish this type of technology and to maintain it. Therefore, time is a limiting factor when establishing stone walls.

A combination of Jatropha hedges and stone walls can be found in the research area. Jatropha planted on the wall might destabilize the structure by opening spaces, through which runoff can attack the structure. Jatropha planted in front of stone walls might increase stability of the structure. In such cases Jatropha works like a net or a gabion that is stabilizing the wall at its back. It is however unknown to what degree this type of combination can help to hinder the wall from collapsing.

The integrated analysis of Jatropha technology shows that additional income might be created if the seeds can be sold. At the current time no real market for Jatropha seeds exists in Bati. If such a market establishes, measures to reduce inequalities among farmers should be implemented. Poor farmers should as well be able to participate in the Jatropha business as well as rich farmers with large plots of land - this could be done if farmers organize themselves in groups to improve their power in the market so not every single farmer is competing with others.

Jatropha hedges as well as stone walls collect soil particles from runoff. They reduce off-site water pollution so the rivers are clearer downstream. This may reduce tensions between upstream and downstream population. However, since the technologies are also holding back water , downstream population has to be sensitized. Without technology water is simply washed away whereas with technologies it is available for production behind the technology. The slowing down and the collection of the water increases production in upstream areas so less water tapping in these areas is needed. At the end more water is available downstream as well.

6.1.3. Jatropha as an energy crop in Bati

Jatropha is used in the Bati region as a live fence and as a soil and water conservation technology. The plant's seeds are not yet used for energy production in Bati. To run on Jatropha oil, generators have to be modified or the oil has to be further processed. Therefore it remains questionable if decentralized energy production with Jatropha biofuel makes sense in the region of Bati since he town itself is connected to the national electricity grid and is well accessible. For larger villages in remote areas it could make sense to establish decentralized energy production with Jatropha. But these villages can not afford the needed technologies so they are still depending on additional support.

It remains questionable if Jatropha yields are sufficient for efficient energy production since in the region Jatropha is not planted in plantations but only as fences, hedges or SWC measures. In addition the farmers prune the plants every year to reduce sunlight and water competition with their crops, so Jatropha yields remain modest. Therefore it remains questionable if an actual decentralized energy production could establish in the region. Such a decentralized production also needs sophisticated technologies as well as large financial support. It seems therefore wiser to support farmers to substitute traditional energy such as wood or dung with Jatropha by creating access to affordable Jatropha stoves or lamps.

6.2. Recommendations for Jatropha as a SWC technology and an energy crop

Jatropha can be easily propagated by cuttings and establishing and maintaining of Jatropha SWC technologies needs almost no time. Jatropha therefore can be recommended to be used as a SWC technology to prevent or mitigate erosion. Since the technology works in mitigating and preventing gully erosion it should work to hinder hillside erosion or similar erosion processes as well. The plant is best used to prevent erosion or to stop erosion at the beginning of erosion processes since larger gullies or erosion rills are difficult to rehabilitate because of the maximum soil accumulation height of 1 m for Jatropha hedges. Once rooted, the plant is flexible enough to cope with heavy runoff. If for once a technology is destroyed it is easily replaced by new Jatropha cuttings with little effort.

To rehabilitate gullies deeper than 1 m stone wall SWC technologies are recommended. Since it takes a lot of work and time to establish these technologies it may be necessary to support the farmers by food for work programs for example. Since farmers in the Bati region experienced such support in earlier times, they are still seeking support today. The best solution is however to sensitize farmers to combat already small erosion rills by Jatropha hedges so no deep gully establishes and therefore also no additional support is needed. With the local Agricultural Office there already exists an institution that is well accepted in the area that can distribute the Jatropha hedge technology.

Since decentralized energy production needs bigger financial and technological inputs, it is recommended to start supporting the utilization of Jatropha at a smaller scale. Stoves and lamps fueled by crushed Jatropha seeds or oil already exist. With some support, local people could learn to build these technologies themselves. On the other hand the population has to be supported so they can afford these technologies in order to substitute traditional energy forms such as wood, charcoal or dung. Not only is the smoke from burning Jatropha oil less harmful than smoke from burning wood but also a lot of pressure on the environment could be taken away if less wood or charcoal is needed. After some time, a Jatropha stove or lamp market may establish as well as a market for the Jatropha seeds and maybe no more support from outside is needed.

