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Master Thesis

Evaluation of the Impact of Stone Bunds on Soil Loss and Surface Runoff in the Gumara-Maksegnit Watershed, Northern Highlands of Ethiopia

to obtain the academic degree of

Diplomingenieurin

submitted by

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As this work was part of the project "Unlocking the potential of rain-fed agriculture in Ethiopia for improved rural livelihood", I would like to mention the cooperation partners, ICARDA, ARARI, as well as the Austrian Development Agency, who financed this project. Furthermore, I would like to thank the Gondar Agricultural Research Center (GARC) and all of its stuff, for the on-site support. Special thanks go to Nigus Demelash, who was not only a great advisor for technical issues, but who was always there for us, when life got rough.

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Abstract

Ethiopia is highly affected by land degradation and one of the key problems is soil erosion. It is mainly caused by the rapid population increase, deforestation, low vegetation cover and unbalanced livestock and crop production. As far as about 85 % of the Ethiopian population depends on agriculture, it is essential to prevent or reduce further degradation.

In the Northern Highlands of Ethiopia, stone bunds are widely used as a soil and water conservation measure (SWC). Stone bunds are little embankments of stones along the contour lines and influence the translation processes of surface runoff.

In June 2015 a field experiment in the Gumara-Maksegnit watershed was carried out to investigate the impact of stone bunds on surface runoff and soil erosion using 4 m wide and 20 m long bounded plots monitoring surface runoff and sediment yield with and without stone bunds. The average slope of the plots is about 8 %. The novel design of the plots (with stone bunds) allowed the monitoring of runoff along the contour (stone bund) as well as the bund overflow. The sideflow and overflow were separately collected and routed via a multi-slot-divider to different storage ponds. Representative samples were taken at a roughly weekly interval for a sediment concentration assessment. Precipitation was measured in daily intervals next to the study site.

Total rainfall of the observation period in 2015 (July to September) was 601 mm. During the same time period plots without stone bunds generated approximately 15 t/ha soil loss, whereas plots with stone bunds produced approximately 4 t/ha. However, only 19 % of the sediment from the treated plots was transported over the stone bunds, the rest (81%) either deposited in front of the bund or moved along and was spilled as sideflow. Throughout the investigation period 91 mm of surface runoff were produced on the treated plots. This corresponds to a runoff coefficient of 0.17. Around 30% of this runoff overtopped the stone bunds, the remaining part ran off along the contour.

Overall, stone bunds can be seen as effective soil and water conservation measures under the conditions of the Ethiopian Highlands.

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1 Introduction

In Ethiopia, land degradation is a widespread environmental problem. It leads to low agricultural productivity, rural poverty and an ongoing food insecurity. The major causes are severe soil loss, rapid population increase, deforestation, low vegetation cover and an unbalanced livestock and crop production. As history shows, fighting land degradation is mainly focused on physical conservation structures (Gashaw et al., 2014).

Stone bunds are a widely used conservation structure in Ethiopia. They can be defined as embankments of different sized stones, built along the contour lines.

This master thesis was done in the course of the project “Unlocking the potential of rain-fed agriculture in Ethiopia for improved rural livelihoods” (UNPRA). The project aims to achieve an improvement of the livelihood of the rural communities in the rain-fed agro-ecosystem of the Amhara region. This is done by investigating strategies to slowdown the ongoing soil degradation and sustainably enhancing the productivity of the rain-fed agriculture in the Gumara-Maksegnit watershed in the Northern Highlands of Ethiopia. This should be achieved by preserving the natural ecosystem resources through the integration of appropriate and affordable technologies in a beneficial socio-economic environment (Bayu et al., 2015, p. 22). The project was realized through an international cooperation between the International Center for Agricultural Research in Dry Areas (ICARDA), the Amhara Regional Agricultural Research Institute (ARARI) and the University of Natural Resources and Life Science, Vienna (BOKU). It was funded by the Austrian Development Agency (ADA).

The practical research for this master thesis was undertaken between June and September 2015 in the so-called rainy season, it was carried out in cooperation with the Gondar Agricultural Research Center (GARC). This included the installation of erosion plots at the chosen location and the subsequent collection of the runoff and soil loss data.

The main aim of this thesis is to evaluate the effect of stone bunds as soil and water conservation (SWC) method and its influence on soil erosion and surface runoff. For this purpose, two metal sheet bordered erosion plots with stone bunds were installed. The set-up allowed the measurement of the amount of runoff, which was routed along the stone bund and the amount that flowed over the stone bund. Additionally, two erosion plots without any SWC methods were implemented in order to acquire reference data.

2 Hypotheses and Objectives

Ahead of the data collection in Ethiopia general hypotheses about the impact of stone bunds on soil loss and surface runoff were defined. They were derived from what can be assumed as common knowledge about stone bunds and are as follows:

- Stone bunds create a barrier for eroded soil particles, this leads to an accumulation of soil above the stone bund.
- Inclination is reduced by the formation of terraces above the stone bunds, which is caused by accumulation processes.
- Stone bunds reduce soil loss, because eroded soil is partly stored above the stone bund.
- Surface runoff is reduced by stone bunds, because of the higher infiltration rates above the stone bunds.
- Increasing plant cover has a reducing impact on runoff and soil loss.

Based on these hypotheses, the objectives for this master thesis were defined as follows:

- Assess the amount of soil, which is accumulating/ eroding from the area above the stone bund.
- Analyze the decrease of inclination above the stone bund.
- Determine the quantity of soil loss at a study site with stone bunds as soil conservation method and at a study site without any soil conservation methods. Compare the data of these two cases.
- Collect data about the quantity of surface runoff at a study site without stone bunds as well as at a study site with stone bunds.
- Assess the influence of changing plant cover on surface runoff and soil loss.

3 Fundamentals

3.1 Land Degradation

Changing definitions over time illustrate that the concept of land degradation is an ever-evolving term:

- *"FAO 1979: Land degradation is a process which lowers the current or potential capability of soils to produce.*
- *UNEP 1992: Land degradation implies reduction of resource potential by a combination of processes acting on land.*
- *MEA 2005: The reduction in the capacity of the land to perform ecosystem goods, functions and services that support society and development.*
- *LADA 2009: The reduction in the capacity of the land to provide ecosystem goods and services to assure its functions over a period of time for its beneficiaries."*

(Nachtergaele et al., 2010)

3.1.1 Land Degradation Worldwide

Over the last two decades, economic development, emerging global markets and increasing human population have driven remarkable land-use changes. The most significant changes have been in expansion and intensification of cropland, forest cover and composition and the growth of urban areas. Established evidence associates land degradation with climate change and loss of biodiversity, both as effect and cause. Land degradation is driven by unsustainable land use through nutrient depletion, soil erosion, contamination as well as pollution. Direct effects include loss of soil water storage and regulation, belowground biodiversity and soil organic carbon. This results, indirectly, in a loss of wildlife habitat and productive capacity (Dent, et al., 2007, p. 84 ff.).

Land degradation is a worldwide problem. Current information suggests that it has increased over the last decades and if there will be no action taken, it will increase even further. This kind of degradation is driven or at least intensified by humans (Jones et al., 2012, p. 34).

There have been many attempts to assess the degradation. Between 2006 and 2010, the *Food and Agriculture Organization of the United Nations* (FAO) initiated the *Land Degradation Assessment in Drylands* (LADA). The project took advantage of remote sensing technology and GIS to produce assessments on the impacts, status and causes of land degradation (Nkonya et al., 2011, p. 26 ff.). It was done in two phases; the first one was the *Global Land Degradation Assessment* (GLADA), which identified trends in the greenness of vegetation between the years 1981 and 2006. Areas where both the rain-use efficiency and the greenness were declining were defined as critical areas. The second phase was the *Global Land Degradation Information System* (GLADIS) (Biancalani, et al., 2013, p. 6). It is based on six axes: soil health, water quantity, biomass, biodiversity, social/cultural indicators and economy provision. GLADIS offers a wide spectrum of maps on the trends and status of ecosystem services, complimented with databases and maps on socioeconomic and physical parameters. (Nachtergaele et al., 2011, p. 14; Nkonya et al., 2011, p.40 ff.) One of them is the Land Degradation Impact Index (LDII), which places emphases on the linkage between land degradation and population pressure, especially poverty. This is done with databases on population density and infant mortality rates. As shown in Figure 3-1 densely populated and poor regions are most impacted by land degradation, like India, China, South-East-Asia and several countries in Sub-Saharan Africa (Nachtergaele et al., 2011, p. 58 ff.; Nkonya et al., 2011, p.43).

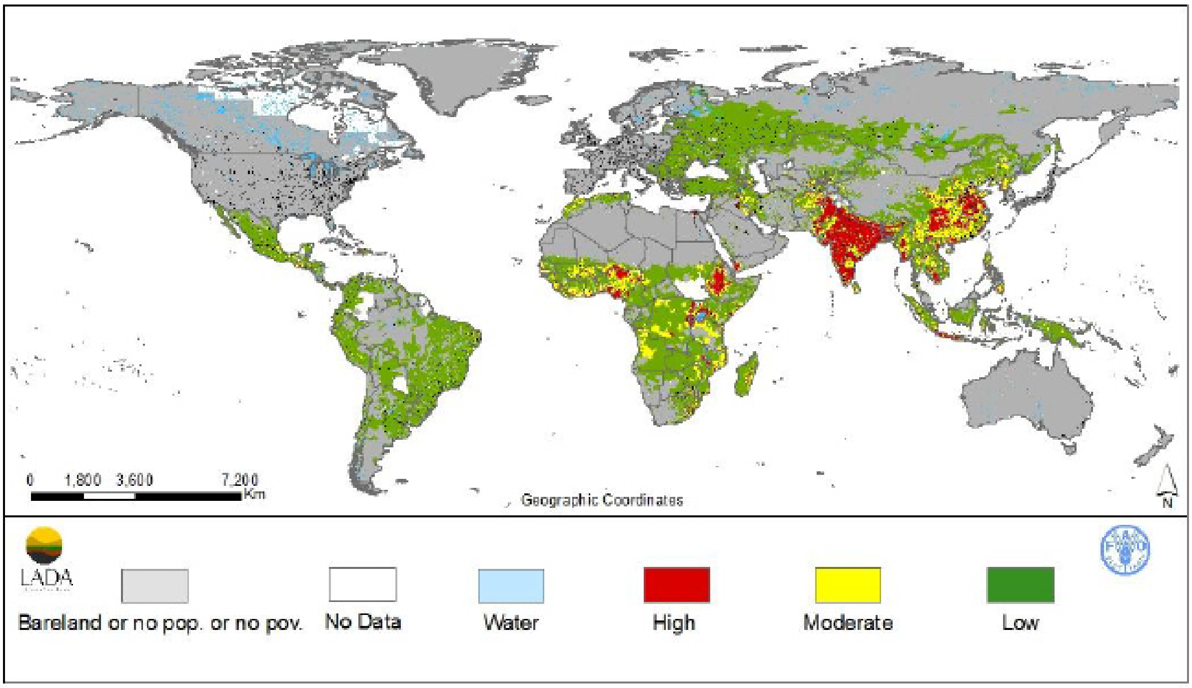

Figure 3-1: Land Degradation Impact Index (Nachtergaele, 2011)

3.1.2 Land Degradation in Ethiopia

The agricultural sector is a cornerstone of the Ethiopian economy and plays an important role in the social and economic life. Around 80-85 % of the population work in agriculture, especially in farming. The backbone of this sector are smallholders, which cultivate 95 % of the cropped land. Subsistence farming is dominant in the Highlands of Ethiopia; it is mostly rain-fed and generates low yields. (Mengistu, 2006, p. 5). On average, the farm sizes are smaller than one hectare per household. (Hurni et al., 2010, p. 188). High human population and livestock numbers turn land into a rare good and force farmers to open new cropland at the expense of forest and grazing land. Ethiopia´s population has risen only in the last 15 years by nearly one third (2000: 66.444.000 to 2015: 99.391.000 inhabitants). These are estimated numbers by the United Nations in 2015. As one can see in Figure 3-1 and Figure 3-2 Ethiopia is a country, which is highly affected by soil and land degradation.

According to the GLADA Report from 2008, 26 % of the Ethiopian territory are considered as degrading areas, this leads to more than 20 million affected people (Bai et al, 2008; p.25).

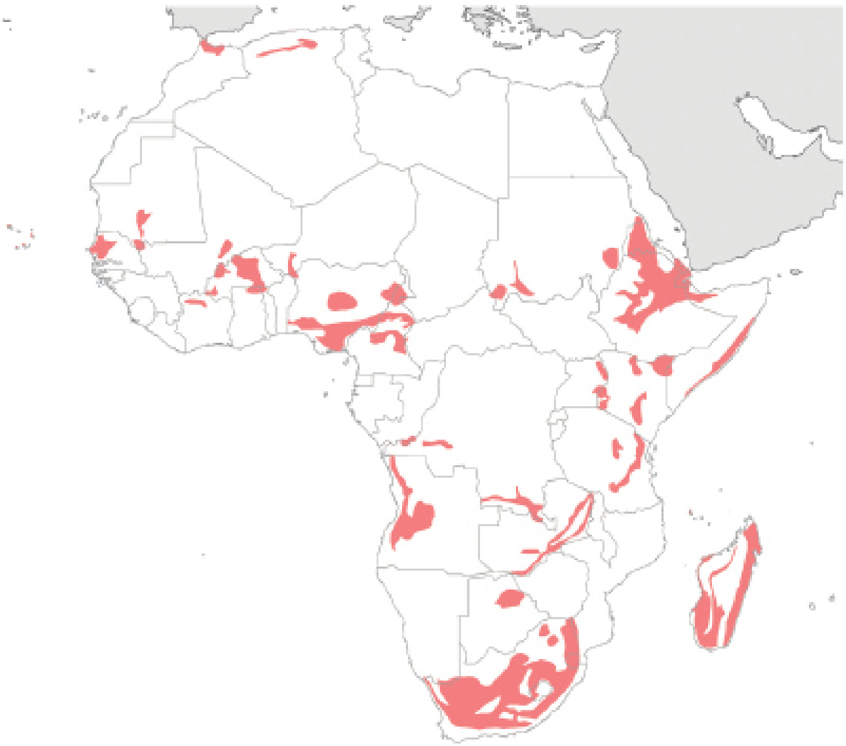

Figure 3-2: Map with areas of high and very high severity of soil degradation in Africa (Jones et al., 2013, p.149)

3.2 Soil Erosion

"*The word erosion is of Latin origin being derived from the verb erodere – to eat away (rodere – to gnaw), to excavate"* (Zachar, 1982, p. 15).

According to Van-Camp et al., in 2004, the driving forces and pressures of soil erosion are of physical, economic, social and ecological origin, but all of them operate in a combined way. The forces of wind, water, temperature change, ice, gravity or other natural or anthropogenic agents, directly drive soil erosion. They provide the energy for erosion and transport processes. Soil or other geological material is detached, abraded and removed from one point on the earth's surface and is subsequently deposited elsewhere (Gashaw, 2015; Van-Camp et al., 2004). This process leads over the long term to a stable landscape with low erosion rates (Mitiku, 2006). However, it occurs that, if vegetation as well as the upper soil layers are impaired in their regulation and storage functions, it is mainly due to the influence of human actions. These pressures could be lessened if there would be more awareness and concern about the effects and consequences of soil erosion, regarding the irreversible loss of capital and the productivity of soils (Van Camp et al., 2004).

Therefore, two main types of erosion can be defined: geological and accelerated erosion. The geological erosion is a natural process of weathering, which is at low rates essential to the formation of soil. It takes place over long geological horizons and is not influenced by humans. The accelerated erosion however is mainly caused by the above-mentioned anthropogenic influences such as deforestation, intensive and uncontrolled grazing, burning of biomass as well as intensive plowing on agricultural used land (Blanco and Lal, 2008, p.3).

Soil erosion is one of the most threatening environmental and public health issues humans are facing these days. It is an especially urging concern because over 99 % of the world's food production is obtained from land. Every year around 10 million hectare of cropland are lost because of soil erosion, this leads to a reduction of available land for the production of food (Pimentel, 2006). With the fact that the world's population is rapidly increasing, these figures pose a serious threat.

While soil erosion cannot be completely prevented, the excessive erosion should be reduced to a tolerable level (Blanco and Lal, 2008, p.3). In literature, many definitions for this tolerable level can be found. Blanco and Lal define this estimated average tolerance, used in soil and water conservation planning in the USA, with 11 t/ha*year.

As stated in the publication by Schwertmann et al, from 1987 the tolerance limit of soil erosion can be described as follows: “The natural yield potential of soil should not be weakened within the period of 300-500 years.” The determination of the estimated values depends on the soil depth, for shallow (<30 cm) soils only 1 t/ha*year is considered as tolerable, in contrast for very deep (>100 cm) soils 10 t/ha*year are believed to be acceptable.

3.2.1 Soil Erosion by Water

Water erosion is, on a global scale, by far the most important type of soil erosion, it affects about 1100 million hectare of land worldwide (Blanco and Lal, 2008, p.3; Oldeman 1992, p.26). In semiarid areas, as the Northern Highlands of Ethiopia are, water erosion is a severe problem, because the limited precipitation mostly occurs in intense storms, when soil is bare and unprotected by vegetation (Blanco and Lal, 2008, p.4). According to Jones et al., 2013 annual soil loss due to water erosion can be greater than 50 t/ha*year.

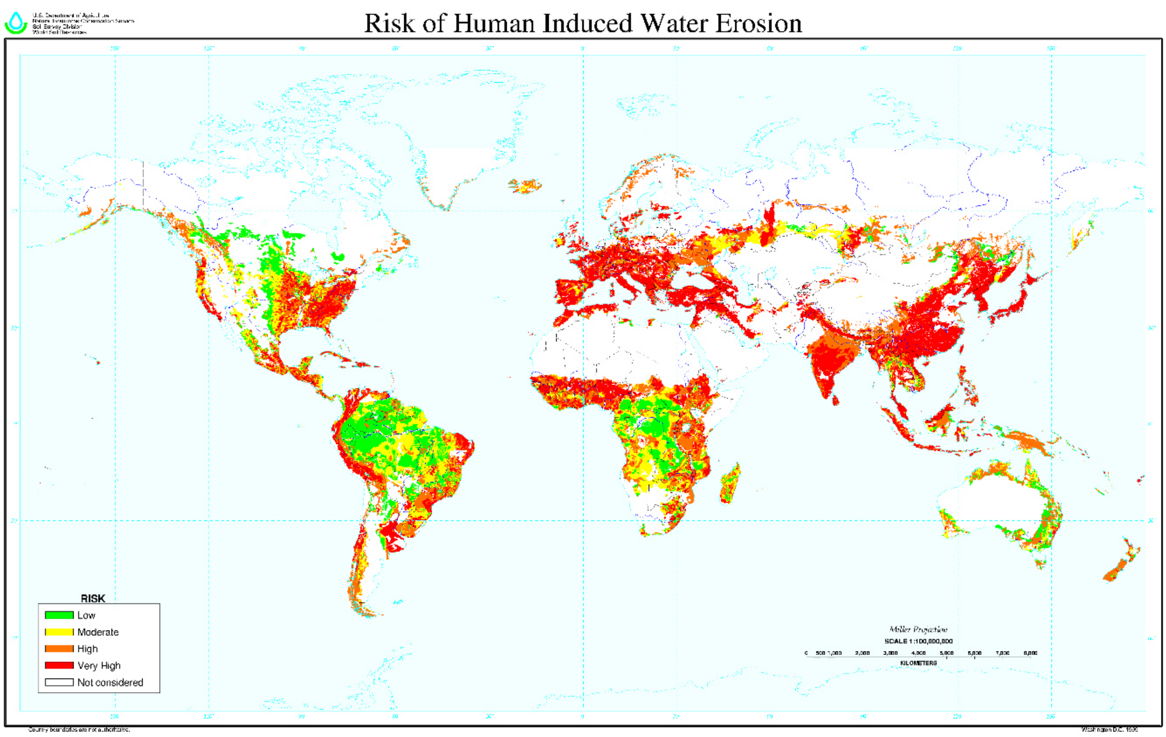

Figure 3-3: World map for risk of human induced water erosion (USDA, 2003)

Blanco and Lal, 2008, defined water erosion as the wearing away of the soil surface by water from rain, runoff, irrigation and snowmelt. The main driver is rainwater in the form of runoff.

Water erosion takes place involving different processes but also different scales in magnitude of impact and space. These processes reach from the initial impact of a raindrop, over the formation of surface runoff, to the concentration of runoff. This leads to various classifications of precipitation driven water erosion in literature (Schürz, 2014, p.8). A common classification follows below.

Splash Erosion:

This type of erosion is caused by the bombardment of the soil surface by raindrops, which dispense and splash the soil. This results in a displacement of particles from their original position. The raindrops attack the soil like little bombs forming craters of different depths, this process is a function of raindrop size, shape and velocity (Blanco and Lal, 2008, p.21).

Interrill or Sheet Erosion:

As soon as runoff starts, it immediately forms diminutive rills and the amount of runoff that flows in the space between these rills is therefore called interrill erosion (Blanco and Lal, 2008, p.22). The more or less uniform erosion of soil over the entire land surface is the main characteristic of this category. It includes the removal of particles loosened by weathering and easily dissoluble matter (Zachar, 1982, p. 49). It is the most common form of soil erosion. Splash and interrill erosion occur simultaneously, with splash erosion being dominate in the initial process. Both together make up about 70 % of the total occurring water driven erosion (Blanco and Lal, 2008, p.22).