6.3. Outlook

This thesis is contributing knowledge to the topics of SWC and Jatropha. Since these are quite broad themes, very detailed questions could not always be answered by this thesis. Therefore there are still open questions that need further research:

- It is unknown why farmers decide to implement SWC technologies or not. The active gully in the Tullu Iyensa watershed is hindering some farmers in their activities but still it is not rehabilitated. It is not known what triggers farmer's decision to rehabilitate a gully. It could be financial support, an extreme event that damages a lot of fields or something completely different.

- The different conservation technologies are implemented wherever needed in the research area. There might be an optimal spacing and dimensioning of these technologies so farmers lose only little land and need less time to establish the optimal number of technologies.

- Behind SWC technologies grass cover is to some extend denser than in front of the technology. It is unknown if this indicates the ability to store water behind the technologies. It could as well just represent how farmers plow their fields.

- Stone walls and Jatropha hedges as SWC technology are focused in this thesis. These two technologies in combination however are quite widely used in the region of Bati. Therefore additional in depth analysis of the combined technology is needed to fully understand its strengths and weaknesses.

- If economically comparing Jatropha hedges and stone walls latter are by fare more expensive and as well time consuming to establish. However, farmers experienced support through food for work programs in earlier times so these stone walls may be built “for free” for some farmers. Therefore the economic comparison in this thesis is only a raw value. To be able to really compare these structures more detailed information is needed.

- Jatropha is used almost 30 years in the Bati area. However the plant's long term behavior and effects are yet little known. Jatropha is still a plant that was once introduced from outside and its long term effects on the local environment are still little known.

- To avoid shading and water competition the farmers in the research area are pruning the Jatropha hedges every year what drastically reduces the seed yields. A solution has to be found in order to minimize Jatropha's competition with other plants and to maximize seed yields.

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Appendices

A.1. WOCAT fact sheets

Jatropha curcas hedge: pages 98 – 102.

Stone wall check dam: pages 103 – 107.


left: Jatropha planted across a shallow, partly rehabilitated gully.
(Photo: Simon Bach)
right: Detailed view of the Jatropha technology.
(Photo: Simon Bach)

Jatropha curcas hedge

Ethiopia - Agulo Keter (Amharic)

Gully rehabilitation and hill stabilization with Jatropha hedges.

In the area around Bati in Ethiopia, Jatropha is used to stabilize hills ore to rehabilitate gullies. The technology was introduced during the last decade by local farmers on their plots. The advantage of Jatropha against other shrubs is that it is poisonous and therefore not browsed by animals. Additionally the seeds can be collected by household members and sold on the local market. The seed's oil can be used as a lamp oil or even for the production of bio-fuel.

Besides hedges and living fences, Jatropha is used for combating sheet or gully erosion. To stop erosion processes the Jatropha cuttings are planted across a gully or along hill sides to stabilize them in the same manner as check dams or terraces do. The plant is chosen because of its very tolerant character, rather high accessibility in the area and because it is easy to propagate by cuttings. Often Jatropha is used in combination with traditional stone check dams or terraces aiming for an increased stability of the technology itself. For that purpose Jatropha is planted in front of the stone walls or also on top of them.

In earlier times Jatropha was planted by seeds but nowadays, since there are a lot of plants in the area, propagation by cuttings is the more prominent form. Since the plants are pruned every year anyway, the cuttings are accessible almost in any case for free. At markets further away, the cuttings cost around one cent per piece. In order to rehabilitate a gully Jatropha cuttings are planted as near as possible in the selected area in a row across the gully. After rooting, the spaces between the plants are filled up with litter, shrubs or stones. In order to have a thick stem and avoid competition with crops, the plants are pruned every year. The thick main stems reach a height of approximately one meter which delineates the maximum height of possible soil collection. If the area behind the filled up gaps and the cuttings has silted up, the height is increased by adding new litter in the higher up gaps. In off farming season, the Jatropha seeds are collected and sold on the market to create additional income.