Rill Erosion:

This erosion refers to the soil erosion that occurs in rills and small channels, due to concentrated flow along the sub-surface drainage lines. Where surface runoff is intense enough to entrain soil particles directly, material is eroded by the rill flow. This process happens at faster rates than interrill erosion. The force of flow and the creeping soil particles, which are moving along the rill bed, enlarge these rills, especially during heavy rainfalls. Nevertheless, tillage operation can easily restore the initial conditions (Blanco and Lal, 2008, p.23; Van Camp et al., 2004).

Gully Erosion:

Where the inclination is at least locally steep and heavy rainfall occurs, erosion can lead to great incisions and form gullies. They are either U- or V-shaped channels and are wider and higher than 0.3 m. This form of erosion is irreversible by normal farm practices, the development of these gullies can fragment farmland and make cultivation impracticable (Blanco and Lal, 2008, p.24; Van Camp et al., 2004).

Figure 3-4: Gully Erosion in the Gumara-Maksegnit watershed (photo: S. Wakolbinger)

Figure 3-5: Photo series Part I: Rill erosion at the beginning of a heavy rainfall event in the Gumara-Maksegnit watershed (photo: S. Wakolbinger)

Figure 3-6: Photo series Part II: Rill erosion during a heavy rainfall event in the Gumara-Maksegnit watershed (photo: S. Wakolbinger)

Figure 3-7: Photo series Part III: Rill erosion and deposition of sediment after a heavy rainfall event in the Gumara-Maksegnit watershed (photo: S. Wakolbinger)

3.3 Soil and Water Conservation Measures

According to Van Lynden et al., in 2002, soil and water conservation (SWC) measures are defined as activities to enhance or maintain the productivity of areas that are affected or are likely to be affected by land degradation. SWC include amongst others the prevention and reduction of soil erosion.

For the success of SWC measures, it is important that new techniques have the same basic characteristics as traditional ones. They should be simple in appliance, cheap, easy to understand and in the end sucessful (Hudson, 1987, p.26). Furthermore it is essential that politicians and decision makers assess how soil is used on a national scale and subsequently identify areas, which are at risk or vulnerable to soil erosion (Jones et al., 2013, p.155)

Soil and water conservation measures can be divided into two different groups, mechanical and biological measures.

The *biological conservation measures* include conservation tillage practices such as no-till, reduced tillage, minimum tillage, direct drill, mulch tillage or strip tillage. Furthermore, conservation farming is also considered as a biological technique, it stands for any farming practice that improves the yield or reliability of the planted crops or decreases the input of fertilizer or labor. To mention some of these practices: mixed cropping and interplanting, surface mulching, strip cropping or crop rotations. Improved water use efficiency can be achieved with the selection and testing of alternative crops for semi-arid conditions (Hudson, 1987, p.25 ff).

Mechanical conservation measures cover several different types of terraces (bench or step terraces, graded channel terraces etc.), stone lines or bunds, stop-wash lines, furrow systems, ridging and many others. Considering the large choice of mechanical practices, it is important to define one or several objectives and according to these select the appropriate technology (Hudson, 1987, p.29 ff).

3.3.1 Stone Bunds

Stone bunds are 0.25 to 0.3 m high embankments of stones, which are set along the contour lines. They are constructed out of large rock fragments with a size between 0.1 and 0.4 m, medium sized fragments (0.05-0.1 m) are used as backfill. In order to enhance the ability of stone bunds to filter runoff and trap coarse sediment, stone-rich soil or small sized stones (<0.2 m) are used to cover the backfill (Morgan 2005, p.212; Nyssen, 2007).

Nyssen et al., 2007 state that the off-site effects of a stone bund implementation, like the improved hydrological conditions in a catchment and the reduced sediment yield, are definitely positive.

The on-site effects of stone bunds on erosion are not as simple to assess. They can be differed into short- and long-term effects, depending on the time stone bunds need to become effective against soil erosion. According to Bosshart, 1997 the creation of small retention basins for sediment and surface runoff and the reduction of the slope length can be considered as potential short-term benefits. This effect leads to a reduction in volume and erosivity of the runoff and subsequently to reduced soil loss. The reduction in hillslope gradient by the formation of progressive terraces, the development of plant cover on the stone bunds and the change in land management can be seen as medium- and long-term effects.

Stone bunds induce soil erosion and sediment accumulation processes; therefore, they are often associated with a high spatial variability in crop response and soil fertility. In the zone after the stone bund soil can be eroded and bring a less fertile subsoil to the surface, this is especially disadvantaging when soil fertility is concentrated in the top layer (see Figure 3-8) (Vancampenhout et al., 2006).

This sedimentation in front of the stones bund, the concentration of runoff and the possible presence of mice or rats in the structures can also lead to direct damage to the crops (Nyssen et al., 2007).

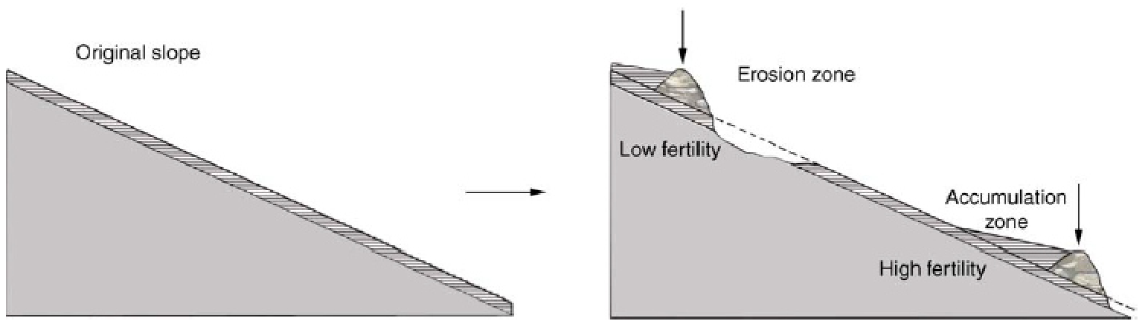

Figure 3-8: Illustration of an erosion and accumulation zone between two stone bunds and the development of a gradient of soil fertility (Vancampenhout, K. et al., 2006).

4 Materials and Methods

In the course of this master thesis, three major workloads were undertaken: fieldwork and laboratory work, as well as analysis and interpretation of the data. The field and laboratory work was done in Ethiopia during the rainy season between June and September 2015.

The fieldwork included the inspection of the study area, the installation of the erosion plots, a topographic survey, a stone and plant cover assessment, an erosion pin assessment as well as runoff and soil loss sampling.

For the sediment concentration analysis, the collected runoff and soil loss samples were filtered in the laboratory.

4.1 Study Area

The study area is defined by the following attributes: location and topography, climate as well as soil characteristics and land use.

4.1.1 Location and Topography

The Gumara-Maksegnit watershed is located about 45 km south-west of Gondar town in the upper part of the Lake Tana basin, which is found in the north-western part of the Amhara region in Ethiopia (see Figure 4-1). The altitude of the investigated watershed ranges from 1923 m to 2860 m above sea level and the total area covers about 54 km². The catchment of the watershed drains into the Gumara River, which subsequently flows into the largest lake of Ethiopia, Lake Tana (Worku et al., 2015, p. 43)

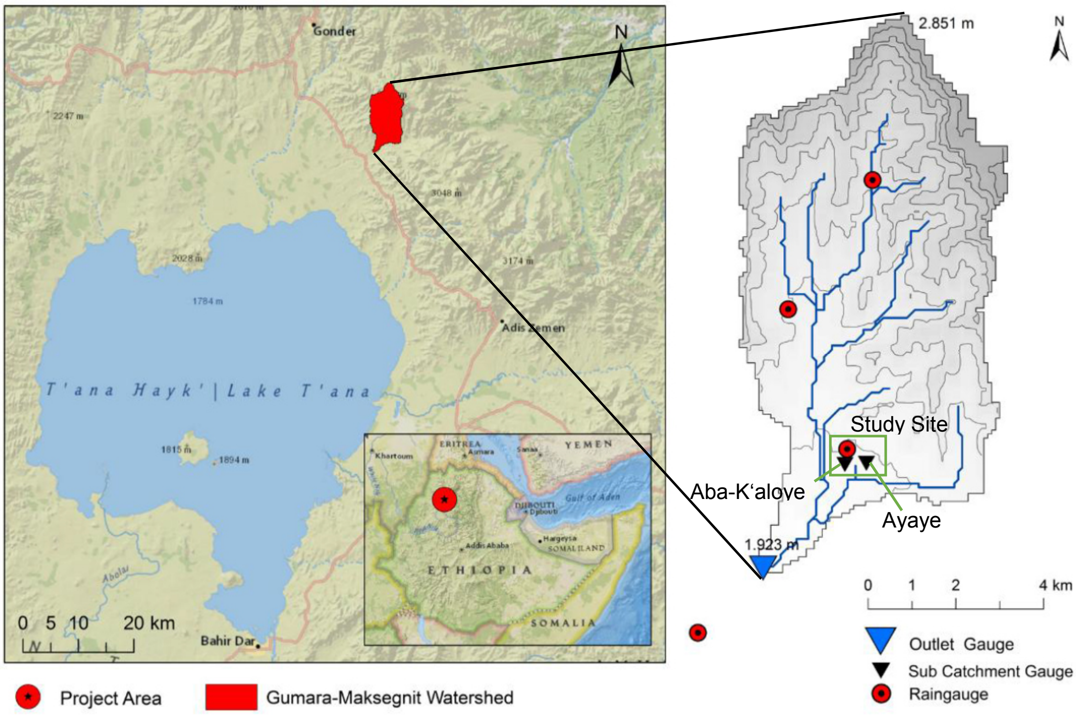

Figure 4-1: Location of the Gumara-Maksegnit watershed (left side) & the watershed topography, rain gauges, outlets and the location of the study site marked with a green square (right side) (Strohmeier et al., 2015)

Within the ongoing project in the watershed, in 2010, two sub-catchments were defined to evaluate the impact of selected soil and water conservation measures on soil erosion and runoff processes on a long-term basis. These two sub-catchments, the Ayaye and the neighboring Aba-K'aloye are both located in the lower part of the watershed (see Figure 4-1). They are characterized by similar topography (average inclination), soil condition and land use. In order to determine the effects of SWC practices, among other measures contour and graded stone bunds were applied in the Ayaye sub-catchment. The Aba-K'aloye watershed was left untreated to produce reference data (Schürz, 2014, p. 14 and Klik et al., 2015, p. 114)

For this master thesis, the main focus was on the effect of the stone bunds on soil loss and surface runoff. Therefore, the study site was located in the Ayaye sub-catchment.

4.1.2 Climate

The study area is described by a bi-modal rainfall distribution (Sisay et al, 2015, p. 86). The mean monthly minimum temperature ranges from 10.6 to 16.1 °C, the mean monthly maximum temperature lies between 25.3 °C and 32 °C. The average temperatures of the area are around 13.6 °C and 28.5 °C respectively. The mean annual rainfall is about 1320 mm but the distribution is very diverse, about 85 % of the rainfall occurs from May to September (Worku et al., 2015, p.44 and Klik et al., 2015, p. 111).

The climate graph in Figure 4-2 shows the average minimum and maximum temperature in °C as well as the average monthly-accumulated precipitation in mm.

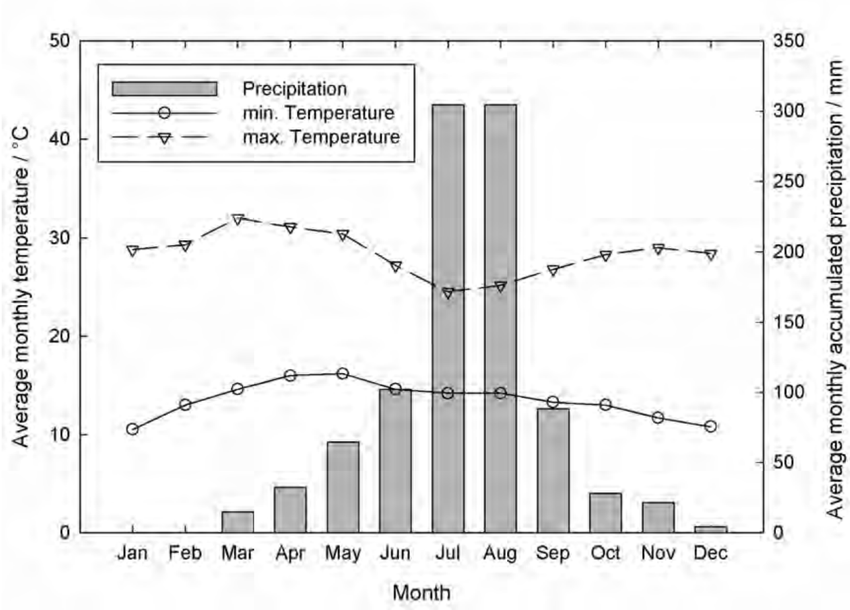

Figure 4-2: Climate graph of the study area (with data from the meteorological station in Maksegnit) (Schürz, 2015, p. 16)

4.1.3 Soil Characteristics and Land Use

Five main soil texture classes are present in the Gumara-Maksegnit watershed: clay, clay loam, loam, sandy clay loam, sandy loam (see Figure 4-3 right hand side). In the upper part of the watershed shallow loam soils with a rooting depth of no more than 15 cm are present, whereas one can find clay soils (rooting depth >80 cm) in the lower part of the watershed (Klik et al., 2015, p.111 and 113). This is also, where the study area is located.

Different soil types characterize the watershed: red soil (nitosol) covers 21 % of the area, black soil (vertisol) 43 % and brown and other types (gleysol and leptsol) account for 36 % (Tilahun und Bayu, 2015, p.172).

In total 1148 households inhibit the watershed, the average family size consists of four persons. Settlements are widespread; land properties are small and fragmented with an average size of 1.33 hectare per household. A mixed crop-livestock subsistence farming system is predominant in the area. Due to an increase in population, the cultivable land each family has to live on is declining. Moreover, forest and communal grazing lands are being converted into settlements and arable lands (Worku et al., 2015, p.44; Tilahun and Bayu, 2015, p.172).

The main staple crops in the watershed are teff, sorghum and chickpea. Furthermore a variety of other crops are being planted, such as beans, bread wheat, garlic, shallot, faba beans, lentils etc. (Tilahun und Bayu, 2015, p.172). About 75 % of the watershed are agriculturally used land (including grassland), 23 % of the area are covered by forest (Klik et al., 2015, p.113). This is shown in Figure 4-3 on the left hand side.

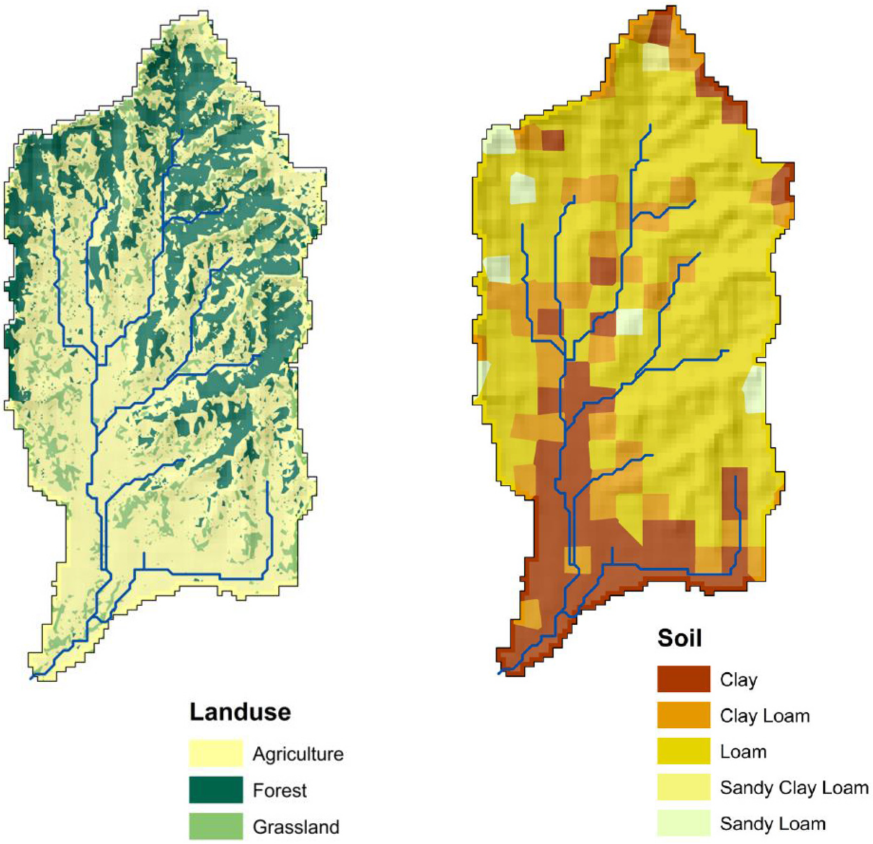

Figure 4-3: Land use and soil classification map of the Gumara-Maksegnit watershed (Kendie Addis, 2013)

4.2 Study Site Set-Up

The study site was located in the Ayaye sub-catchment of the Gumara-Maksegnit watershed. After an inspection of the area two sites with similar slope gradient were selected, one with stone bunds (treated) and one without any SWC measures (untreated). Afterwards four plots, two treated plots and two untreated plots were installed in order to measure the impact of stone bunds on surface runoff and soil loss. Both areas were left uncultivated.

4.2.1 Treated Plots

The treated plots were 20 m long and 4 m wide. They were surrounded by thin metal sheets to isolate the plots from the rest of the study site and to get a well-defined plot area. The metal sheets were 30 cm high and about half of the height was dug into the ground to fix their position. At the bottom of the plot, an additional area of 2 m x 2 m was constructed as an outlet zone. This was necessary in order to prevent a preferential flow towards the installed collection pipe. The lower boundary of the plots is defined by the stone bunds. Figure 4-4 shows the complete layout of the two treated plots.

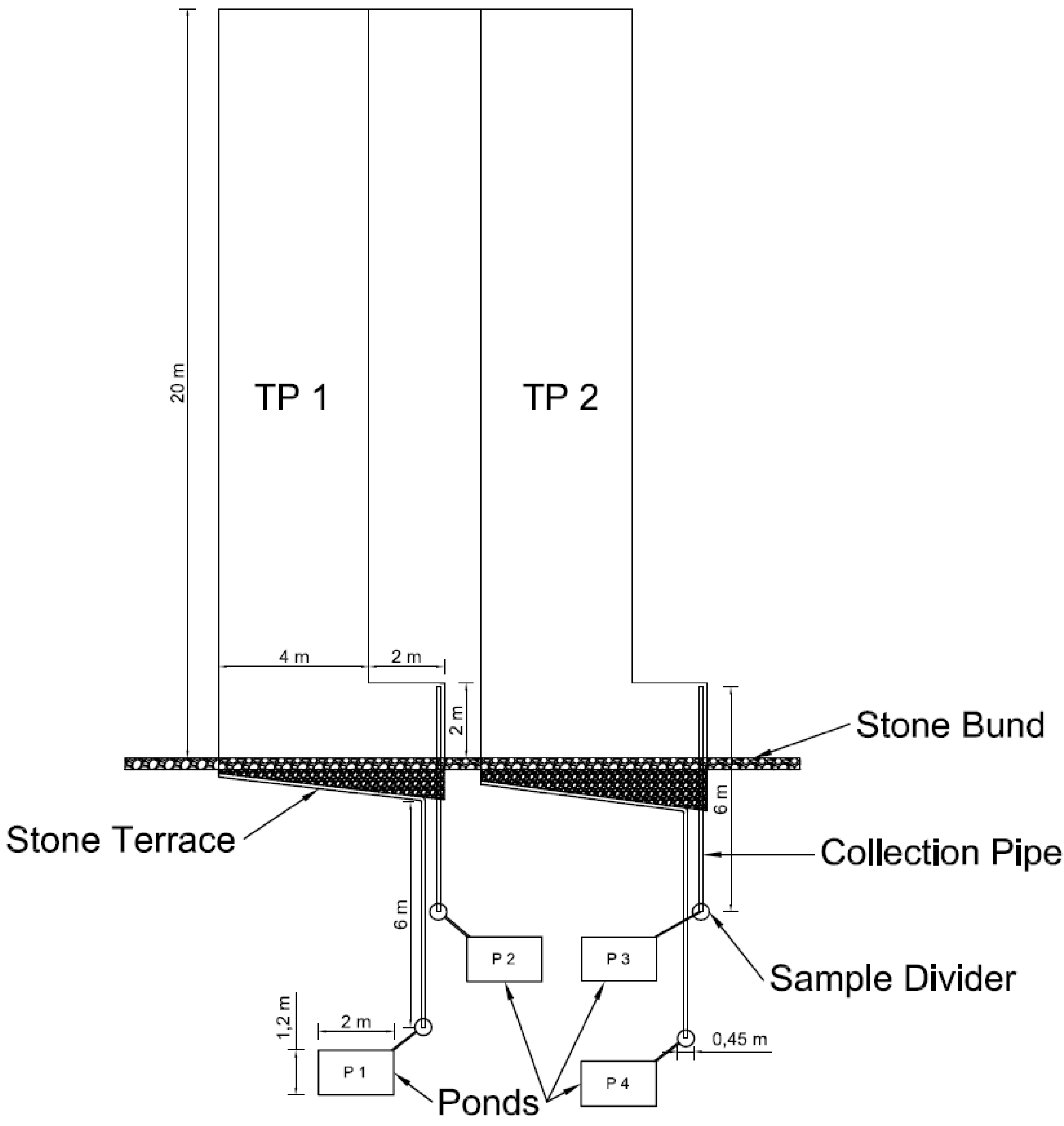

Figure 4-4: Treated plot layout including the location of the stone bund, the stone terraces, the collection pipes, the sample divider as well as the collection ponds

4.2.1.1 Collection Pipes

At each plot, two pipes with openings were installed to collect the surface runoff. One pipe was situated at the right hand side to collect the sideflow (SF), which ran along the stone bund and the other pipe was dug into the ground below the stone bund to collect the overflow (OF). The openings of the pipes were covered with mesh wire to prevent stones from entering.

Figure 4-5: Collection pipe with mesh wire cover (photo: S. Wakolbinger)

4.2.1.2 Stone Terrace

Between the stone bund and the collection pipe, a stone terrace was built. This was done to prevent the runoff from infiltrating after the stone bund and to lead the runoff straight into the collection pipes. The stone terraces were plastered with stones the size of 5 to 10 cm.

Figure 4-6: Installation of stone terraces (photo: S. Wakolbinger)

4.2.1.3 Sample Divider

The runoff was transported by the collection pipes towards the multi-slot sample dividers. The sample dividers were constructed of iron barrels with a height of approximately 30 to 45 cm. Five identical V-shaped cuts were made along the open side of the barrel, these openings had the same distance to another. The sample dividers were situated on an iron bar construction, which put the sample dividers in a horizontal position. As one can see in Figure 4-7 only one opening was linked to a connection pipe, therefore it was possible to collect just 20 % of the runoff. This was necessary because of the high runoff values and the limited space and material for the collection ponds.

Figure 4-7: Sample divider (photo: S. Wakolbinger)

4.2.1.4 Collection Ponds

Following the division, the runoff was stored in collection ponds. The ponds were about 2 m long, 1.2 m wide and 1 m deep. They were lined with plastic foil to stop the water from infiltrating into the ground. At the edges of the ponds the plastic foil was fixed with stones and covered with soil to prevent the excess runoff from outside the plots from entering underneath the foil. The ponds were furthermore covered with corrugated iron sheets plus extra plastic foil and stones to create a closed system and to protect the iron sheets from strong winds. This closed system prevented the collected runoff from evaporating and stopped the rainfall from falsifying the results. In Figure 4-8 and Figure 4-9 one can see an open and a closed collection pond.

Figure 4-8: Open collection pond (photo: E. Obereder)

Figure 4-9: Collection pond covered with corrugated iron sheet, plastic foil and stones (photo: E. Obereder)

4.2.2 Untreated Plots

The untreated plots had basically the same layout as the treated plots. The major difference was the missing stone bund and outlet zones at the bottom of the plots. Therefore, only the total runoff was collected. Figure 4-10 shows the complete layout of the two untreated plots.

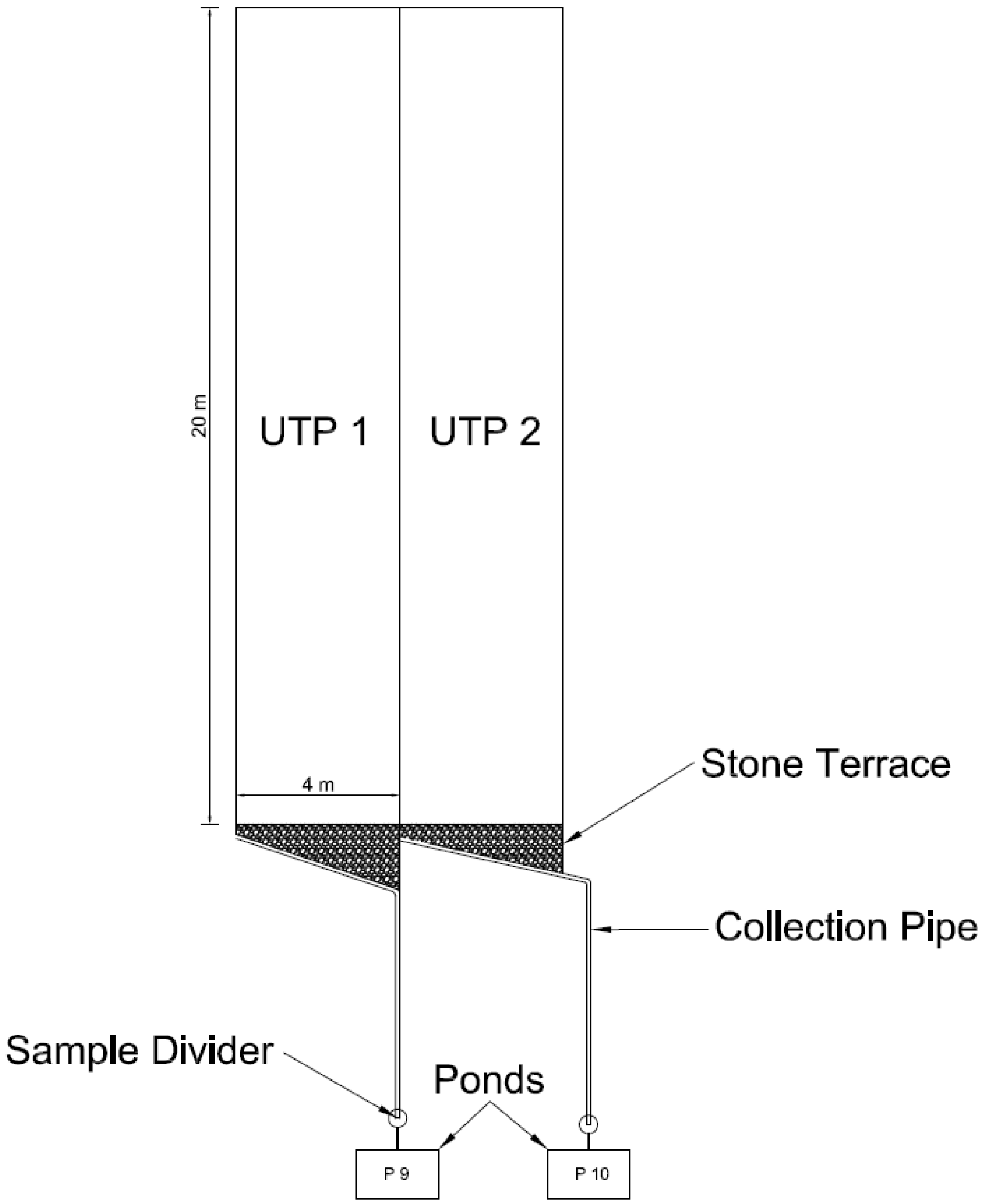

Figure 4-10: Untreated plot layout including the stone terraces, the collection pipes, the sample dividers as well as the collection ponds

4.2.3 Timetable

Table 4-1 shows the timeline for the installation of the erosion plots, the sampling of soil loss and runoff, as well as for the plant cover, inclination and erosion pin assessments. The aim for the installation was to finish before the beginning of the rainy season, which was, aside from some minor rainfalls, achieved. Another aim was to sample the collection ponds after every heavy rainfall event or at least once a week. Due to a lack of information about the rainfall events at the study site, it was not possible to sample the ponds after heavy events, but the aim to sample at least once a week could be accomplished.

Table 4-1: Timetable for plot installation, runoff and soil loss sampling and the different assessments at the study site

	June																						
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Plot Installation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Runoff & Soil Loss Sampling																							
Plant Cover Assessment																							
Inclination Assessment																							
Erosion Pin Assessment																							

	July																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Plot Installation	■	■	■	■	■	■	■																								
Runoff & Soil Loss Sampling								■						■									■	■					■		
Plant Cover Assessment									■					■						■							■				
Inclination Assessment																															
Erosion Pin Assessment																■				■							■				

	August																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Plot Installation																															
Runoff & Soil Loss Sampling						■								■					■							■					
Plant Cover Assessment						■									■				■								■				
Inclination Assessment																		■									■				
Erosion Pin Assessment				■										■					■								■				

	September															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Plot Installation																
Runoff & Soil Loss Sampling	■								■							■
Plant Cover Assessment																
Inclination Assessment																
Erosion Pin Assessment	■															

4.3 Precipitation Data Collection

4.3.1 Manual Rain Gauge

For the precipitation data collection a manual rain gauge was installed at the study site. This rain gauge consisted of a plastic container with scaling, which was tied with a metal wire to a wooden stick (see Figure 4-11). It was located directly next to the plots because the rainfall has a very high spatial variability. The rainfall data was recorded every day in the early morning hours, afterwards the gauge was emptied and tied again to the stick. The recorded values are the sum of the prior 24 hours; therefore, the data does not include information about the intensity of the rainfall. The results can be seen in Chapter 5.1.

Figure 4-11: Manual rain gauge (photo: E. Obereder)

Figure 4-12: Tipping bucket ombrometer (photo: N. Demelash)

4.3.2 Tipping Bucket Ombrometer

Three automatic rain gauges are installed in the watershed, additionally one extra gauging station is located in Maksegnit Town outside the watershed (see Figure 4-1). Less than 1 km away from the study site, in the Aba-K'aloye watershed, one of those tipping bucket ombrometers is installed. It is shown in Figure 4-12. The ombrometer records every tip, which is equal to 0.2 mm of rainfall. Unfortunately, only data from the 6th of August 2015 onwards is available.

4.4 Topographic Survey

In order to get detailed information about the topography of the study area, a surface survey was realized on August 18th 2015. For this survey a see-through tube, two wooden sticks and a measuring tape were used to create a so called 'tube water level'. The tube was 6 m long and 3 cm wide and about three-quarter filled with clear water. To measure the relative altitude difference, the tube was held on each end to a wooden stick, which had a distance of 4 m. This procedure is shown in Figure 4-13. The assessment for each plot started just underneath the top metal sheet boundary; this spot was used as reference point with a reference altitude of 0 m. The survey was done in five steps downhill to cover the whole length of the plots. Using a conventional measuring tape, the relative difference in water level could be determined for each section. For each plot two sets of measurements, one on the left hand side and one on the right hand side, were conducted. This was done to get an average value of inclination for each plot. The results were later pictured with AutoCad® (see Figure 5-19 and Figure 5-20 in Chapter 5.4).

Figure 4-13: Inclination assessment with the tube water level (photo: E. Obereder)

Furthermore, a more detailed assessment of the inclination along the stone bunds was undertaken on August 27th 2015. This was done in order to see how inclination changed over time close to the stone bund. The initial inclination was 0.75 % towards the collection pipe. The location for this assessment was 1 m above the stone bund, in the middle of the outlet zone (see Figure 4-14). The distance between the measurements was reduced to 1 m, except in front of the pipe the distance was only 0.8 m. Again the results were pictured with AutoCad® and are shown in Chapter 5.4

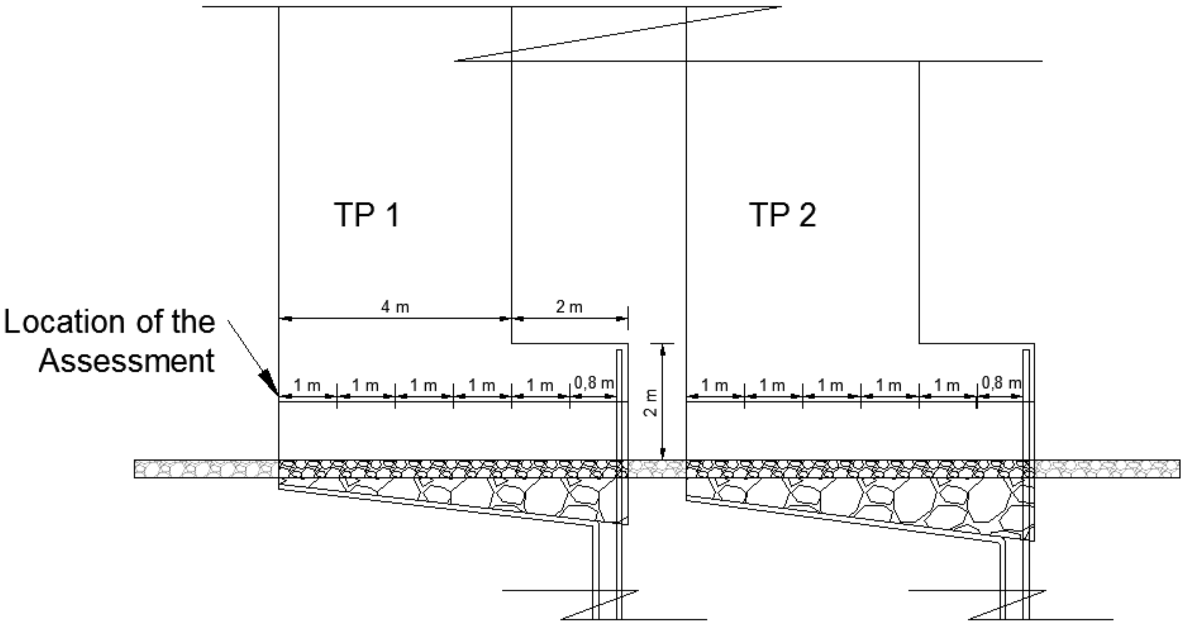

Figure 4-14: Location of the detailed inclination assessment

4.5 Erosion Pin Assessment

The erosion pin assessment started on the 16th of July 2015 with the installation of the erosion pins. Seven measurements followed in the next six and a half weeks. The assessment was concluded on the 1st of September 2015.

On each plot, nine erosion pins were installed in the accumulation zone in order to observe the soil redistribution over time. Each erosion pin was about 30 cm long and was marked with a red tape at 5 and 10 cm. Subsequently the pins were buried with 10 cm of height remaining above the surface (see Figure 4-15 and Figure 4-16).

Figure 4-15: Erosion pin arrangement in the accumulation zone (photo: S. Wakolbinger)

Figure 4-16: Single erosion pin (photo: S. Wakolbinger)

The height was measured in an interval between 4 to 10 days. The detailed layout of the arrangement of the erosion pins can be seen in Figure 4-17. For the calculation of soil loss and soil accumulation a raster of assigned areas was created, using a perpendicular bisector construction between the erosion pins (see Figure 4-18). The difference in height over the observation time was multiplied by the area and divided by an estimated soil density of 1.3 t/m³. This assessment was done in order to see how much soil accumulated in front of the stone bund and how much eroded from this area. The results were pictured with AutoCad®.

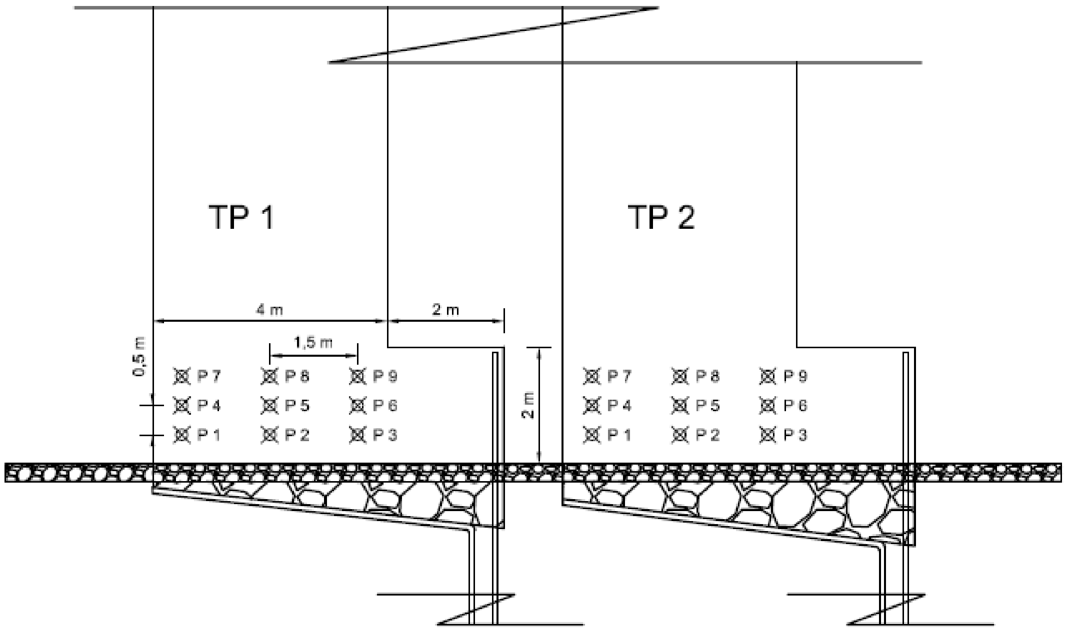

Figure 4-17: Erosion pin assessment layout

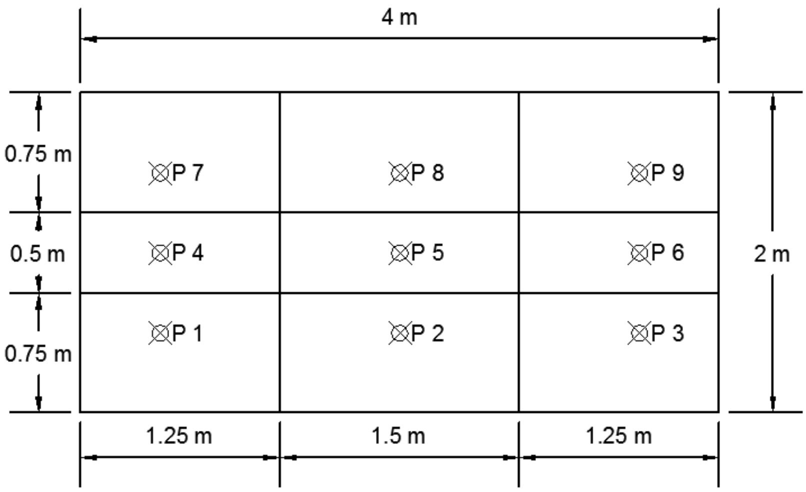

Figure 4-18: Assigned areas for erosion pin assessment

4.6 Assessment of Plant Cover and Stone Cover

4.6.1 Plant Cover

Plant cover was under investigation in order to see, if an increase in biomass on the erosion plots has an effect on surface runoff and soil loss. To assess the change in plant cover over the rainy season for each plot a series of photos was taken between the 9th of July and the 27th of August. This was done in an interval between 4 and 10 days, in total eight pictures for each plot were taken. In order to get comparable areas a frame with the dimensions of 70 cm x 70 cm was built. It consisted of two metal sticks, which were perpendicularly welded together. Additionally, a measurement tape was fixed on one side to get a reference length for the following analysis (see Figure 4-19). The area for this assessment was located in the middle of the plots, 10 m underneath the top metal sheet boundary and 2 m away from the side boundary (see Figure 4-20). For each measurement the frame was supposed to be placed at the same spot, therefore a wooden stick was positioned as marker. The photos were always taken from the same height and position.

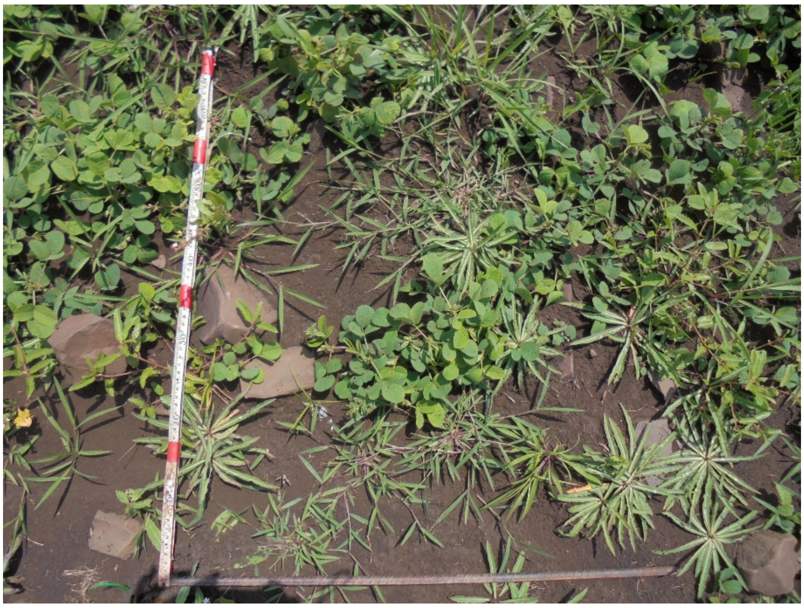

Figure 4-19: Metal frame (70 cm x 70 cm) for the plant and stone cover assessment (photo: E. Obereder)

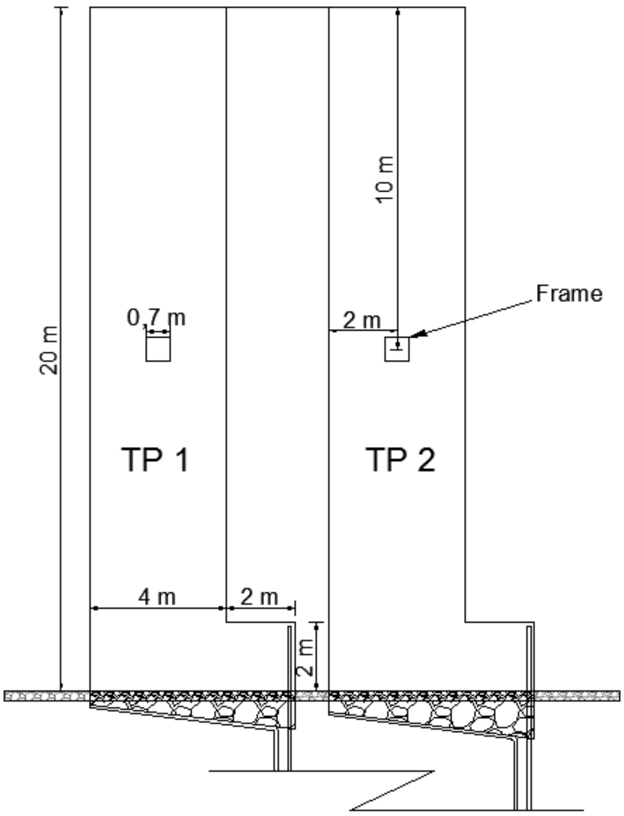

Figure 4-20: Layout of the frame position for the plant cover assessment

For the analysis, an image classification tool by ArcGIS® was used. For this approach each picture was cut to the size of the frame described above and so-called training samples were selected. This was done for all three classes: soil, stones and plants. Subsequently the classification of all the picture pixels was done using the maximum likelihood classification. The result was a list with the sum of pixels of each class. The values were then converted into percent.