The case study site, Bati, lays in an semiarid climatic zone on 1600 m a.s.l. Rainfalls are erratic and the rain sum per year is between 500-1000 mm. The landscape is very hilly with rather steep slopes. The area has a high population density and growth. The agricultural sector is very dominant and lead by a lot of small scale farming with a lot of livestock and small plots of cropland.

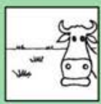
Location: Ethiopia / Amhara Region
Region: Bati
Technology area: 0.7 km2
Conservation measure: vegetative, structural
Stage of intervention: rehabilitation / reclamation of denuded land
Origin: Developed through land user`s initiative, 10-50 years ago; externally / introduced through project, recent (<10 years ago)
Climate: semiarid
WOCAT database reference: ETH562
Compiled by: Simon Bach, CDE Centre for Development and Environment
Date: 30th Apr 2011

1

Classification

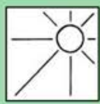
Land use problems: Too much soil loss and land degradation, no vegetation cover and poor soil moisture. Deforestation, overgrazing, cultivation of erosion-sensitive areas or steep slopes.

Land use

Annual cropping, extensive grazing land
mixed farming (crop & livestock)
rainfed

Climate

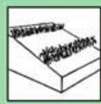
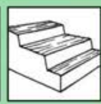


semiarid

Degradation

Soil erosion by water: gully erosion

Conservation measure

vegetative: Tree and shrub cover
structural: Bench terraces / Walls
(slope of terrace bed <6%)

Stage of intervention

- Prevention
- Mitigation / Reduction
- Rehabilitation

Origin

- Land users initiative: 10-50 years ago
- Experiments / research
- Externally introduced: < 10years ago

Level of technical knowledge

- Agricultural advisor
- Land user

Main causes of land degradation:
Direct causes - Human induced: deforestation / removal of natural vegetation, over-exploitation of vegetation for domestic use, overgrazing, cultivation of very steep slopes.
Direct causes - Natural: change of seasonal rainfall, erratic rainfall
Indirect causes: population pressure, poverty

Main technical functions:
- control of concentrated runoff: retain / trap
- control of concentrated runoff: impede / retard
- reduction of slope angle
- increase / maintain water stored in soil
- increase of groundwater level / recharge of groundwater
- sediment retention / trapping, sediment harvesting

Secondary technical functions:
- reduction of slope length
- increase of infiltration

Environment

Natural Environment

Average annual rainfall (mm)

- > 4000
- 3000-4000
- 2000-3000
- 1500-2000
- 1000-1500
- 750-1000
- 500-750
- 250-500
- < 250

Altitude (m a.s.l.)

- > 4000
- 3000-4000
- 2500-3000
- 2000-2500
- 1500-2000
- 1000-1500
- 500-1000
- 100-500
- <100

Landform

- plateau / plains
- ridges
- mountain slopes
- hill slopes
- footslopes
- valley floors

Slope (%)

- flat
- gentle
- moderate
- rolling
- hilly
- steep
- very steep

Soil depth (cm)

- 0-20
- 20-50
- 50-80
- 80-120
- >120

Growing season(s): 90 days (June to September)
Soil texture: coarse / light (sandy)
Soil fertility: low
Topsoil organic matter: low (<1%)
Soil drainage/infiltration: good

Soil water storage capacity: medium
Ground water table: 5 - 50 m
Availability of surface water: poor / none
Water quality: poor drinking water
Biodiversity: low

Tolerant of climatic extremes: temperature increase, seasonal rainfall increase, seasonal rainfall decrease, heavy rainfall events (intensities and amount), wind storms / dust storms, droughts / dry spells, decreasing length of growing period

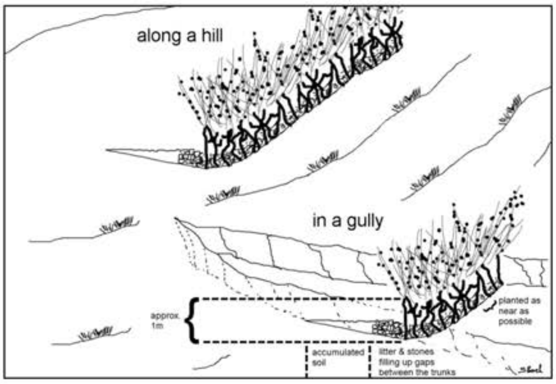
2

Human Environment

Mixed land per household (ha)	
■	<0.5
☐	0.5-1
☐	1-2
☐	2-5
☐	5-15
☐	15-50
☐	50-100
☐	100-500
☐	500-1,000
☐	1,000-10,000
☐	>10,000