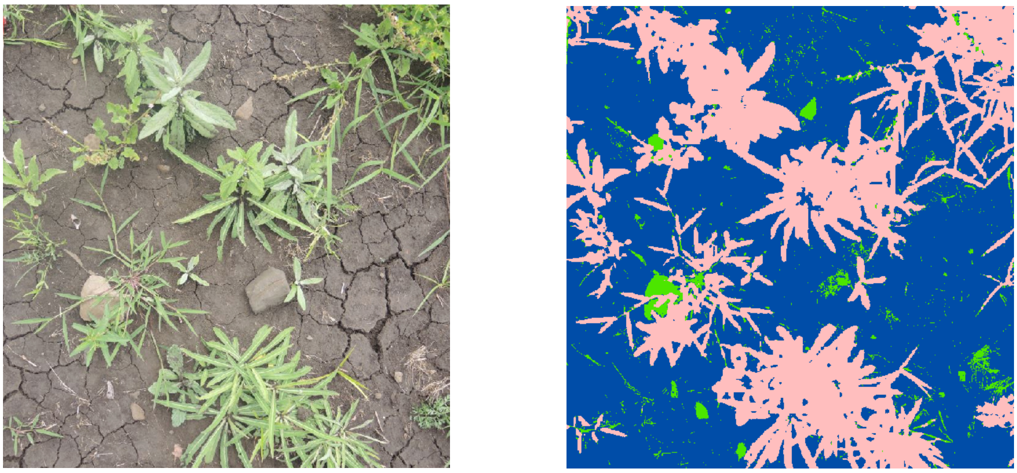

Figure 4-21: Left side: photo for plant cover assessment, which was analyzed with ArcGIS®(photo: E. Obereder); right side: result of the three classes using the image classification tool (rose: plant; green: stone; blue: soil)

4.6.2 Stone Cover

For the assessment of the stone cover a series of photos was taken on the 9th of July 2015. It was assumed that the stone cover is constant over the rainy season; therefore, the measurement was only done once. The same frame was used as for the plant cover assessment; the size (70 cm x 70 cm) represents about three times the maximum stone diameter. The frame was placed along the plot with a distance between 1 and 4 m and about 20 cm away from the metal sheet border. The exact arrangement of the frame can be seen in Figure 4-22. The photos were taken from the same height and position.

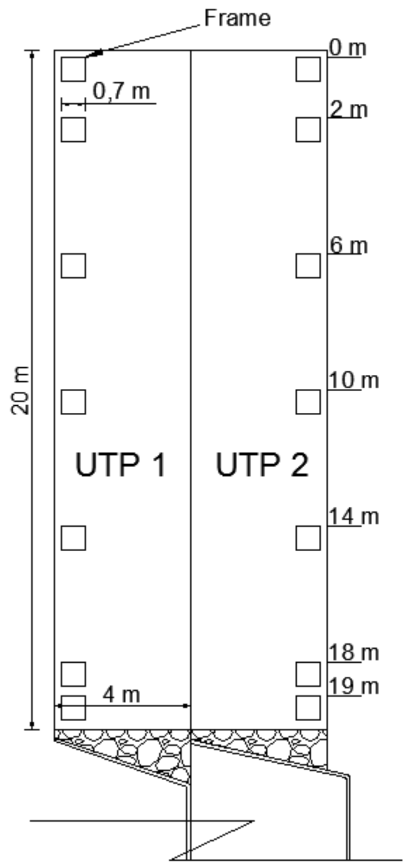

Figure 4-22: Layout of the frame position for the stone cover assessment

4.7 Sampling

The sampling of the collection ponds took place between the 3rd of July and the 16th of September 2015 in the interval of 5 to 8 days. In total, the ponds were sampled eleven times, at one occasion sampling was scheduled, but no water was present in the ponds. To obtain the runoff values the ponds were uncovered and a person had to get inside the pond. The collected runoff was then stirred with the feet to get a homogenous suspension of rainfall water and eroded soil particles. Afterwards a bottle with 1.8 liter volume was filled and later taken to the laboratory. This was always done for each pond in order to get the sediment data. The process of sampling can be seen in Figure 4-23. Subsequently the ponds were emptied using a 10 liter bucket, the total volume of water was recorded. This was done to get the total runoff values per plot. During the first few weeks several problems occurred, they were all recorded to enable a more sophisticated interpretation. Furthermore, the weather and soil conditions were listed for each sampling (see Annex A.1).

Figure 4-23: Demonstration of the sampling process (photo: S. Wakolbinger)

4.8 Sediment Concentration Analysis

For the sediment concentration analysis, the collected sediment-runoff samples were filtered in the laboratory. This was done with the use of textile filters due to simplicity and lack of other options. The filters were weighed in at the beginning and were then placed inside self-constructed metal cones. These cones were subsequently situated on plastic buckets, where an opening was cut into the lid. Figure 4-24 shows the simple filtering system.

A portion of the sediment-runoff sample was slowly poured into the filter-lined cones and left untouched until the cone was empty. This was repeated until the whole sample was filtered. The procedure took several days for each sample The sediment filled filters were then removed and placed in a drying oven with approximately 40 °C. In the end, the filters with the dried sediment were weighed in with a scale, which had an accuracy of 0.001 g.

Figure 4-24: Filtering system including plastic buckets, metal cones and textile filters (photo: S. Wakolbinger)

4.9 Curve Number Assessment

Over time, a number of different methods and models have been developed to predict the runoff volume, which is generated by a rainfall event. The Soil Conservation Service Curve Number (SCS-CN) approach was developed by the United States Department of Agriculture and is widely used. The curve number is affected amongst other factors by the following: soil type, land cover and management as well as hydrological conditions. It can be derived from tables or be estimated from measured rainfall and runoff data (Mishra and Singh, 2013; Soulis and Valiantzas, 2012).

The basic form of the SCS-CN method for calculating the runoff from rainfall is as follows:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Q= Direct runoff in mm

P= Total rainfall in mm

I_a= Initial abstraction in mm

S= Potential maximum retention in mm

Several studies in agricultural used catchment areas have shown that the initial abstraction I_a can approximately be described by the following formula:

$$I_a = 0.2 * S$$

Inserted into the equation from above, it results in a new formula to calculate the direct runoff.

$$Q = \frac{(P - 0.2 * S)^2}{P + 0.8 * S}$$

For better usability of the runoff equation, the values for the potential maximum retention S are being transformed into curve numbers:

$$S = 254 * \left(\frac{100}{CN} - 1\right)$$

These formulas were used to estimate the curve number of the described study area (Klik et al., 1996).

5 Results and Discussion

5.1 Surface Runoff

During the observation period between the 8th of July and the 16th of September 2015 surface runoff was sampled eleven times. One additional attempt of sampling was undertaken on the 20th of July, but the collection ponds were all empty.

As far as at the beginning of the samplings several problems occurred, the data was divided into two parts. The division of data was set on the 6th of August, because after this date the performance of the plots got significantly better and almost no further problems occurred. In order to assess if all data can be used for calculations or only the second part of the data, several calculations were undertaken.

The second data set had a precipitation sum of 344 mm; the total precipitation during sampling was 542 mm. Therefore, the results were multiplied by 542 mm and divided by 344 mm. The results show, that there is a difference in the two data sets. One has to take into account that the high rainfall event from 23rd/24th of July was excluded in the second data set; this explains the lower values in runoff. Overall, it is seen as plausible to use all data for further calculations.

Table 5-1: Comparison of the two runoff (RO) data sets, left side: all data; right side: data starting from the 6th of August

Date	Precip. in mm	RO TP Mean in mm	RO UTP Mean in mm	Precip. in mm	RO TP Mean in mm	RO UTP Mean in mm
08.07.2015	38	9.1	3.7			
14.07.2015	38	6.3	2.4			
23.07.2015	71	6.9	-			
24.07.2015	101	-	16.4			
29.07.2015	51	16.8	-			
29.07.2015	21	-	1.8			
06.08.2015	49	1.8	2.3	49	1.8	2.3
14.08.2015	49	8.1	5.7	49	8.1	5.7
19.08.2015	35	7.2	2.2	35	7.2	2.2
26.08.2015	62	9.0	4.9	62	9.0	4.9
01.09.2015	35	2.5	0.5	35	2.5	0.5
09.09.2015	48	7.7	0.8	48	7.7	0.8
16.09.2015	66	15.4	10.2	66	15.4	10.2
Sum per plot	542	90.8	50.7	344	51.7	26.4
				344 --> 542	81.5	41.6

Figure 5-1 and Figure 5-2 show the total runoff values for all four plots, including the mean values of the treated and untreated plots.

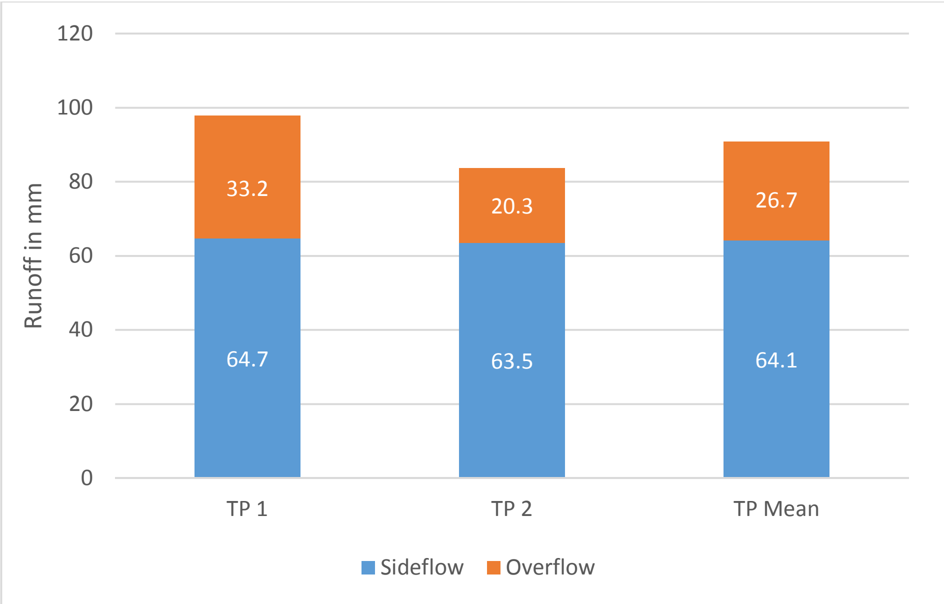

Figure 5-1: Total runoff values (side- and overflow) of the TP 1 and TP 2, including the mean value of the treated plots

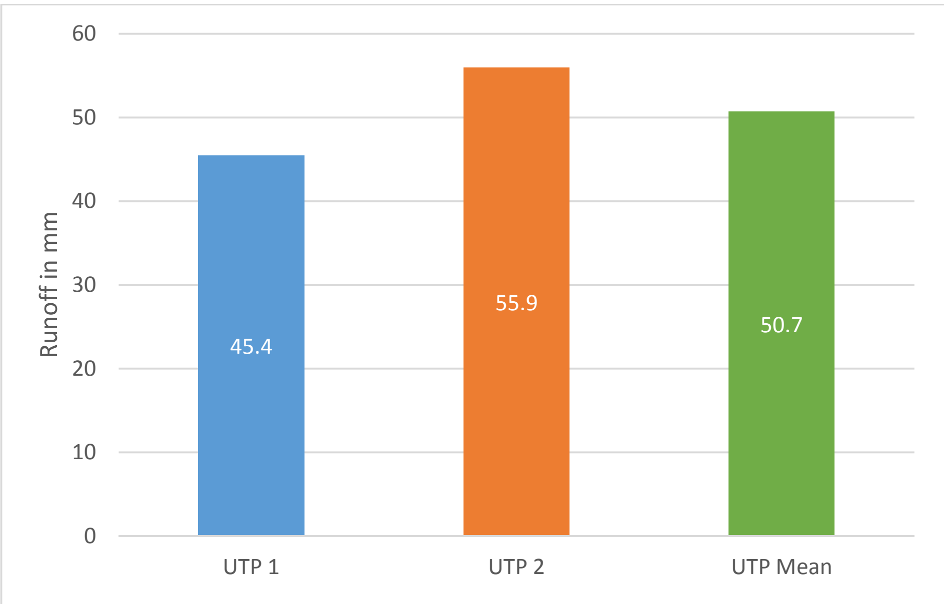

Figure 5-2: Total runoff values of the UTP 1 and UTP 2, including the mean value of the untreated plots

Figure 5-3 shows the runoff values of the treated and the untreated plots compared to the corresponding precipitation. The precipitation data has two values, one for the treated plots and one for the untreated plots. This is because the sampling on 23rd of July was interrupted by a heavy rainfall event and the data collection had to be stopped after the treated plots. This resulted in different precipitation sum values for the following two samplings on the 24th and 29th of July.

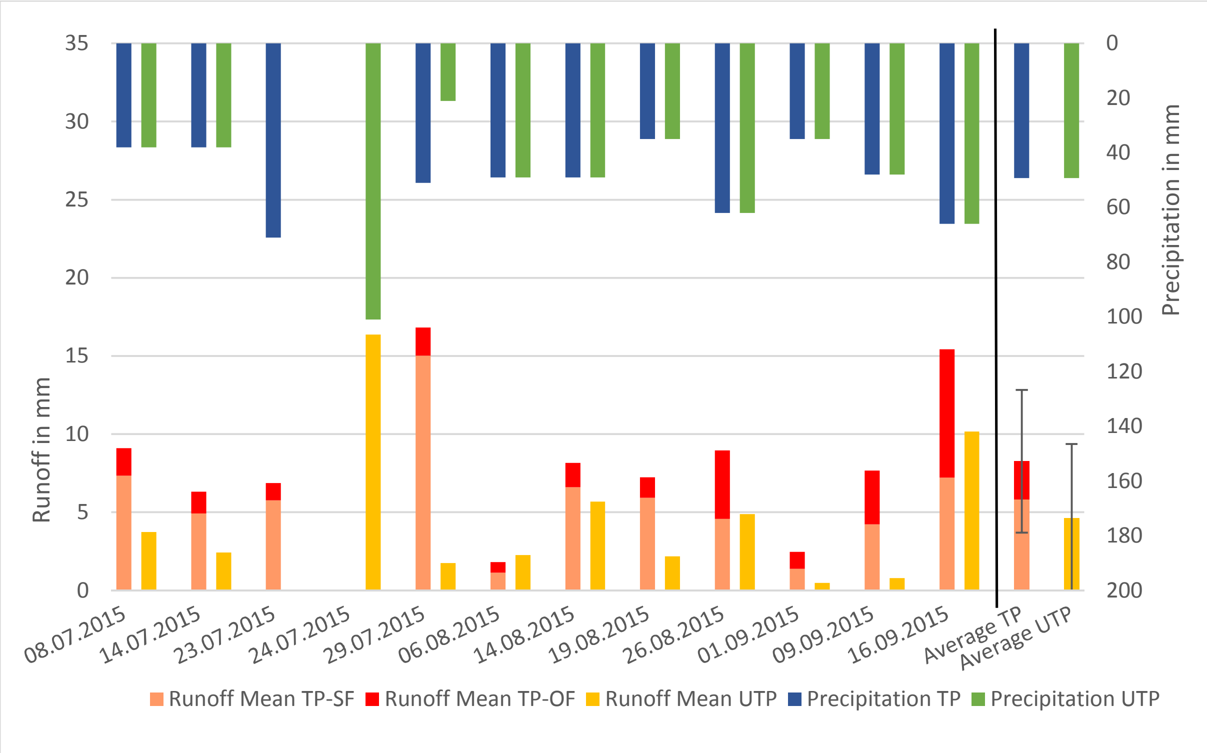

Figure 5-3: Mean runoff values (mean between TP 1 & TP 2 and UTP 1 & UTP 2) for the treated plots (SF= sideflow and OF= overflow) and the untreated plots in comparison to the corresponding precipitation; additional on the right hand side: average runoff and precipitation values (average of all samplings) for the TP and UTP including +/- standard deviation of the runoff

The minimum mean value of runoff was measured on the 1st of September at the untreated plots with only 0.5 mm, although the precipitation sum after the last sampling was accounted with 35 mm (see green ellipses in Table 5-2). This could be due to a low intensity in rainfall. A similar rainfall amount (between two samplings) of 38 mm was recorded on the 8th and 14th of July and resulted in 3.7 mm and 2.4 mm runoff respectively. What distinguishes these two rainfall sums from the case describes before, is that two rainfall events >10 mm happened right after each other (see green ellipses in Table A.2-1 in the Annex). One can assume that the soil was still saturated from the rainfall the day before and that the following rainfall led to high surface runoff.

The maximum mean runoff values of 16.4 mm at the UTP and 16.8 mm at the TP were detected on 24th and 29th of July respectively. On 23th of July a very heavy and intense (observed on the field) rainfall event took place and interrupted the 3rd sampling after the treated plots. Therefore, on 24th of July only the untreated plots were sampled and a total of 101 mm of rainfall was recorded. This event led to a very high runoff as seen in Figure 5-3. The treated plots were next sampled on the 29th of July and also in this case high runoff could be measured, although the rainfall sum was since the last sampling only 51 mm. This heavy event from 23rd of July had obviously great influence on the runoff values (see red ellipses in Table 5-2).

Table 5-2: Precipitation sum values and runoff (RO) values of the treated plots (OF= overflow and SF= sideflow) in mm, additional in the two bottom lines: sum and average values for the mean runoff; green ellipses marks the minimum value at the UTP and the corresponding precipitation; red ellipses marks the maximum values of both plots and the corresponding precipitation

Date	Precipitation Sum mm	Runoff TP Mean mm	Runoff OF Mean mm	Runoff SF Mean mm	Runoff UTP Mean mm
08.07.2015	38	9.1	1.8	7.3	3.7
14.07.2015	38	6.3	1.4	4.9	2.4
23.07.2015	71	6.9	1.1	5.8	-
24.07.2015	101	-	-	-	16.4
29.07.2015	51	16.8	1.8	15.0	-
29.07.2015	21	-	-	-	1.8
06.08.2015	49	1.8	0.7	1.1	2.3
14.08.2015	49	8.1	1.5	6.6	5.7
19.08.2015	35	7.2	1.3	5.9	2.2
26.08.2015	62	9.0	4.4	4.6	4.9
01.09.2015	35	2.5	1.1	1.4	0.5
09.09.2015	48	7.7	3.4	4.2	0.8
16.09.2015	66	15.4	8.2	7.2	10.2
Sum	-	90.8	26.7	64.1	50.7
Average	-	8.3	2.4	5.8	4.6

The total runoff during the rainy season for the treated plots was 90.8 mm and only 50.7 mm for the untreated plots as seen in Table 5-2. The runoff values were expected to be about the same, due to the similar plot set-up. A possible explanation of this diversion of runoff could be that the collection pipes of both untreated plots were often partly blocked with sediments. The reason for this blockage could be that the inclination in the lower parts of the plots as well as in the area below the plots was less than on the rest of the study area. Therefore, the collection pipes had to be removed several times, subsequently be cleared of sediment and be installed again afterwards. Despite all efforts, no satisfying solution could be acquired. Figure 5-4 shows the problem of the blocked pipe. The result of this problem could be that some of the surface runoff went over the pipe and therefore was not collected in the ponds.

Figure 5-4: Blocked collection pipe at the UTP 1 (photo: S. Wakolbinger)

Figure 5-5 shows the correlation of rainfall and the corresponding surface runoff of the treated and the untreated plots. The correlation coefficient R^2 is much lower ($R^2 = 0.15$) at the treated plots than on the untreated plots ($R^2 = 0.81$). The reason for this deviation could be the more complex plot set-up of the treated plots, which resulted in more sources of errors. However, one has to take into account that some of the runoff of the untreated plots went over the collection pipe and was not collected. Therefore, the correlation values of the untreated plots should be considered with care.