Land user: Individual / household, Small scale land users, common / average land users, mainly men
Population density: 100-200 persons/km2
Annual population growth: 3%
Land ownership: individual, titled
Land use rights: communal (organized), individual
Water use rights: open access(unorganized)
Relative level of wealth: rich - 1% of the land users

Importance of off-farm income: less than 10% of all income: Off-farm income has low importance.
Access to service and infrastructure: low: employment (e.g. off-farm), market, roads & transport, drinking water and sanitation, financial services; moderate: health, education, technical assistance, energy



Technical drawing

Jatropha hedges as they can be found in the region of Bati. Often the plant is used for gully rehabilitation. For that purpose it is planted (mostly by cuttings) with a minimal interval between each plant to create a barrier-like hedge. The gaps are filled up with litter or stones.
Approximately 1 m of soil can be collected by the trunk - above that height it is too thin. The Jatropha seed can create additional income besides the purpose of soil and water conservation. Often, the plant is used in combination with traditional technologies (terraces, stone walls) and planted on top or in front of these traditional structures to improve their stability. (Simon Bach)

Implementation activities, inputs and costs

Establishment activities for 500 m of hedge

- One time initial sawing of Jatropha seeds (30 years ago).
- Cutting of the Jatropha cuttings (12.5 person days needed).
- Planting of the Jatropha cuttings (12.5 person days needed).
- Filling up the gaps with litter (5 person days needed).

Establishment inputs and costs per ha (500 m of hedge)

Inputs	**Costs (US$)**	**% met by land user**
Labor	30.00	100
Equipment		
- tools	5.00	100
Construction material		
- stone	For free	100
- wood	For free	100
Agricultural		
- seeds	(30 years ago: 2.00)	100
- cuttings	For free	100
TOTAL	**35.00**	**100**

Maintenance/recurrent activities for 500 m of hedge

- Collection of Jatropha seeds (5 person days needed).
- Filling up the gaps with litter (5 person days needed).
- Pruning of the Jatropha hedges (15 person days needed).

Maintenance/recurrent inputs and costs per ha (500 m) per year

Inputs	**Costs (US$)**	**% met by land user**
Labor	25.00	100
Equipment		
- tools	5.00	100
Construction material		
- stone	For free	100
- wood	For free	100
Agricultural		
- cuttings	For free	100
TOTAL	**30.00**	**100**

Remarks:
Rough topology in the area, questionable availability of construction materials if they are not found nearby.
Total costs of a hectare are calculated for a hedge of 100 m length every 20 m (500 m total hedge) in the year 2011. Tool prices were estimated and labor costs were calculated with a daily wage of 1$.

3

Assessment

Impacts of the Technology

Production and socio-economic benefits	Production and socio-economic disadvantages
+++ increased crop yield	+++ increased labor constraints
+++ increased farm income	++ increased economic inequity
+++ diversification of income sources	++ loss of land
+++ increased production area	+ hindered farm operations
+++ increased product diversification	
++ reduced risk of production failure	
+ reduced expenses on agricultural inputs	
+ simplified farm operations	

Socio-cultural benefits	Socio-cultural disadvantages
+++ improved food security / self sufficiency	
++ knowledge conflict mitigation	
++ improved situation of disadvantaged groups	

Ecological benefits	Ecological disadvantages
+++ increased water quantity	+++ increased niches for pests
+++ improved harvesting / collection of water	++ waterlogging
+++ increased soil moisture	++ increased competition
+++ reduced surface runoff	
+++ recharge of groundwater table / aquifer	
+++ reduced hazard towards adverse events	
+++ reduced soil loss	
+++ increased beneficial species	
+++ increased / maintained habitat diversity	
++ reduced soil crusting / sealing	
++ reduced soil compaction	
+ reduced evaporation	
+ reduced wind velocity	
+ improved soil cover	
+ increased biomass above ground C	
+ increased nutrient cycling recharge	
+ increased soil organic matter / below ground C	
+ reduced emission of carbon and greenhouse gases	
+ increased animal diversity	
+ increased plant diversity	