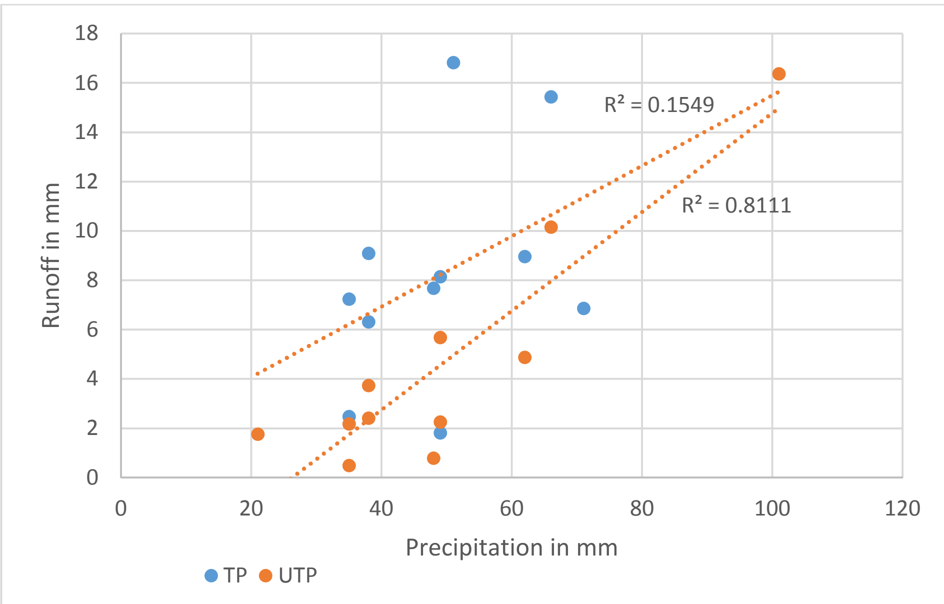

Figure 5-5: Correlation between precipitation values and mean runoff values in mm of the TP= treated plots and the UTP= untreated plots

5.1.1 Runoff Coefficient

The runoff coefficient describes the relationship between the runoff and the precipitation, the coefficient has no unit.

$$Runoff\ Coefficient = \frac{Runoff\ in\ mm}{Precipitation\ in\ mm}$$

Figure 5-6 shows the runoff coefficient of the treated and the untreated plots compared to the corresponding runoff, including the average values of the runoff coefficient and the runoff. The values of the runoff coefficient range from 0.04 to 0.33 at the TP and from 0.01 to 0.16 at the UTP, the average being 0.17 and 0.08 respectively. This means on average only 8 to 17% of the precipitation resulted in runoff.

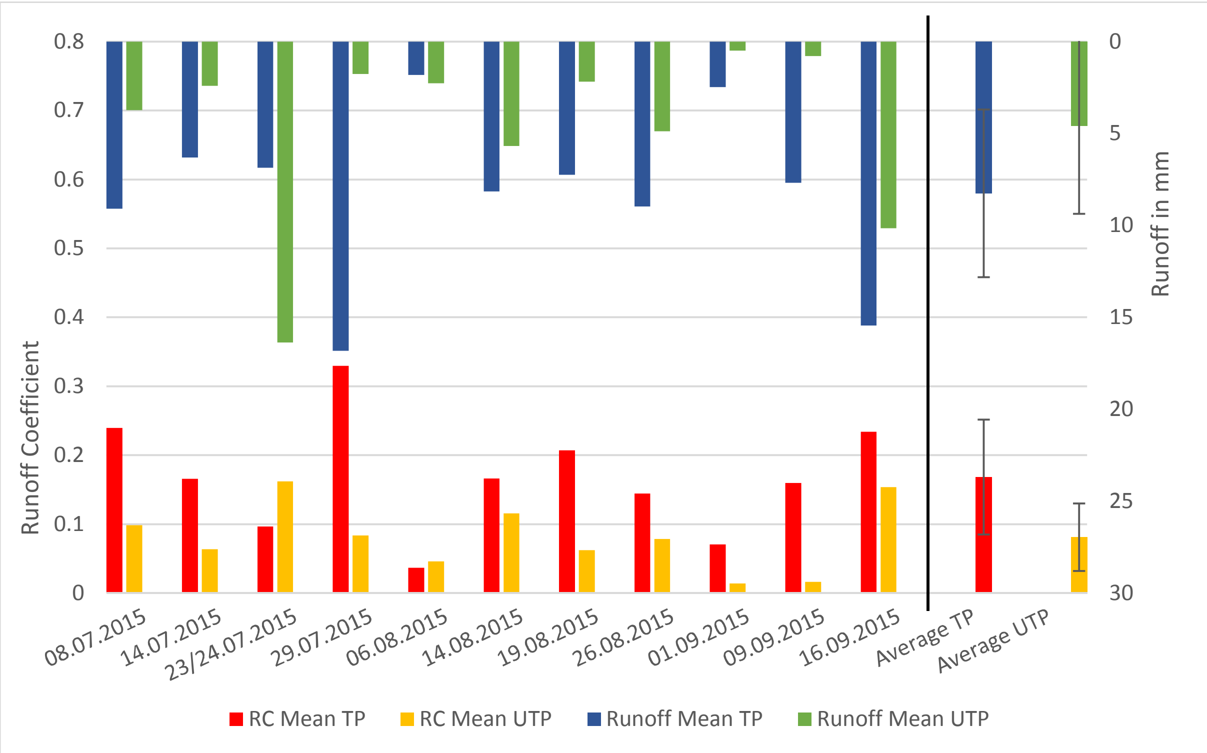

Figure 5-6: Mean runoff coefficient values (mean between TP 1 & TP 2 and UTP 1 & UTP 2) for the treated plots and the untreated plots in comparison to the corresponding runoff values; additional on the right hand side: average runoff coefficient and runoff values (average of all samplings) for the TP and UTP including +/- standard deviation

Table 5-3 represents all mean values for the runoff coefficient of the treated and untreated plots and corresponding runoff values. The minimum values for the runoff coefficient are marked with green ellipses, the maximum values with red ellipses.

Table 5-3: Mean runoff coefficient and mean runoff values of the treated (TP) and untreated plots (UTP); maximum values are marked with red ellipses, minimum values with green ellipses; additional in the bottom line: sum values of the mean runoff and average values for the mean runoff coefficient

Date	Runoff Mean in mm		Runoff Coefficient Mean	
	TP	UTP	TP	UTP
08.07.2015	9.1	3.7	0.24	0.10
14.07.2015	6.3	2.4	0.17	0.06
23/24.07.2015	6.9	16.4	0.10	0.16
29.07.2015	16.8	1.8	0.33	0.08
06.08.2015	1.8	2.3	0.04	0.05
14.08.2015	8.1	5.7	0.17	0.12
19.08.2015	7.2	2.2	0.21	0.06
26.08.2015	9.0	4.9	0.14	0.08
01.09.2015	2.5	0.5	0.07	0.01
09.09.2015	7.7	0.8	0.16	0.02
16.09.2015	15.4	10.2	0.23	0.15
Sum/ Average	90.8	50.7	0.17	0.08

Figure 5-7 shows the mean runoff coefficient values as well as the precipitation sums between the samplings. The standard deviation for the treated plots is 0.17 and for the untreated plots, the standard deviation is 0.05. This diagram indicates that there is low correlation between the two parameters.

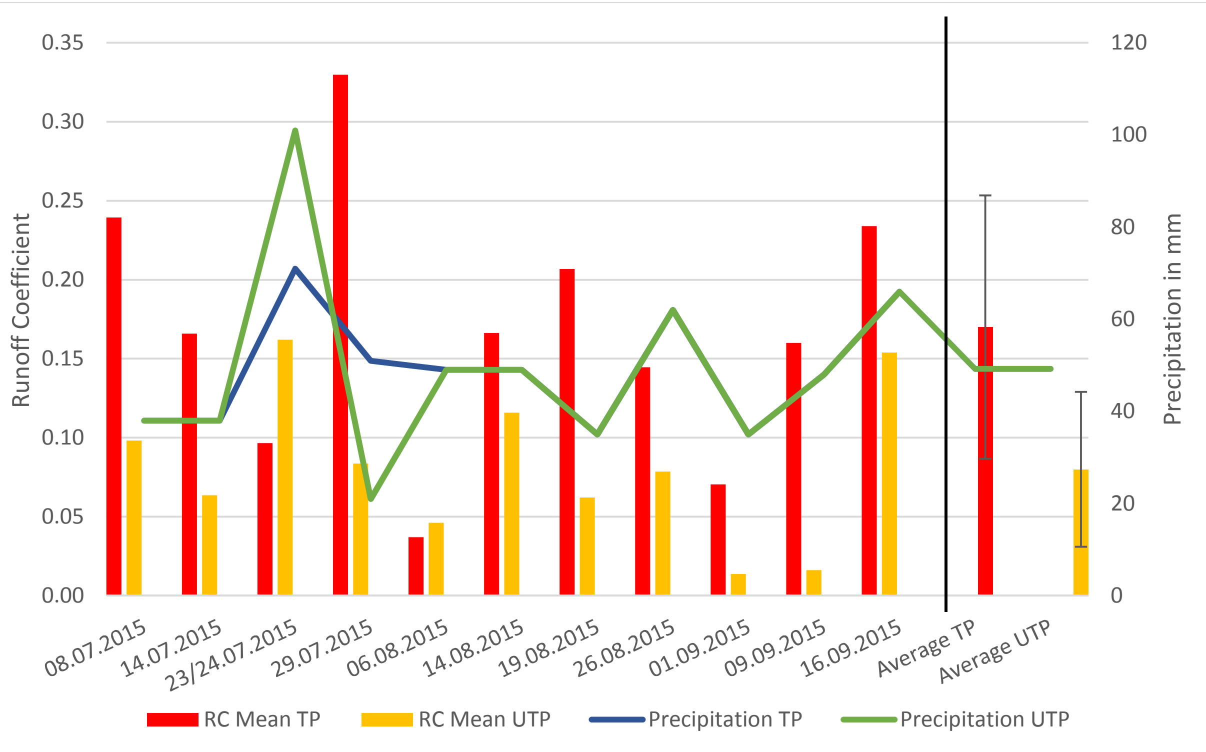

Figure 5-7: Mean runoff coefficient values (mean between TP 1 & TP 2 and UTP 1 & UTP 2) for the treated plots and the untreated plots in comparison to the corresponding precipitation; additional on the right hand side: average runoff coefficient values (average of all samplings) for the TP and UTP including +/- standard deviation

Figure 5-8 shows the correlation between the precipitation and the runoff coefficient. It confirms the assumption mentioned above, that there is hardly no correlation between the precipitation values and the runoff coefficient. Therefore, no conclusion can be drawn if heavy rainfall leads to a higher runoff coefficient.

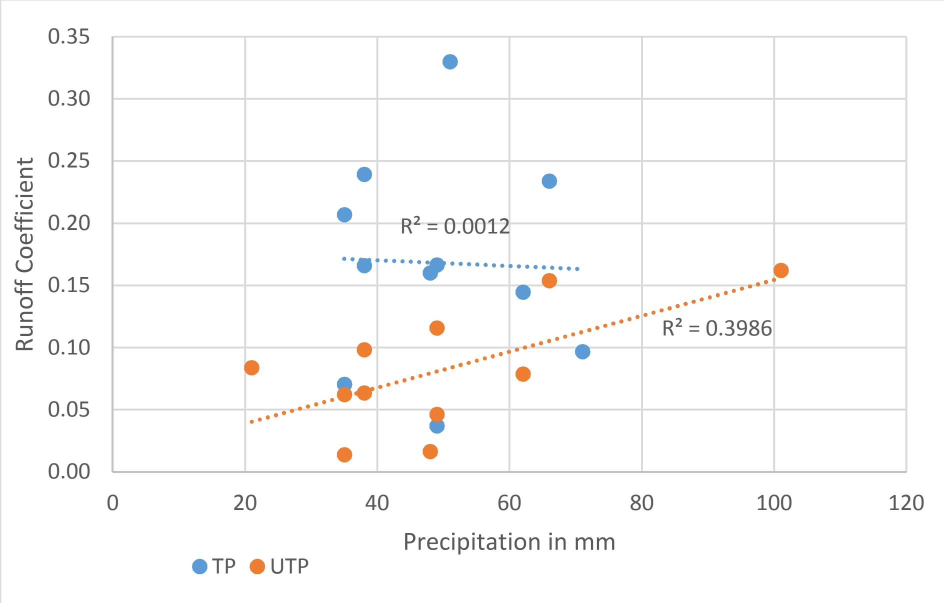

Figure 5-8: Correlation between precipitation values and mean runoff coefficient values of the TP= treated plots and UTP= untreated plots

5.1.2 Runoff Ratio between Sideflow and Overflow

Figure 5-9 represents the mean ratio of runoff between the overflow and the sideflow of the treated plots. The values range from only 11 % overflow on the 29th of July to 53 % of overflow at the last sampling on the 1st of September. On average did 30 % of the runoff flow over the stone bund. One can see, that there is an increase of overflow over the observation period, this could be due to the formation of progressing terraces in front of the stone bund.

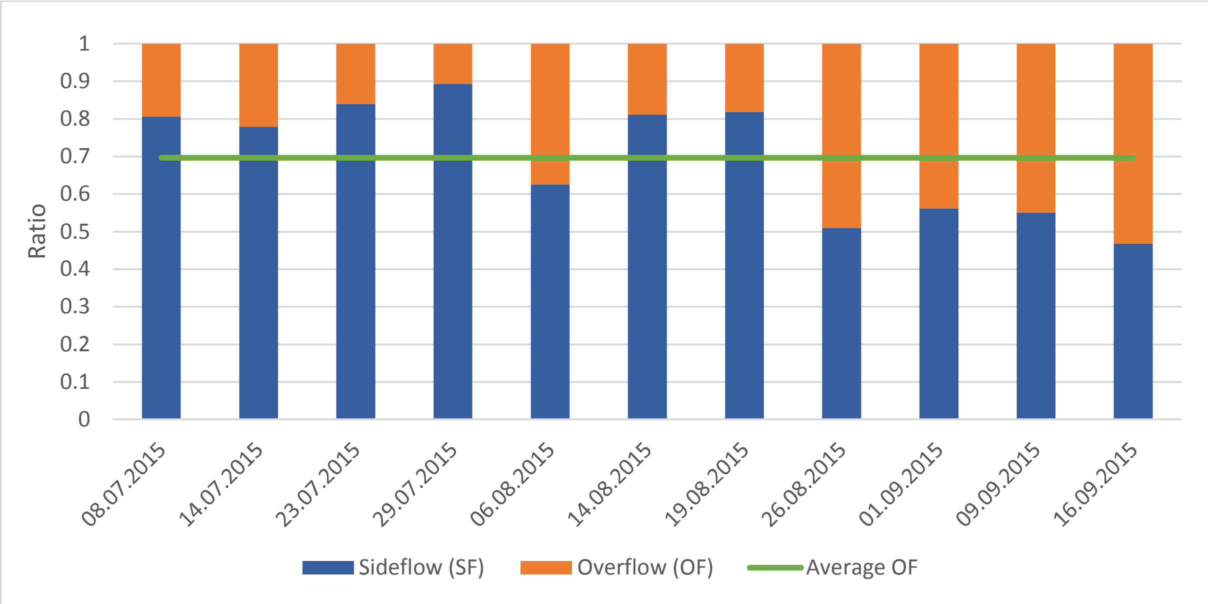

Figure 5-9: Ration between the mean runoff OF= overflow and the SF= sideflow of the treated plots, including the average OF value

5.2 Soil Erosion

The sampling for the soil loss data was done within the course of the runoff sampling during the research period between the 8th of July and the 16th of September as described in Chapter 4.7. The combination of the collected runoff data and the results of the sediment concentration analysis allowed the evaluation of soil erosion data.

As already mentioned in Chapter 5.1 at the beginning of the samplings several problems occurred, therefore the data was divided into 2 parts.

The results show, that there is also a difference of the two data sets in soil loss. Nevertheless, as explained above one has to take into account that the high rainfall event from 23rd/24th of July was excluded in the second data set, therefore the lower values in soil loss are still plausible.

Table 5-4: Comparison of the two soil loss (SL) data sets, left side: all data; right side: data starting from the 6th of August

Date	Precip. in mm	SL TP Mean in t/ha	SL UTP Mean in t/ha	Precip. in mm	SL TP Mean in t/ha	SL UTP Mean in t/ha
08.07.2015	38	0.68	0.71			
14.07.2015	38	0.14	0.40			
23.07.2015	71	0.45	-			
24.07.2015	101	-	6.61			
29.07.2015	51	1.04	-			
29.07.2015	21	-	0.52			
06.08.2015	49	0.12	0.21	49	0.12	0.21
14.08.2015	49	0.38	1.49	49	0.38	1.49
19.08.2015	35	0.21	0.90	35	0.21	0.90
26.08.2015	62	0.22	1.79	62	0.22	1.79
01.09.2015	35	0.03	0.10	35	0.03	0.10
09.09.2015	48	0.10	0.05	48	0.10	0.05
16.09.2015	66	0.48	1.92	66	0.48	1.92
Sum per plot	542	3.86	14.69	344	1.54	6.46
				344 --> 542	2.43	10.18

Figure 5-10 and Figure 5-11 show the total soil loss values for all four plots, including the mean values of the treated and untreated plots.

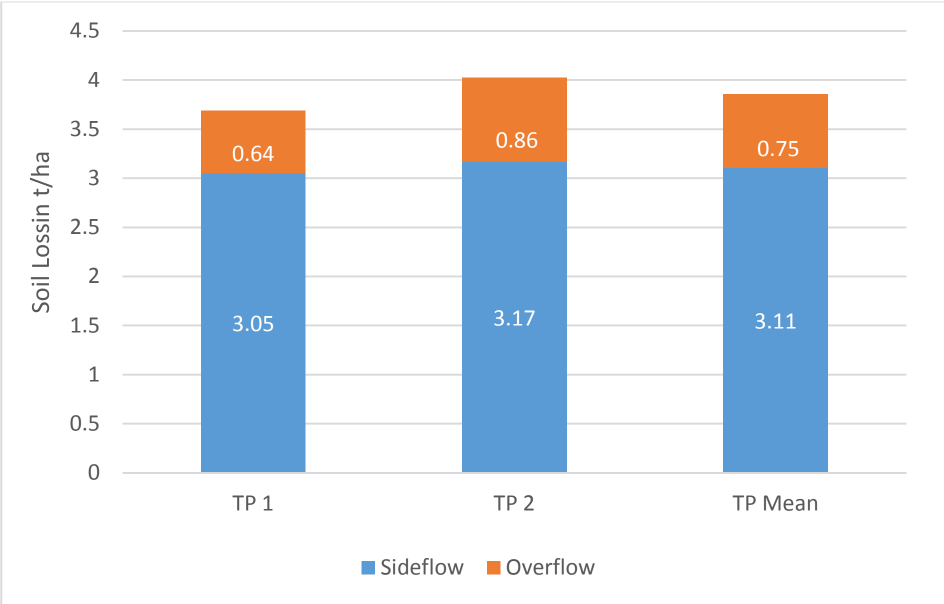

Figure 5-10: Total values of soil loss (side- and overflow) of the TP 1 and TP 2, including the mean value of the treated plots

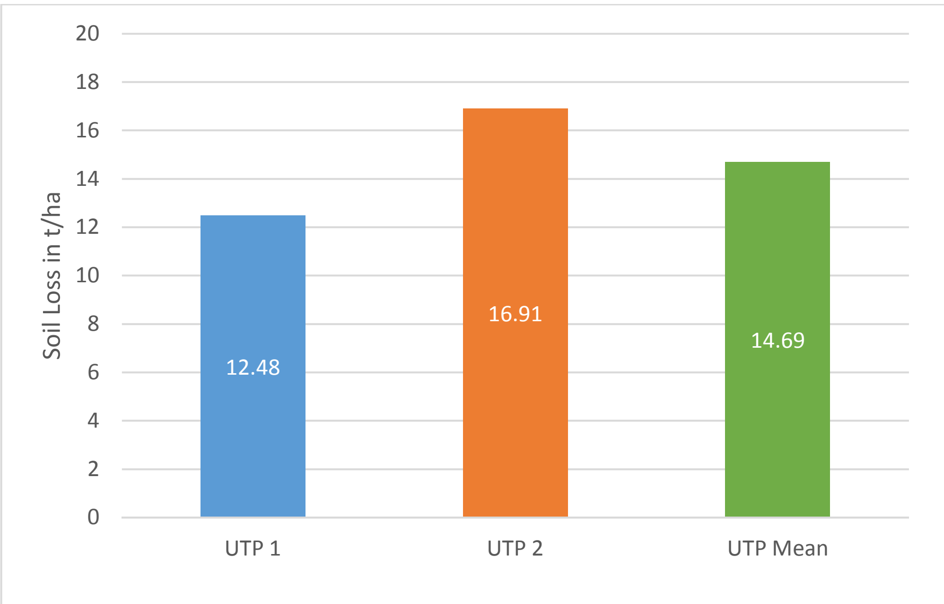

Figure 5-11: Total values of soil loss of the UTP 1 and UTP 2, including the mean value of the untreated plots

5.2.1 Soil Loss - Precipitation

Figure 5-12 shows the mean soil loss values of the treated and untreated plots in comparison to the corresponding precipitation between the samplings. The highest soil loss on the treated plots was 1.04 t/ha and was detected on the 28th of July after the heavy rainfall event mentioned above. The same event also led to the highest soil loss on the untreated plot with a loss of 6.61 t/ha, this is by far the highest event measured during the entire rainy season. For better visibility of the remaining data, this column ends with a red cross, because the soil loss axis ends at 4 t/ha and the exact value is not displayed. The second highest values were measured at the last sampling on 16th of September, with 0.48 t/ha for the treated plots and 1.92 t/ha for the untreated plots. In this diagram too, the precipitation data has two different values. The reason for this was mentioned above in Chapter 5.1 on page 39.