Off-site benefits	Off-site disadvantages
+++ increased water availability	+++ reduced sediment yields
+++ reduced downstream flooding	++ reduced river flows
+++ increased stream flow in dry season	
+++ reduced downstream siltation	
+++ reduced groundwater river pollution	
+++ improved buffering / filtering capacity	
+++ reduced damage on neighbor's fields	
+++ reduced damage on public / private infrastructure	

Contribution to human well-being / livelihoods

+++ Accumulation of soil leads to new space for fields and additional food security or even income (if crop surplus is sold). Collection of Jatropha seeds - they can be sold (additional income) or processed to oil (lamp oil etc.)

Benefits/costs according to land user

Benefits compared with costs	short-term:	long-term:
Establishment	slightly negative	very positive
Maintenance/recurrent	very positive	very positive

Establishment needs a little time, although not very much. Maintenance work is little needed and can be done if needed or in off-farming season. But overall, establishment and maintenance costs are none or very little.

4

Acceptance/adoption:

0% of land user families have implemented the technology with external material support. local technology spread from farmer to farmer. 100% of land user families have implemented the technology voluntary. Completely based on farmer's initiative. There is strong trend towards (growing) spontaneous adoption of the technology. A lot of farmer are adopting (or already have adopted) Jatropha as a SWC technology in the region.

Concluding statements

Strengths and → how to sustain/improve	Weaknesses and → how to overcome
Very low labor and money input for establishment and maintenance. → Keep the technology as simple as it is today.	Jatropha is an alien plant although it is used for more than 30 years in the region. → Research on the long term effects of Jatropha in specific areas.
Easy to adopt in a wide range of environments (Jatropha is a rather tolerant plant). →Additional research to improve knowledge of Jatropha.	If the plant should reach maximum yields inputs have to be increased as well and it has to be planted on fertile soil (food competition). → Make sure people only use it as fence or as a SWC plant on bare land.
Selling of the seeds is an additional income. If the seeds are crushed to oil it can substitute for example lamp oil that has to be bought.→ Improve market situation and find technologies suitable to use Jatropha oil or biofuel.	To avoid shading the plant is often pruned every year and the yield is therefore very small (economically irrelevant). → Find a good compromise between pruning and maximum tolerated shade to maximize yield.
The plant can be used in a wide range of rehabilitation purposes (gully rehabilitation, hill stabilization, improvement of micro climate etc.) → Create and maintain awareness of the farmers.	The plant is poisonous. People have to take care and children have to be sensitized. But according to the farmers eating the leaves or the seeds leads to stomach ache and is not too dangerous. → Create awareness in the society that the plant is poisonous and should not be eaten.
If planted on bare land only, the plant does not compete with food production.) → Sensitize the farmers that food is more important than gaining an extra income so they do not give up their fields for Jatropha seed production.	Farmers plant and use Jatropha quite randomly and without any specific approach. → The role of science: find the best practice.
Soil and water conservation are very important. Also the conservation of soil moisture. → Create farmer's awareness that SWC is very important for a sustainable land management.	If children eat the seeds they get sick. → Raise awareness that the plant is poisonous.
In combination, Jatropha can also be used to stabilize traditional stone structures (terraces, dams). These physical structures are not considered very stable and need a lot of work to establish and maintain. → Further research to improve physical structures, Jatropha structures as well as their combination.	Plant competes for soil moisture. → Find a good compromise between pruning and maximum tolerated shade as well as maximum soil moisture that can be taken by the plant to maximize yield.
The roots bind the soil and holding it together and help collecting additional soil that otherwise would be washed out. The root and the plant also help to slow down flowing water. → Research on how tolerant is the plant on flooding etc.	Plant competes for sun light. → Find a good compromise between pruning and maximum tolerated shade as well as maximum soil moisture that can be taken by the plant to maximize yield.
Jatropha is also a very good life fence that animals do not browse through because the leaves are poisonous. → Create awareness in the society that the plant is poisonous and should not be eaten.	
The seeds can be sold.→ Creating and improving markets, infrastructures and technologies that need Jatropha oil or biofuel.	