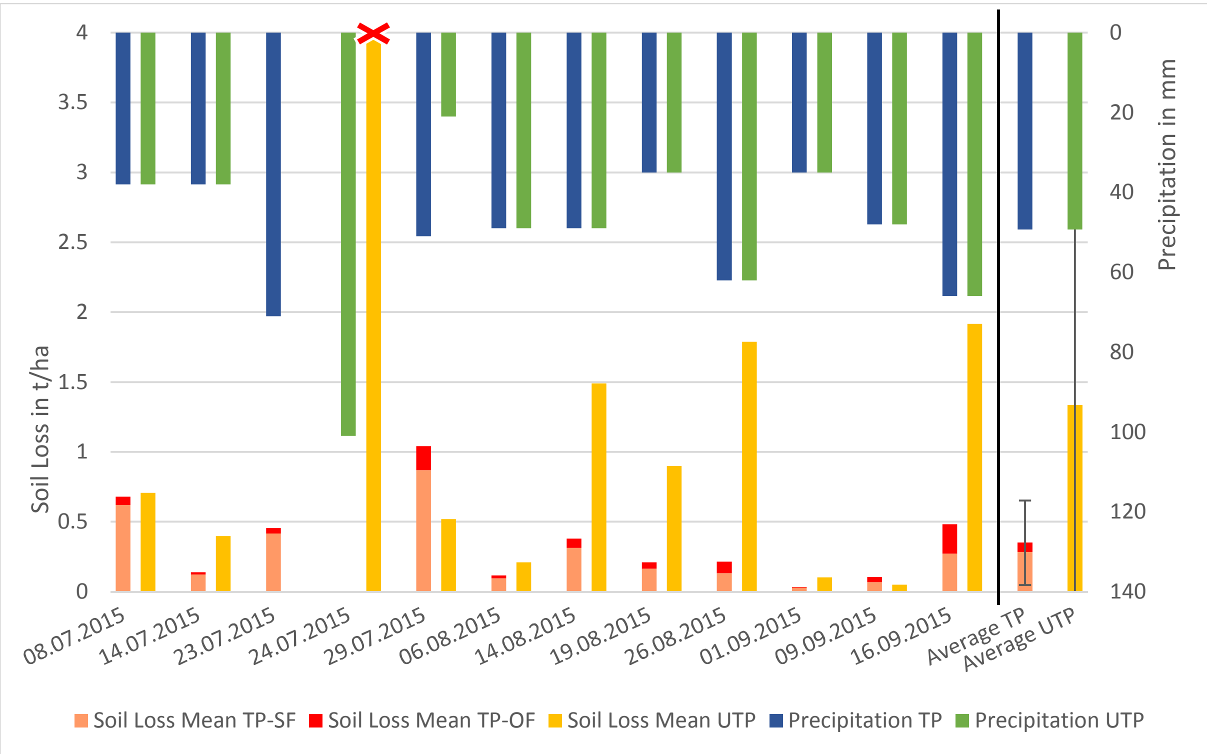

Figure 5-12: Mean soil loss values (mean between TP 1 & TP 2 and UTP 1 & UTP 2) for the treated plots (SF= sideflow and OF= overflow) and the untreated plots in comparison to the corresponding precipitation; additional on the right hand side: average soil loss and precipitation values (average of all samplings) for the TP and UTP including +/- standard deviation of the soil loss

Table 5-5 displays the mean soil loss values as well as the corresponding sediment concentration. The average sediment concentration is significantly higher at the untreated plots (27.5 g/l) than on the treated plots (3.9 g/l). This leads to the conclusion that the stone bunds hold back a lot of sediment.

Table 5-5: Mean soil loss and mean sediment concentration values of the treated and untreated plots (SF= sideflow and OF= overflow), additional in the bottom line: sum values of the mean soil loss and average values for the mean sediment concentration

Date	Soil Loss Mean in t/ha				Sediment Concentration Mean in g/l			
	TP-SF	TP-OF	TP-Sum	UTP	TP-SF	TP-OF	TP-Sum	UTP
08.07.2015	0.62	0.06	0.68	0.71	8.037	4.866	6.451	32.489
14.07.2015	0.12	0.02	0.14	0.40	1.956	0.523	1.240	16.088
23.07.2015	0.42	0.04	0.45	-	7.762	3.329	5.546	-
24.07.1015	-	-	-	6.61	-	-	-	38.203
29.07.2015	0.87	0.17	1.04	0.52	6.039	7.082	6.560	29.763
06.08.2015	0.10	0.02	0.12	0.21	11.503	2.641	7.072	29.303
14.08.2015	0.31	0.07	0.38	1.49	4.703	3.937	4.320	26.221
19.08.2015	0.17	0.04	0.21	0.90	3.040	3.189	3.115	42.065
26.08.2015	0.13	0.08	0.22	1.79	2.852	2.178	2.515	39.847
01.09.2015	0.03	0.01	0.03	0.10	1.486	1.412	1.449	22.256
09.09.2015	0.07	0.03	0.10	0.05	1.681	1.289	1.485	7.239
16.09.2015	0.27	0.21	0.48	1.92	4.036	3.207	3.622	18.981
Sum/ Average	3.11	0.75	3.86	14.69	4.827	3.059	3.943	27.496

Figure 5-13 shows the correlation between the precipitation values and the mean soil loss values of the treated and the untreated plots. The correlation of the treated plots is lower than the correlation of the untreated plots. The correlation coefficient R^2 between the soil loss and rainfall of the treated plots is only 0.23, whereas the coefficient of the untreated plots is 0.79. Maybe the more complex plot set-up of the treated plot led to more mistakes in sampling and therefore to a higher variability in data. Furthermore, there is no information about the rainfall distribution over time and therefore no conclusion can be drawn about the relationship between the intensity of rainfall and the soil loss data.

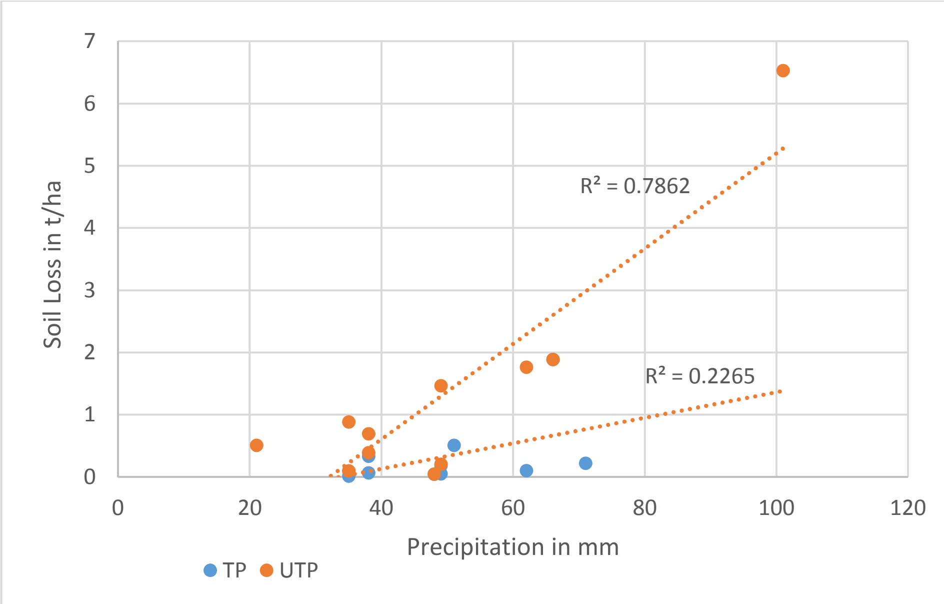

Figure 5-13: Correlation between the precipitation values and the mean soil loss values of the TP= treated plots and UTP= untreated plots

5.2.2 Soil Loss - Runoff

Figure 5-14 shows the mean soil loss values in comparison to the corresponding mean surface runoff values between the 8th of July and the 16th of September 2015. Although the runoff is mostly lower on the untreated plots, the soil loss values are significantly higher. If one takes into account that possibly not all the runoff was collected at the untreated plots, the soil loss values could be even higher. Again, the red cross marks a point where the soil loss column ends, the exact value of 6.61 t/ha is not displayed.

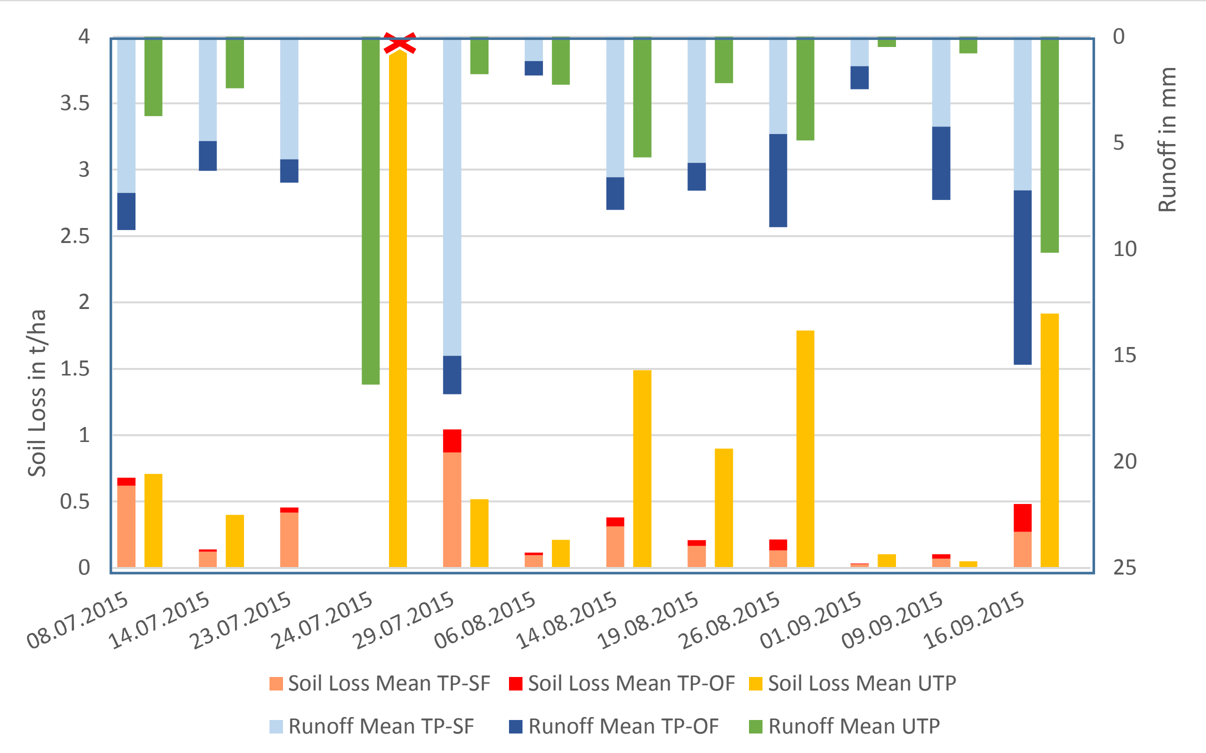

Figure 5-14: Mean soil loss values (mean between TP 1 & TP 2 and UTP 1 & UTP 2) for the treated plots (SF= sideflow and OF= overflow) and the untreated plots in comparison to the corresponding mean runoff values

Figure 5-15 depictures the correlation between the mean soil loss data and the mean runoff data of the treated and untreated plots. The correlation coefficients are significantly higher than the coefficients between rainfall and soil loss. The values are $R^2 = 0.63$ for the treated plots and $R^2 = 0.89$ for the untreated plots. This leads to the conclusion that the higher the runoff, the higher the soil loss.

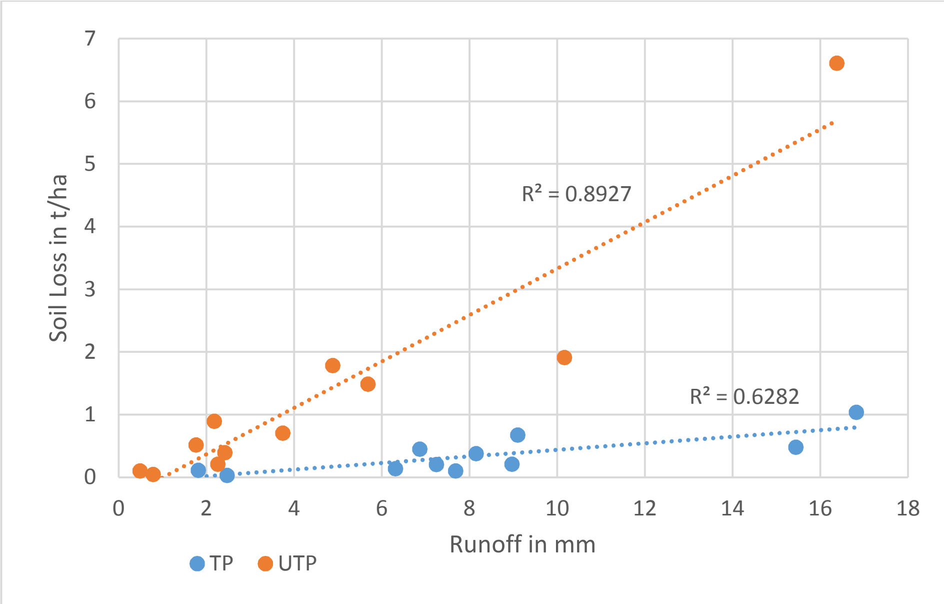

Figure 5-15: Correlation between the mean soil loss values and the mean runoff values of the TP= treated plots and UTP= untreated plots

Figure 5-16 shows an overview about the total soil loss and surface runoff data, which was collected over the rainy season 2015. One can see that soil loss was about 300 % higher on the untreated plots than on the treated plots. However, less surface runoff was collected at the untreated plots compared to the treated plots.

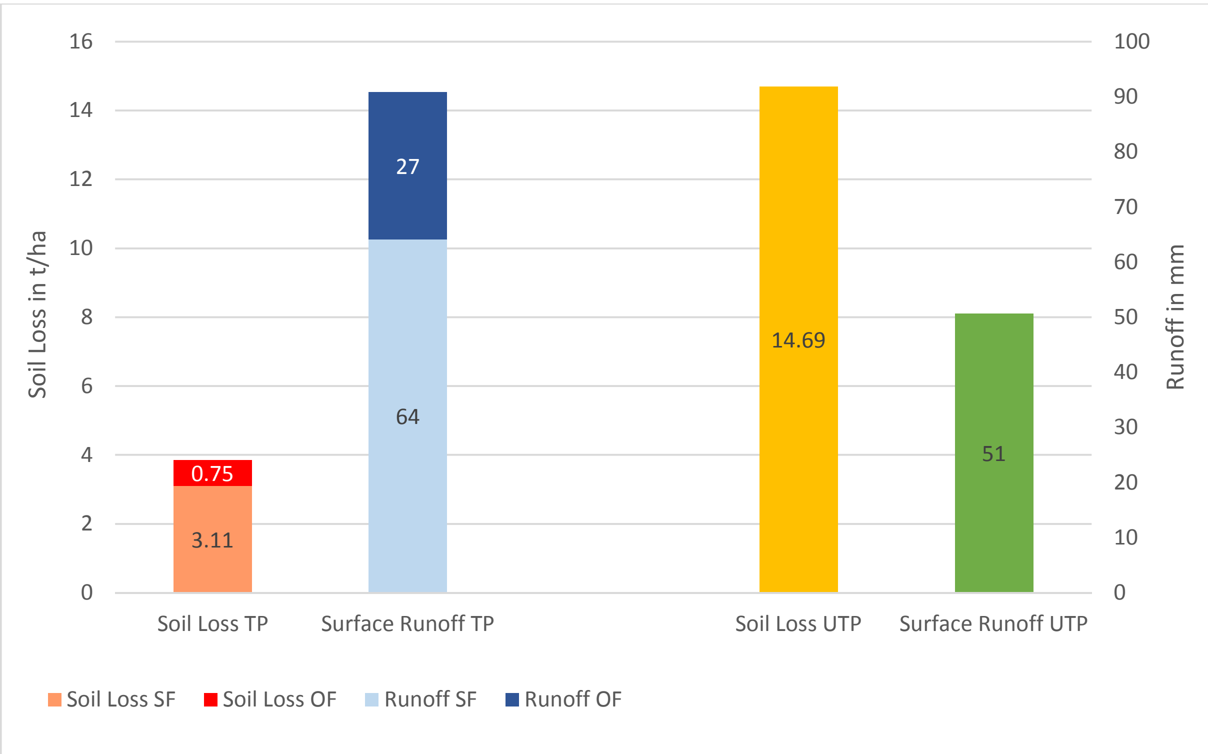

Figure 5-16: Total values for mean soil loss in t/ha compared to the mean runoff in mm of the treated (TP) and untreated plots (UTP); OF= overflow and SF= sideflow

Table 5-6 shows the total mean soil loss and the mean surface runoff values of the treated and untreated plots.

Table 5-6: Total values for mean soil loss in t/ha compared to the mean runoff in mm of the treated (TP) and untreated plots (UTP); OF= overflow and SF= sideflow

<table>
<tr><th>Plot</th><th colspan="3">Soil Loss Mean in t/ha</th><th colspan="3">Surface Runoff Mean in mm</th></tr>
<tr><td>TP 1 - SF</td><td>3.05</td><td rowspan="2">3.69</td><td rowspan="4">3.86</td><td>65</td><td rowspan="2">98</td><td rowspan="4">91</td></tr>
<tr><td>TP 1 - OF</td><td>0.64</td><td>33</td></tr>
<tr><td>TP 2 - SF</td><td>3.17</td><td rowspan="2">4.03</td><td>64</td><td rowspan="2">85</td></tr>
<tr><td>TP 2 - OF</td><td>0.86</td><td>21</td></tr>
<tr><td>UTP 1</td><td>12.48</td><td>12.48</td><td rowspan="2">14.69</td><td>45</td><td>45</td><td rowspan="2">51</td></tr>
<tr><td>UTP 2</td><td>16.91</td><td>16.91</td><td>56</td><td>56</td></tr>
</table>

5.3 Precipitation Data

Precipitation data was recorded with a manual rain gauge next to the erosion plots, as well as with an ombrometer in the adjacent Aba-K'aloye watershed as described in Chapter 4.3.

Figure 5-17 shows the precipitation data recorded from the 24th of June up to the 16th of September, it includes the daily precipitations sum, the precipitation average, the event average as well as the accumulative precipitation over the recording period.

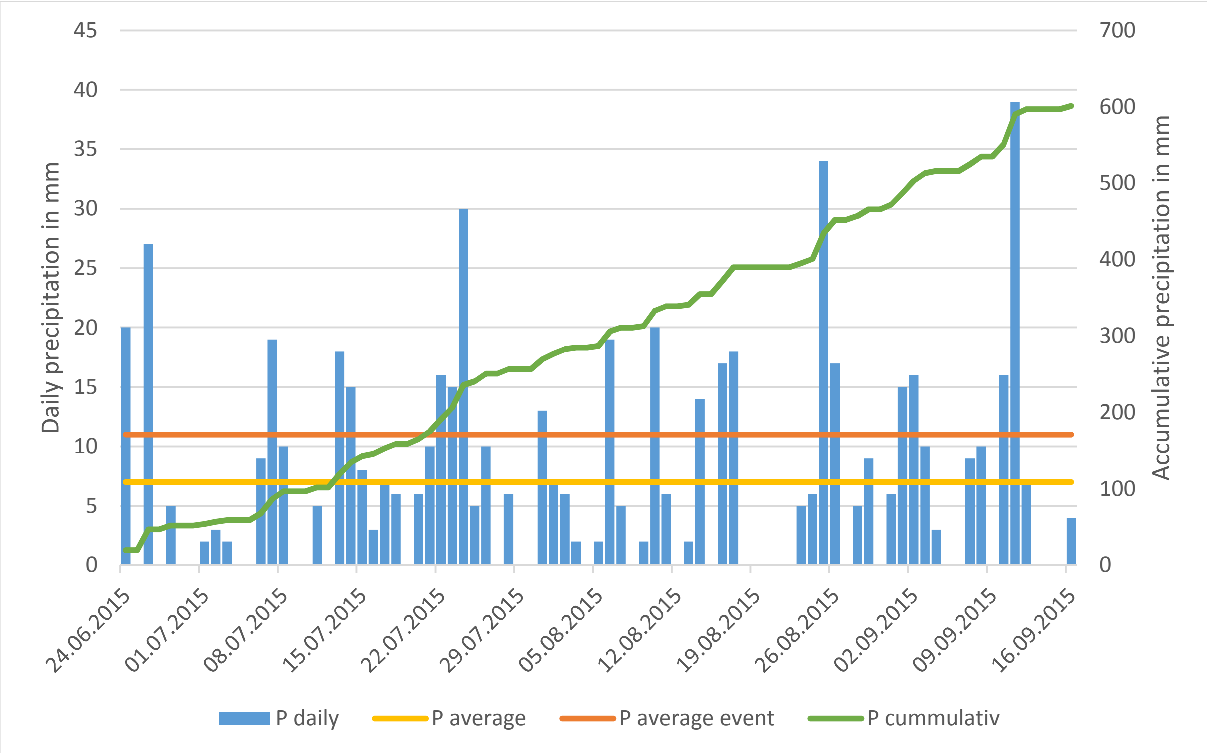

Figure 5-17: Daily precipitation (P) data collected with the manual rain gauge between the 24th of July and the 16th of September; including the average precipitation, the average event precipitation and the accumulative precipitation

The daily rainfall was recorded on 85 consecutive days. No rainfall event exceeded 40 mm. The single events varied from 2 mm to 39 mm of daily precipitation and only on four days, the rainfall sum was higher than 20 mm. Within those 85 days of recording 55 events were measured. The average rainfall event had an amount of 11 mm. In total, the average rainfall (including the 30 days without rainfall) was 7 mm.

The total precipitation over this period was 601 mm. Compared with the longtime rainfall data from the Maksegnit weather station (see Figure A.2-2 in the Annex) the rainy season 2015 can be considered as drier than the average. The precipitation data from Maksegnit show, that between 1997 and 2011 the average rainfall sum between beginning of July and mid of September was 813 mm.

As shown in Figure A.2-1 in the Annex sampling was attempted on 20th of July, but there was no water in the collection ponds. The maximum rainfall event between the proceeding sampling and this date was 8 mm. The minimum event that led to surface runoff was 15 mm, recorded on 1st of September. This leads to the assumption that the precipitation that produces surface runoff lays somewhere between 9 mm and 14 mm.

The rainfall recorded with the ombrometer in the Aba-K'aloye watershed show high diversion from the data that was recorded with the manual gauge in the Ayaye watershed, although these two locations are only a few hundred meters apart.

The maximum deviation was accounted with 33.8 mm, which was recorded on the 11th of September, where only 5.2 mm were measured in the Aba-K'aloye watershed and 39 mm in the Ayaye watershed. The maximum deviation in percent was 1150 %, recorded on the 8th of September. These values seem very high, but one has to consider the chronology of the measured data. For example, on this 8th of September 10 mm were recorded with the manual gauge and only 0.8 mm with the ombrometer, this leads to the high deviation in %. However, the next day, the measurement was nearly vice versa. On the 9th of September 0 mm where recorded manually and 9.8 mm with the automatic device, therefore the precipitation amount over these two days was almost the same. The deviation in precipitation sums between the samplings is still significant, with a maximum deviation of 30.6 mm. All deviation values can be found in Table A.2-3 in the Annex.

Possible explanations are evaporation from the manual rain gauge, which should lead to lower values, but only one third of the recorded data show this pattern. In two thirds of the cases, the measured precipitation is higher in the Aba-K'aloye watershed. Another explanation could be a problem with the automatic recording of the Ombrometer, as well as the high spatial variability in rainfall. In addition, human errors cannot be excluded. The deviations seem extremely high and question the reliability of both rainfall data sets.

Precipitation distribution is highly variable, therefore only the data from the manual gauge was used for calculations.

Figure 5-18 shows the correlation between the precipitation dataset of the manual rain gauge, which was situated at the study site next to the erosion plots and the dataset of the automatic tipping bucket ombrometer, which was located in the Aba-K'aloye watershed. The correlation coefficient R^2 of the two dataset is only 0.39, therefore no significant correlation can be detected. Possible reasons for this have been mentioned earlier.

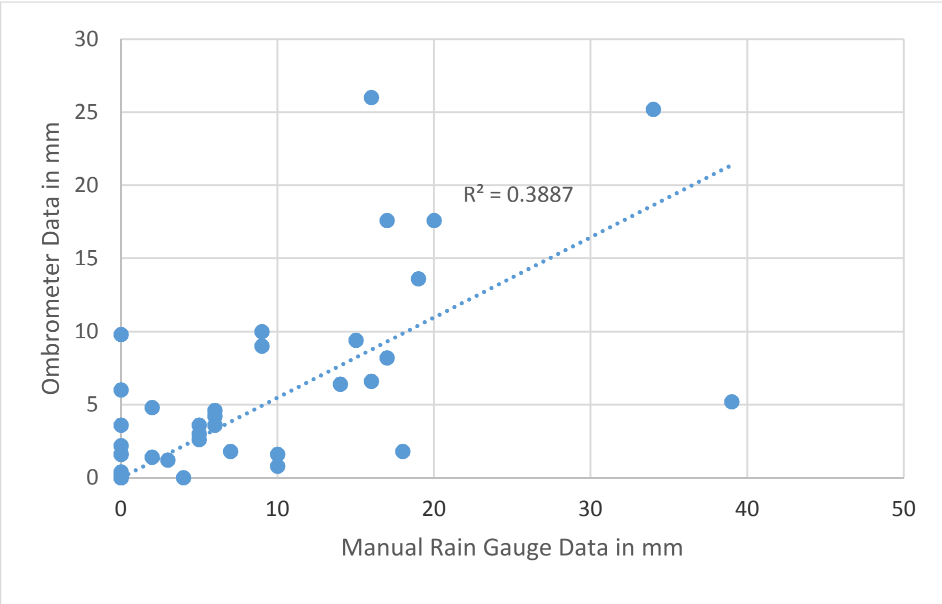

Figure 5-18: Correlation between the daily precipitation data of the manual rain gauge and the automatic tipping bucket ombrometer

5.4 Topography of the Erosion Plots

The results of the topographic survey, which was conducted in the middle of August 2015 are shown in Figure 5-19 and Figure 5-20.

In the longitudial section of the treated plots one can see that in front of the stone bund soil was accumulating and progressive terraces were evolving. The inclination decreases from around 9 % in the top part of the plot to about 4 % in the last four meters before the stone bund. The same pattern can be seen in both treated plots.

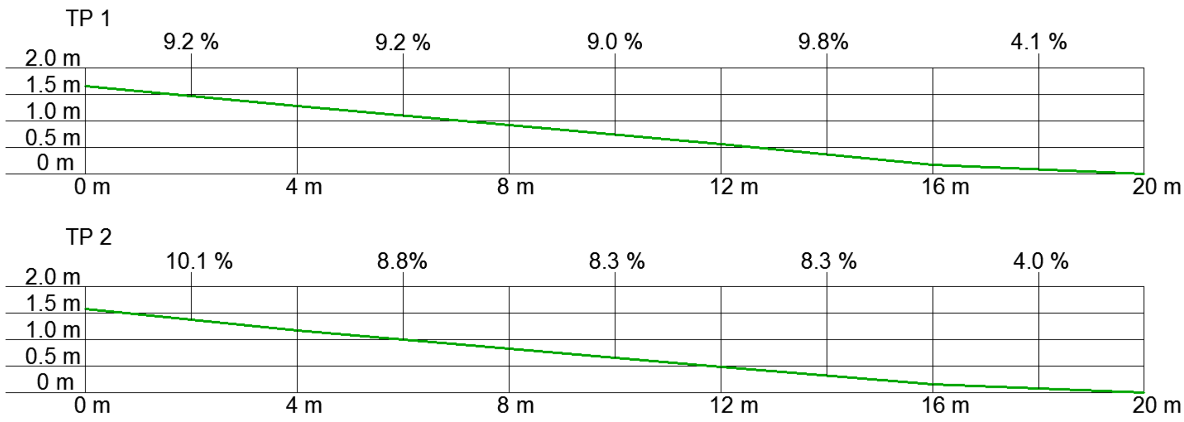

Figure 5-19: Longitudinal inclination of the two treated plots

At the untreated plots the inclination also decreases, but only to an inclination between 5.5 and 7.6 % (see Figure 5-20). The area in the lower part of the plot, as well as underneath the plot was visibly less inclined than the rest of the study area. Additionally, one has to consider that the assessment was done on 18th of August, so there were 6 weeks between the initiation of the plot and the assessment of inclination. Although there was no stone bund given, the implementation of the stone terrace and the collection pipes created an additional barrier. This could have led to a supplementary accumulation of soil in the lower area of the plot and explain the decrease of inclination.

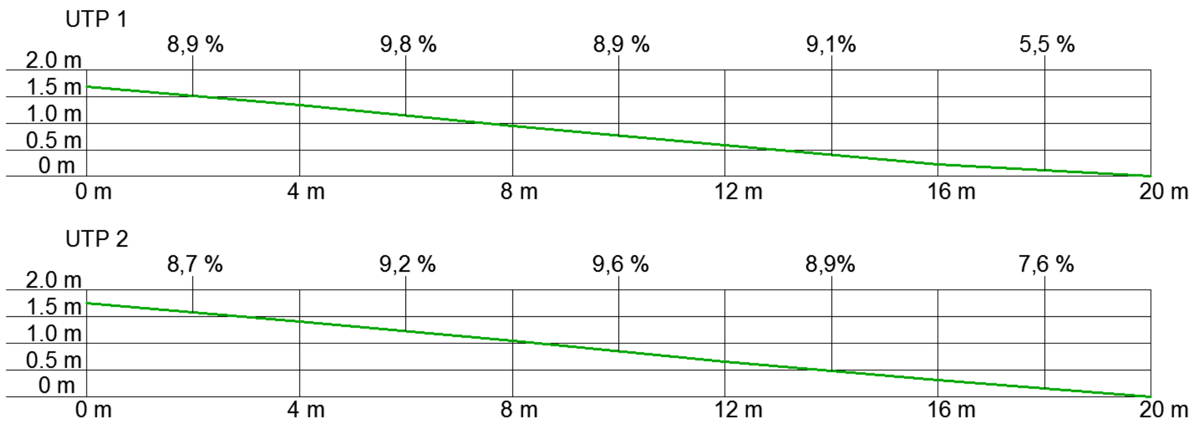

Figure 5-20: Longitudinal inclination of the untreated plots

The average slope inclination over the whole 20 m length and of all (treated and untreated) plots is 8.35 %. This is depictured in Figure 5-21.

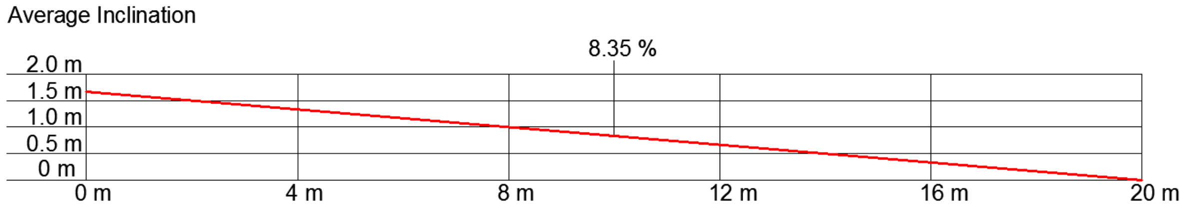

Figure 5-21: Average slope inclination of the study area

On 27th of August 2015, a more detailed investigation of the inclination along the stone bunds was undertaken. As far as the initial inclination was manipulated to about 0.75 % towards the collection pipe, Figure 5-22 shows a significant change in this inclination over the course of 6 weeks. This can be explained by accumulation processes and soil loss in this area.

Both treated plots showed more or less the same pattern. The inclination increased in the first few meters along the stone bund and created little depressions. The water was ponding there; this is marked with a blue ellipse in Figure 5-22 and can also be seen in Figure 5-23.

The red ellipse in Figure 5-22 highlights the area where the right hand side metal sheet border ends and the outlet zone begins. In this area soil accumulation can be detected. This leads to the assumption that sediment was transported along this metal sheet border and then accumulated funnel shaped in front of the stone bund, also seen in Figure 5-23.

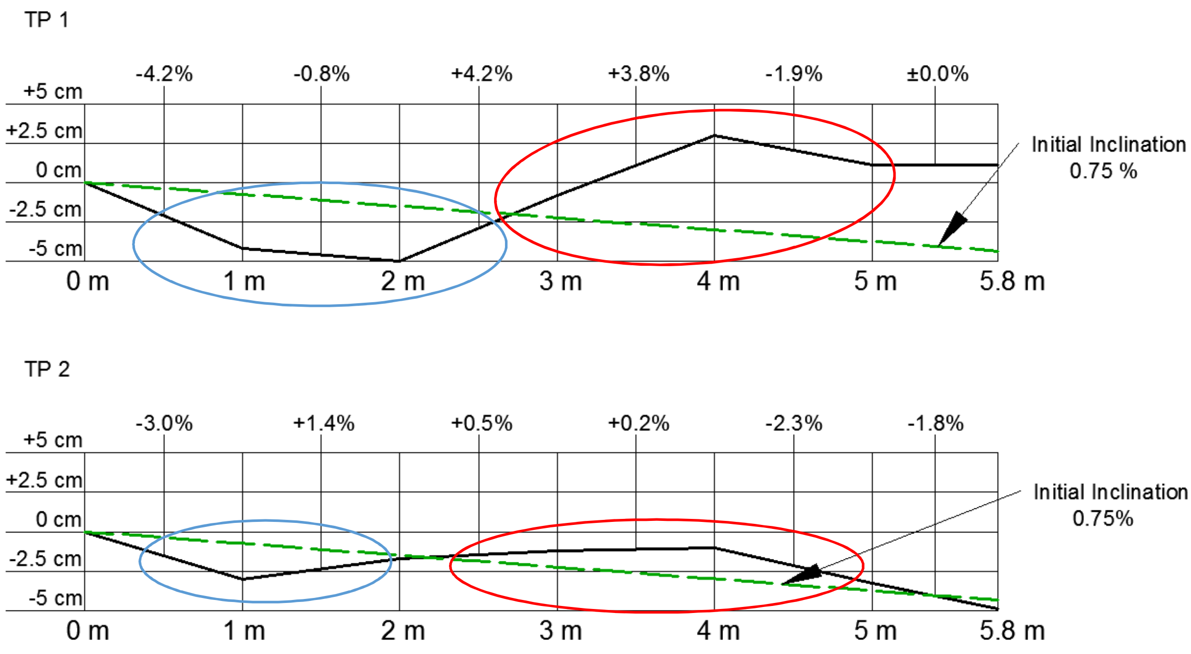

Figure 5-22: Detailed inclination along the stone bunds, including the initial inclination; blue ellipses mark ponding areas; red ellipses mark accumulation areas

Figure 5-23: Visible soil loss and soil accumulation processes along the stone bund (photo: E. Obereder)

5.5 Erosion Pin Assessment

The results of the erosion pin assessment are pictured in Figure 5-24, the corresponding data can be found in Table 5-7.

This assessment was conducted to see how much soil is accumulating in front of the stone bund and how much of the original soil from this area is transported over or along the stone bund.

Figure 5-24 shows that in the first section above the stone bund on both treated plots soil was eroded. This might be due to the little embankment in front of the stone bund. Therefore, surface runoff was more likely to run along this embankment and transport soil away from this area. The embankment can be clearly seen Figure 4-15 in Chapter 4.5. On the rest of the area, soil was accumulating over time, with one exception, the area around erosion pin number nine on TP 2. However, the soil loss was only accounted with 1 kg and is therefore not very significant.

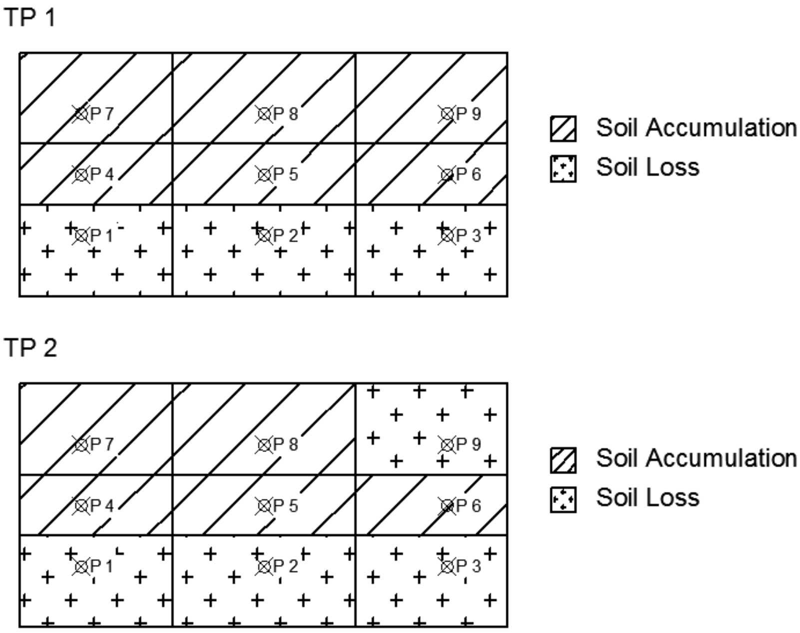

Figure 5-24: Assigned erosion pin areas with soil accumulation and soil loss

In Table 5-7, the exact values for soil loss and soil accumulation are presented. 102 kg of soil accumulated on TP 1 above the stone bund and 23 kg on TP 2, the average being 62.5 kg. This value divided by 80 m² results in 0.8 kg/m² or 8 t/ha of soil accumulation. That leads to the conclusion that the 4 t/ha of soil loss on the treated plots, plus this 8 t/ha that have accumulated (and would have been eroded, if there was no stone bund) result in a similar value (12 t/ha), compared to the 15 t/ha soil loss on the untreated plots (see Chapter 5.1).

Table 5-7: Results for soil loss and soil accumulation of the erosion pin assessment of TP 1 and TP 2

TP 1 Erosion Pin	Area in m²	Height Diff. in m	Soil in m³	Soil Loss in t	Soil Accum. in t
EP 1	0.938	-0.004	-0.004		-
EP 2	1.125	-0.006	-0.007	-0.011	-
EP 3	0.938	-0.004	-0.004		-
EP 4	0.625	0.028	0.018	-	
EP 5	0.750	0.005	0.004	-	
EP 6	0.625	0.025	0.016	-	0.102
EP 7	0.938	0.045	0.042	-	
EP 8	1.125	0.027	0.030	-	
EP 9	0.938	0.025	0.023	-	

TP 2 Erosion Pin	Area in m²	Height Diff. in m	Soil in m³	Soil Loss in t	Soil Accum. in t
EP 1	0.938	-0.003	-0.003		-
EP 2	1.125	-0.003	-0.003	-0.011	-
EP 3	0.938	-0.008	-0.008		
EP 4	0.625	0.005	0.003	-	
EP 5	0.750	-0.016	-0.012	-	
EP 6	0.625	0.015	0.009	-	0.023
EP 7	0.938	0.019	0.018	-	
EP 8	1.125	0.010	0.011	-	
EP 9	0.938	-0.002	-0.002	-0.001	-

5.6 Plant Cover Assessment

As mentioned in Chapter 4.6.1 no specific crop was planted at the study site, but weeds covered increasingly the erosion plots. As seen in Table 5-8 and Figure 5-25 the plant cover changed from around 1 % up to 33 - 51 %, with an average plant cover of 43 % at the end of August. In the first few weeks, plant cover increased steady with around 5 %, but starting from the 6th of August the vegetation grew a lot faster for about two weeks. This is marked in Figure 5-25 with a red ellipse. Within those two weeks plant cover increased by about 20 %. Table 5-8 shows the exact values for all four plots, including the average values. These results were determined with the program ArcGIS®, also described in Chapter 4.6.1. Due to very high variability in runoff and soil loss data no definite statement about the influence of plant cover on these parameters can be made.

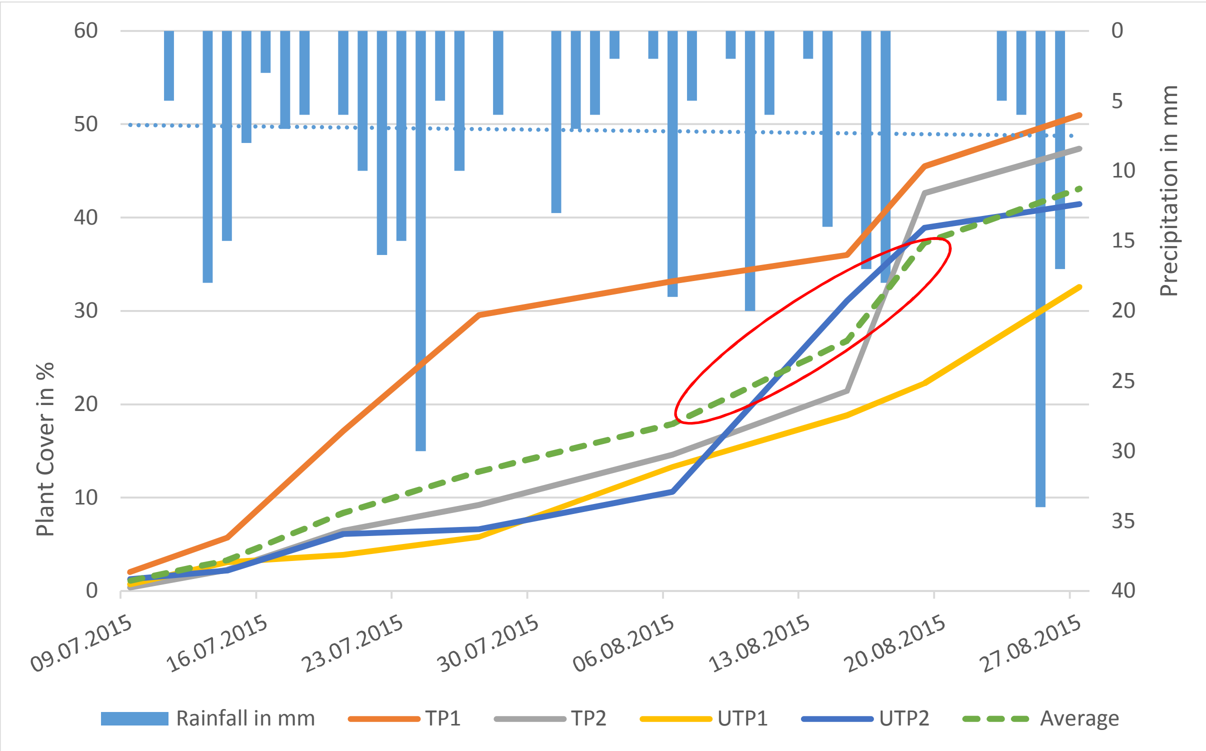

Figure 5-25: Plant cover change of both treated and untreated plots, including the precipitation data with trend line (blue dotted line); red ellipse marks the rapid growth from the 6th to the 20th of August

Table 5-8: Plant cover change from 9th of July to 27th of August in %

Date	Plant Cover in %				
	TP1	TP2	UTP1	UTP2	Average
09.07.2015	2	0	1	1	1
14.07.2015	6	2	3	2	3
20.07.2015	17	6	4	6	8
27.07.2015	30	9	6	7	13
06.08.2015	33	15	13	11	18
15.08.2015	36	21	19	31	27
19.08.2015	45	43	22	39	37
27.08.2015	51	47	33	41	43

An influence on the runoff coefficient by increasing plant cover can be assumed, due to the decrease in trend line of both treated and untreated plots, as seen in Figure 5-26. In addition, the according amount of precipitation has to be taken into account, but the trend line of it shows a slight increase over the rainy season. Therefore, the decrease of runoff coefficient is not due to a decrease in rainfall (see blue dotted line in Figure 5-25). But as mentioned above the runoff data has a very high variability, therefore no definite statement can be made.