Key reference: Bach S. (2012) Potentials and limitations of Jatropha curcas as a multipurpose crop for sustainable energy supply and soil and water conservation - a case study in Bati, Ethiopia, using the WOCAT approach. Unpublished master's thesis, Centre for Development and Environment, University of Bern.

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left: A large stone wall check dam across a deep gully filled up with alluvial soil. (Photo: Simon Bach))
right: Building of a stone wall check dam. (Photo: Simon Bach)

Stone wall check dam

Ethiopia - Yedengay Keter (Amharic)

Stone wall check dams are built across a gully to collect alluvial soil and hinder further gully erosion.

During the 1980s stone walls and terraces were introduced in Ethiopia in order to combat soil erosion. The technology of stone walls or terraces is used to stabilize hills or to refill gullies also in Bati, Ethiopia. Stone walls can form a very strong check dam to rehabilitate gullies even several meters deep.
Although stone walls can be used for different purposes, this case study is focusing on stone walls used to combat gully erosion. Farmers in the Bati region often use stone walls to rehabilitate gullies if the material is easily accessible, otherwise they may search for alternatives.
Following procedure is undertaken to build a stone wall check dam: After breaking the stones in the source-area they are transported to the target-area either by hand, by camels or by donkeys, depending on the distance. After digging a foundation for the wall of approximately 30 cm depth, the gap between two rows of big stones 1 m apart is filled up with smaller stones and gravel. These actions are repeated until the desired height and width of the wall are reached. If once silted up, the height of the wall can be increased in the same manner.
The case study site, Bati, lays in an semiarid climatic zone on 1600 m a.s.l. Rainfalls are erratic and the rain sum per year is between 500-1000 mm. The landscape is very hilly with rather steep slopes. As almost in all Ethiopia, the area has a high population density and growth. The agricultural sector is very dominant and lead by a lot of small scale farming with a lot of livestock and small plots of cropland.

Location: Ethiopia / Amhara Region
Region: Bati
Technology area: 0.6 km2
Conservation measure: structural
Stage of intervention: rehabilitation / reclamation of denuded land
Origin: Developed externally / introduced through project, 10-50 years ago
Climate: semiarid
WOCAT database reference: ETH604
Compiled by: Simon Bach, CDE Centre for Development and Environment
Date: 02nd May 2011

Classification

Land use problems: Too much soil loss and land degradation, no vegetation cover and poor soil moisture. Deforestation, overgrazing, cultivation of erosion-sensitive areas or steep slopes.

Land use

Annual cropping, extensive grazing land
mixed farming (crop & livestock)
rainfed

Climate

semiarid

Degradation

Soil erosion by water: gully erosion

Conservation measure

structural: Bench terraces (slope of terrace bed <6%)
structural: Dams / pans: store excessive water
structural: Walls / barriers / palisades

Stage of intervention

Prevention
Mitigation / Reduction
Rehabilitation

Origin

Land users initiative: 10-50 years
agoExperiments / research
Externally introduced: 10-50 years ago

Level of technical knowledge

Agricultural advisor
Land user

Main causes of land degradation:
Direct causes - Human induced: deforestation / removal of natural vegetation (incl. forest fires), over-exploitation of vegetation for domestic use, overgrazing, other human induced causes, Cultivation of very steep slopes.
Direct causes - Natural: change of seasonal rainfall, Heavy / extreme rainfall (intensity/amounts)
Indirect causes: population pressure, poverty / wealth

Main technical functions:
- control of concentrated runoff: retain / trap
- control of concentrated runoff: impede / retard
- reduction of slope angle
- reduction of slope length
- increase / maintain water stored in soil
- sediment retention / trapping, sediment harvesting

Secondary technical functions:

Environment

Natural Environment

Average annual rainfall (mm)

> 4000
3000-4000
2000-3000
1500-2000
1000-1500
750-1000
500-750
250-500
< 250

Altitude (m a.s.l.)

> 4000
3000-4000
2500-3000
2000-2500
1500-2000
1000-1500
500-1000
100-500
<100

Landform

plateau / plains
ridges
mountain slopes
hill slopes
footslopes
valley floors

Slope (%)

flat
gentle
moderate
rolling
hilly
steep
very steep

Soil depth (cm)

0-20
20-50
50-80
80-120
>120

Growing season(s): 90 days (June to September)
Soil texture: coarse / light (sandy)
Soil fertility: low
Topsoil organic matter: low (<1%)
Soil drainage/infiltration: good

Soil water storage capacity: medium
Ground water table: 5 - 50 m
Availability of surface water: poor / none
Water quality: poor drinking water
Biodiversity: low

Tolerant of climatic extremes: temperature increase, seasonal rainfall increase, seasonal rainfall decrease, heavy rainfall events (intensities and amount), wind storms / dust storms, floods, droughts / dry spells, decreasing length of growing period

2

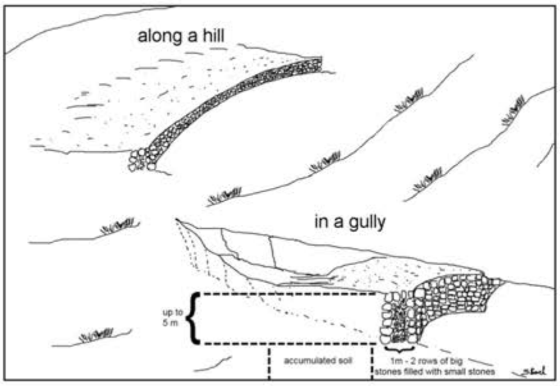
Human Environment

Mixed land per household (ha)

■	<0.5
□	0.5-1
□	1-2
□	2-5
□	5-15
□	15-50
□	50-100
□	100-500
□	500-1,000
□	1,000-10,000
□	>10,000

Land user: Individual / household, Small scale land users, common / average land users, mainly men
Population density: 100-200 persons/km2
Annual population growth: 3%
Land ownership: individual, titled
Land use rights: communal (organized), individual
Water use rights: open access(unorganized)
Relative level of wealth: rich - 1% of the land users

Importance of off-farm income: less than 10% of all income: Off-farm income has low importance.
Access to service and infrastructure: low: employment (e.g. off-farm), market, roads & transport, drinking water and sanitation, financial services; moderate: health, education, technical assistance, energy



Technical drawing

Stone wall check dams as they can be found in the region of Bati. The approximately 1 m wide gap between two rows of larger stones is filled up with small stones or gravel. This is done for every new level of the wall until the wall reaches its final height. The first row of stones is placed in the top 30 cm of the ground and on each side the dam is entering the hill to some extent. After a wall has silted up, the height is increased by other rows of stones until desired dimension is reached. Walls up to 5 m can be found in the case study site. (Simon Bach)

Implementation activities, inputs and costs

Establishment activities for 500 m of stone wall (1m height, 1 m width)

- Preparation of the stones (500 person days needed).
- Transportation of the stones (depending on the distance).
- Digging a foundation of 30 cm depth (165 person days needed).
- Building of the stone wall (500 person days needed).

Establishment inputs and costs per ha

Inputs	Costs (US$)	% met by land user
Labor	1165.00	50
Equipment - tools	5.00	100
Construction material - stone	For free	100
TOTAL	**1170.00**	**50**

Maintenance/recurrent activities for 500 m of stone wall (increasing height of 0.5 m and 1 m width)

- Prepare the stones (250 person days needed).
- If dam is silted up, increasing the height by 0.5 m (250 person days needed)

Maintenance/recurrent inputs and costs per ha per year

Inputs	Costs (US$)	% met by land user
Labor	500	50
Equipment - tools	5.00	100
Construction material - stone	For free	100
TOTAL	**505.00**	**50**

Remarks:
Rough topology in the area, questionable availability of construction materials if they are not found nearby.
Total costs of a hectare were calculated for a wall of 100 m length and 1 m of height every 20 m (500 m total wall) in the year 2011. Tool prices were estimated and labor costs were calculated with a daily wage of 1$.

Assessment

Impacts of the Technology

Production and socio-economic benefits	Production and socio-economic disadvantages
+++ increased crop yield	+++ increased labor constraints
+++ increased farm income	++ loss of land
+++ increased farm income	++ hindered farm operations
+++ increased production area	+ increased economic inequity
++ reduced risk of production failure	
+ reduced expenses on agricultural inputs	
+ simplified farm operations	
Socio-cultural benefits	**Socio-cultural disadvantages**
+++ improved food security / self sufficiency	
++ conflict mitigation	
++ knowledge conflict mitigation	
Ecological benefits	**Ecological disadvantages**
+++ increased water quantity	+++ increased niches for pests
+++ improved harvesting / collection of water	++ waterlogging
+++ increased soil moisture	
+++ reduced surface runoff	
+++ recharge of groundwater table / aquifer	
+++ reduced hazard towards adverse events	
+++ reduced soil loss	
Off-site benefits	**Off-site disadvantages**
+++ increased water availability	+++ reduced sediment yields
+++ reduced downstream flooding	++ reduced river flows
+++ increased stream flow in dry season	
+++ reduced downstream siltation	
+++ reduced groundwater river pollution	
+++ improved buffering / filtering capacity	
+++ reduced damage on neighbor's fields	
+++ reduced damage on public / private infrastructure	

Contribution to human well-being / livelihoods

+++ Accumulation of soil leads to new space for fields and additional food security or even income (if crop surplusis sold).

Benefits/costs according to land user

Benefits compared with costs	short-term:	long-term:
Establishment	very negative	positive
Maintenance/recurrent	slightly negative	positive

Big labor input for establishment. Also maintenance needs some work every year. But also high benefit by additional farming land gained due to the check dams.

Acceptance/adoption:

100% of land user families have implemented the technology with external material support. In the past 6 years the local Agricultural Office has supported farmers to treat their watersheds with SWC technologies based on a food for work program. Today farmers build the structures on their own but seek support. 0% of land user families have implemented the technology voluntary. There is moderate trend towards (growing) spontaneous adoption of the technology. Most of the farmers build SWC technologies (including stone check dams in gullies) because of the food for work program.

Concluding statements

Strengths and → how to sustain/improve	Weaknesses and → how to overcome
Stone check dams are a quite durable structure. → Stability could be enhanced by additional technologies e.g. similar as gabions or planting of trees/shrubs in front of the wall to reduce collapsing possibility.	Large labor input at establishment and during maintenance period. → Possibly by machinery but it is very expensive.
The structure collects alluvial soil which can be plowed and used as new farming fields. → Structure maintenance is important. If the dam fails, the field is washed out as well.	During time of establishment/maintenance there is no time for farming activities. These activities can therefore be seen as hidden costs. → Perhaps a "professional" team that takes care of check dams and is paid for it.
The technology is widely used around the world (perhaps with local adaptations) and is therefore well documented. → Keep on with documentation and monitoring of limitations and potentials of stone check dams around the world.	The Land users could not tell any disadvantages of the technology. → Could be an indicator that there is enough spare time to build and maintain structures during off-farming season.
The stone check dams are conserving soil and moisture. → Maintain the dams.	
Due to alluvial soil there is additional farming land and therefore increased productivity. → Take care of the walls as well of the surrounding area and the whole watershed.	

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A.2. Erklärung

Erklärung

gemäss Art. 28 Abs. 2 RSL 05

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Studiengang: Geographie

Bachelor ☐ Master ☒ Dissertation ☐

Titel der Arbeit: Potentials and limitations of Jatropha curcas as a multipurpose crop for sustainable energy supply and soil and water conservation: a case study in Bati, Ethiopia, using the WOCAT approach

LeiterIn der Arbeit: Prof. Dr. Hans Hurni

Ich erkläre hiermit, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche gekennzeichnet. Mir ist bekannt, dass andernfalls der Senat gemäss Artikel 36 Absatz 1 Buchstabe o des Gesetztes vom 5. September 1996 über die Universität zum Entzug des auf Grund dieser Arbeit verliehenen Titels berechtigt ist.

Bern, 31.08.2012

Ort/Datum

Unterschrift