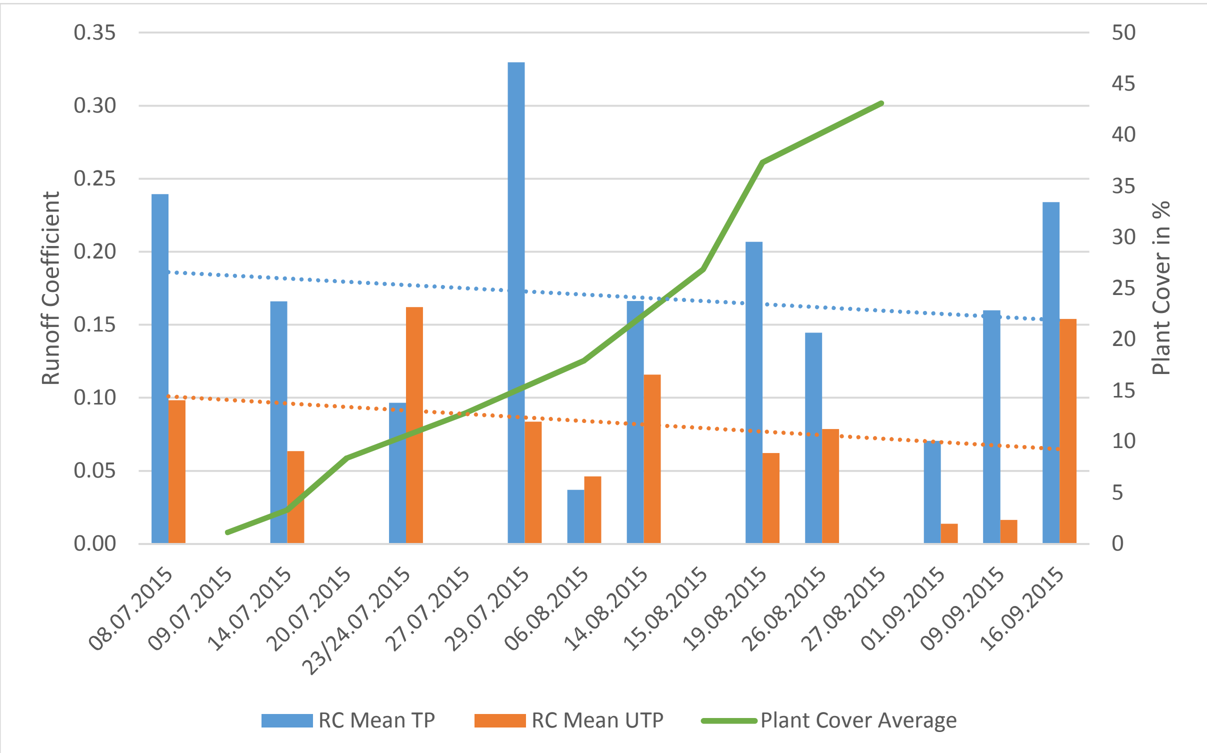

Figure 5-26: Mean runoff coefficient of the treated and untreated plots with corresponding trend lines, including the values for the plant cover change

5.7 Stone Cover Assessment

Unfortunately, the pictures could not be classified with ArcGIS®. Rainfall during the assessment created large dark spots on the stones, which could later not be distinguished by the program from the surrounding soil. Figure 5-27 shows the mentioned problem. According to E. Obereder, 2015 stone cover can be assumed to be around 8 % and constant over the rainy season. This value was assessed at similar plots next to this study site.

Figure 5-27: Dark spots on the stones after rainfall (photo: E. Obereder)

5.8 Curve Number Assessment

The results of the curve number (CN) assessment are shown in Table 5-9 and Table 5-10. Calculations for the mean runoff of the treated plots were undertaken with all of the precipitation values, which resulted in a CN value of 73.

Afterward the precipitation data was selected by deleting all values smaller than 10 mm, as far as they are considered as not runoff-effective. This led to a higher value for the curve number of 81.

Table 5-9: Results of the curve number assessment for the mean runoff values of the treated plots with all and selected precipitation data

Date	Precipitation Sum in mm	Precip. selected in mm	Runoff TP Mean in mm	CN all data	CN selected data
08.07.2015	38	29	9.1	82	89
14.07.2015	38	33	6.3	79	82
23.07.2015	71	49	6.9	60	72
29.07.2015	51	40	16.8	82	88
06.08.2015	49	32	1.8	62	73
14.08.2015	49	34	8.1	74	84
19.08.2015	35	35	7.2	82	82
26.08.2015	62	51	9.0	67	74
01.09.2015	35	24	2.5	73	82
09.09.2015	48	36	7.7	74	82
16.09.2015	66	55	15.4	73	79
Average CN	-	-	-	73	81

The results for the average curve number of the runoff values for TP 1 and TP 2 using the selected runoff data are also around 80. This is conclusive with data from literature, where soil of type C or D with dry soil moisture status and under fallow has values between 76 and 86 (Klik et al., 1996).

Table 5-10: Results of the curve number assessment for the runoff of the TP 1 and TP 2 with selected precipitation data

Date	Precip. selected in mm	Runoff TP 1 in mm	Runoff TP 2 in mm	CN TP 1 selected data	CN TP 2 selected data
08.07.2015	29	2.6	15.6	78	94
14.07.2015	33	0.8	11.8	69	88
23.07.2015	49	5.2	8.6	70	75
29.07.2015	40	20.4	13.2	91	86
06.08.2015	32	2.3	1.3	75	71
14.08.2015	34	9.7	6.6	86	82
19.08.2015	35	10.9	3.6	86	76
26.08.2015	51	13.2	4.8	79	67
01.09.2015	24	3.7	1.2	85	78
09.09.2015	36	9.5	5.8	84	79
16.09.2015	55	19.7	11.2	82	74
Average CN	-	-	-	80	79

6 Summary and Conclusion

During the rainy season from June to September 2015, erosion measurements were undertaken with two different kinds of plots. In order to evaluate the impact of stone bunds on soil loss and surface runoff, two treated plots (including a stone bund as soil and water conservation (SWC) measure) and two untreated plots (without any SWC measures) were constructed. The surface runoff of all four plots was collected and stored in collection ponds. The sediment and runoff samples were taken weekly. For the treated plots, the runoff was divided into sideflow (amount of runoff that ran along the stone bund) and overflow (fraction of runoff that went over the stone bund). In the laboratory, a sediment concentration analysis of the samples was conducted. With this data, the actual soil loss rates could be determined.

In order to highlight the results of this master thesis, the objectives and hypothesis are discussed as follows:

1. Assess the amount of soil, which is accumulating/ eroding from the area above the stone bund.

As the erosion pin assessment showed, on average 62.5 kg of soil accumulated in front of the stone bund. This results in 8 t/ha, which are not eroded but stored in the area above the stone bund. Therefore, the hypothesis: '*Stone bunds create a barrier for eroded soil particles, this leads to an accumulation of soil above the stone bund'* can be seen as fulfilled.

2. Analyze the decrease of inclination above the stone bund.

The inclination assessment indicated that the implementation of stone bunds leads to a decrease in inclination in front of stone bund. The inclination decreases at the treated plots from around 9 % to 4 % in the area above the stone bund. As far as only one assessment was undertaken, no statement about the temporal development can be made. Therefore, the hypothesis: *Inclination is reduced by the formation of terraces above the stone bunds, which is caused by accumulation processes,* cannot be validated.

3. Determine the quantity of soil loss at a study site with stone bunds as soil conservation method (treated) and at a study site without any soil conservation methods (untreated). Compare the data of these two cases.

The assessment of the soil erosion reveals that at the treated plots the soil loss over the rainy season was accounted with 3.86 t/ha and at the untreated plots 14.69 t/ha soil was lost. This leads to the conclusion that the hypothesis: *Stone bunds reduce soil loss, because eroded soil is partly stored above the stone bund*, is confirmed.

4. Collect data about the quantity of surface runoff at a study site without stone bunds as well as at a study site with stone bunds.

The total surface runoff was accounted with 91 mm at the treated plots and 51 mm at the untreated plots. Therefore, the hypothesis: *Surface runoff is reduced by stone bunds, because of the higher infiltration rates above the stone bunds*, cannot be confirmed. As far as the collection pipes at the untreated plots were often partly blocked with sediments, the hydraulic performance of the pipes was probably insufficient to transport all surface runoff into the collection ponds. This leads to the assumption, that not all of the runoff was collected and the actual values at the untreated plots can be assumed to be higher.

5. Assess the influence of increasing plant cover on the runoff coefficient.

The results show that the plant cover changed from 1 % to an average of 43 % over the observation period and that the runoff coefficient slightly decreases over this time. This leads to the assumption, that the hypothesis*: Increasing plant cover has a reducing effect on surface runoff*, is fulfilled. However, further investigation would be necessary to confirm this assumption.

7 Outlook

This master thesis only represents the runoff and soil loss data under the influence of the climatic conditions during one rainy season in 2015. In order to get data, that is more representative, the monitoring of the same plot setup over several years would be necessary. This is partly due to the highly variable climate in the Northern Highlands of Ethiopia, but also because the process of sampling had a high failure rate.

The presented work was realized within the scope of the project “Unlocking the potential of rain-fed agriculture in Ethiopia for improved rural livelihood”, which was financed by the Austrian Development Agency (ADA) for six years. The research financing ended with this year; therefore, a new way of financing for this project would be necessary.

For the plot set-up, following improvements would be advisable:

- Use collection pipes with a bigger diameter (>15 cm) to improve the hydraulic properties. Therefore, all the surface runoff could be collected and be transported away.
- Increase the inclination of the collection pipe in order to prevent sediment blocked pipes.
- Better solution for dividing the runoff samples, because a slight inclination to one side results with this multi-slot method in big inaccuracies.
- Alternatively, install smaller (<80 m²) plots in order to be able to collect all the runoff with a reasonable size of the collection pond.
- Using thicker plastic foil to line the collection ponds, to prevent mice from biting holes into it, which leads to leakages.
- Install good spillways and diversions for the excess runoff from the areas that surround the erosion plots.

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9 Annex

A.1 Sampling Data

Table A.1-1: 1st Sampling on 8th of July 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	Sediment$_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
08.07.2015	TP 1 - OF	38	10.8	13.171	7.317	0.61	0.02	0.05
	*TP 1 - SF	38	32.8	13.469	7.483	1.95	0.05	0.15
	*TP 2 - SF	38	213.8	15.463	8.591	12.73	0.33	1.09
	*TP 2 - OF	38	51.8	4.346	2.414	2.90	0.08	0.07
	UTP 1	38	114.3	30.026	16.681	6.89	0.18	1.13
	*UTP 2	38	9.8	86.934	48.297	0.59	0.02	0.28

General Remarks:

- Weather: sunny
- Soil condition: very moist, soil stuck to the shoes
- Precipitation previous day: 10 mm

* Problems and Solutions:

- TP 1 - OF: No problem
- TP 1 - SF: A hole was detected in the plastic foil (see Figure A.1-1.1), water was undercutting the pond.
  - ➔ The hole was patched and the water was removed from under the plastic foil. Spillways and additional metal sheets were installed to direct the water away from the ponds (see Figure A.1-1.2).
- TP 2 – SF: Surface runoff entered the pond from one side (not through the sample divider) and water was also found underneath the foil.
  - ➔ Spillway and additional metal sheets were installed to direct the water away from the ponds.
- TP 2 – OF: Some water was detected underneath the foil.
  - ➔ The plastic foil was removed and the water underneath the foil was scooped out.

- UTP 1: No problem
- UTP 2: A hole was detected in the plastic foil, therefore probably higher sediment concentration, because water infiltrated through the hole.
    - ➔ The plastic foil was removed; the hole was subsequently patched.

Figure A.1-1.1: Hole in plastic foil at TP 1 – SF (photo: E.Obereder)

Figure A.1-1.2: Spillways to divert the surface runoff (photo: E.Obereder)

Table A.1-2: 2nd Sampling on 14th of July 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	Sediment$_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
14.07.2015	TP 1 - OF	38	-	-	-	-	-	-
	*TP 1 - SF	38	13.3	2.32	1.289	0.79	0.02	0.01
	*TP 2 - SF	38	151.8	4.722	2.623	9.04	0.24	0.24
	TP 2 - OF	38	49.8	1.884	1.047	2.79	0.07	0.03
	*UTP 1	38	30.8	24.826	13.792	1.86	0.05	0.25
	UTP 2	38	49.8	33.092	18.384	2.97	0.08	0.54

General Remarks:

- Weather: cloudy, later sunny
- Soil condition: Morning: very moist, very sticky; Afternoon: dry, cracked soil
- Precipitation previous day: 15 mm

* Problems and Solutions:

- TP 1 - OF: No overflow was measured.
- TP 1 - SF: Several holes were found underneath the collection pipe; some runoff was probably not collected (see Figure A.1-2.1).
  - ➔ The holes were fixed with compacted soil
- TP 2 – SF: Pond was again heavily undercut by water.
  - ➔ An additional spillway was dug above the pond and an embankment was built, so water could pond and infiltrate in front of pond
- TP 2 – OF: Little water was detected underneath the foil
  - ➔ The spillway was renewed.

- UTP 1: Collection pipe was partly blocked with sediments (see Figure A.1-2.2).
    - ➔ The pipe was dug out and flushed with water, the inclination of the pipe was increased.
- UTP 2: No problem

Figure A.1-2.1: Holes underneath the collection pipe (photo: E.Obereder)

Figure A.1-2.2: Blocked pipe at UTP 1 (photo: E.Obereder)

Table A.1-3: 3rd Sampling on 23rd/24th of July 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	$Sediment_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
23.07.2015	TP 1 - OF	71	15.8	6.184	3.436	0.90	0.01	0.03
	*TP 1 - SF	71	71.8	17.724	9.847	4.27	0.06	0.42
	*TP 2 - SF	71	121.8	10.22	5.678	7.25	0.10	0.41
	TP 2 - OF	71	23.3	5.8	3.222	1.30	0.02	0.04
24.07.2015	*UTP 1	101	174.8	56.674	31.486	10.53	0.10	3.28
	*UTP 2	101	371.8	80.856	44.920	22.21	0.22	9.94

General Remarks for 23rd of July:

- Weather: sunny and hot
- Soil condition: medium moist
- Precipitation previous day: 15 mm

Problems and Solutions:

- TP 1 - OF: No problem
- TP 1 - SF: Little water undercut the foil, small hole was present.
  - ➔ The hole was fixed with glue.
- TP 2 – SF: Pond was again heavily undercut by water.
  - ➔ The surrounding of the pond was enlarged and fixed with additional stones (see Figure A.1-3.1).
- TP 2 – OF: Little water was detected underneath the foil.
  - ➔ The surrounding of the pond was enlarged and fixed with additional stones.

The sampling was interrupted after the treated plots by heavy rainfall, the next day the sampling was continued.

General Remarks for 24th of July:

- Weather: mostly cloudy, briefly sunny
- Soil condition: very moist, heavy rainfall during the night, drops of water on the plants
- Precipitation previous day: 30 mm

Problems and Solutions:

- UTP 1: Pipe was again partly blocked, water went probably over the collection pipe, several holes underneath the pipe.
  - ➔ Pipe was removed and flushed, but some sediments remained in the pipe, the holes were compacted with soil.
- UTP 2: The area around the sample divider and the sample divider itself were completely sedimented (see Figure A.1-3.2), entrance of water/ sediment next to the pipe, hole in the plastic foil, walls of the pond partly collapsed.
  - ➔ A wall of mud was built around entrance pipe, the hole was fixed and the walls restored.

Figure A.1-3.1: Enlargement of the surrounding of the pond (photo: E.Obereder)

Figure A.1-3.2: Sedimented sample divider and surrounding area (photo: E.Obereder)

Table A.1-4: 4th Sampling on 29h of July 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	$Sediment_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
29.07.2015	*TP 1 - OF	51	11.8	7.309	4.061	0.67	0.01	0.03
	TP 1 - SF	51	331.8	9.5	5.278	19.75	0.39	1.04
	*TP 2 - SF	51	172.8	12.24	6.800	10.29	0.20	0.70
	TP 2 - OF	51	52.3	18.185	10.103	2.93	0.06	0.31
	*UTP 1	21	29.8	50.809	28.227	1.80	0.09	0.50
	UTP 2	21	28.8	56.338	31.299	1.72	0.08	0.54

General Remarks:

- Weather: sunny, previous day very hot
- Soil condition: dry, slightly cracked
- Precipitation previous day: 0 mm

* Problems and Solutions:

- TP 1 - OF: A Hole was found underneath the collection pipe.
  - ➔ Compacted soil and stones were used to fix the holes.
- TP 1 - SF: No problem
- TP 2 – SF: A hole in the plastic foil was detected.
  - ➔ The hole was patched with additional foil.
- TP 2 – OF: No problem
- UTP 1: One little hole in the plastic foil was detected.
  - ➔ The hole was fixed with glue.
- UTP 2: No problem

Table A.1-5: 5th Sampling on 6th of August 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	$Sediment_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
06.08.2015	TP 1 - OF	49	8.3	3.804	2.113	0.47	0.01	0.01
	TP 1 - SF	49	30.3	11.307	6.282	1.80	0.04	0.11
	TP 2 - SF	49	7.8	30.102	16.723	0.46	0.01	0.08
	TP 2 - OF	49	15.8	5.702	3.168	0.88	0.02	0.03
	*UTP 1	49	3.8	92.635	51.464	0.23	0.00	0.12
	UTP 2	49	71.8	12.856	7.142	4.29	0.09	0.31

General Remarks:

- Weather: cloudy, later in the day sunny
- Soil condition: Morning: very moist and sticky; Afternoon: dry and cracked
- Precipitation previous day: 18 mm

* Problems and Solutions:

- TP 1 - OF: No problem
- TP 1 - SF: No problem
- TP 2 – SF: Very little water was found underneath the foil.
  - ➔ Foil was not removed due to small amount of water.
- TP 2 – OF: No problem
- UTP 1: Hardly no water in the pond, sample divider was slightly inclined.
  - ➔ The sample divider was put back into position.
- UTP 2: No problem

Table A.1-6: 6th Sampling on 14th of August 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	Sediment$_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
14.08.2015	*TP 1 - OF	49	22.8	5.434	3.019	1.30	0.03	0.04
	TP 1 - SF	49	141.3	8.741	4.856	8.41	0.17	0.41
	TP 2 - SF	49	80.8	8.19	4.550	4.81	0.10	0.22
	*TP 2 - OF	49	31.8	8.74	4.856	1.78	0.04	0.09
	*UTP 1	49	109.8	49.866	27.703	6.61	0.13	1.81
	*UTP 2	49	79.3	44.53	24.739	4.74	0.10	1.17

General Remarks:

- Weather: sunny and hot
- Soil condition: slightly moist but not sticky
- Precipitation previous day: 14 mm

* Problems and Solutions:

- TP 1 - OF: 3 of the 5 v-shaped cuts of the sample divider were blocked with weeds (see Figure A.1-6.1).
  - ➔ The sample was cleaned of the weeds.
- TP 1 - SF: No problem
- TP 2 – SF: Still very little water underneath the foil.
  - ➔ Foil was not removed due to small amount of water.
- TP 2 – OF: Sample Divider inclined towards the pipe, it is possible that too much water was collected in this pond.

- UTP 1: Sample Divider connection piece was partly loose.
  - ➔ The connection was glued back onto the sample divider.
- UTP 2: Sample Divider was filled with sediment, also a lot of sediment in the pond (see Figure A.1-6.2)
  - ➔ The sediment was partly removed and the surface was smoothened.

Figure A.1-6.1: Blocked sample divider cut (photo: E.Obereder)

Figure A.1-6.2: Sedimented sample divider (photo: E.Obereder)

Table A.1-7: 7th Sampling on 19th of August 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	$Sediment_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
19.08.2015	TP 1 - OF	35	25.3	5.282	2.934	1.44	0.04	0.04
	TP 1 - SF	35	158.8	4.716	2.620	9.45	0.27	0.25
	TP 2 - SF	35	40.3	6.229	3.461	2.40	0.07	0.08
	TP 2 - OF	35	21.3	6.199	3.444	1.19	0.03	0.04
	UTP 1	35	31.8	82.262	45.701	1.92	0.05	0.87
	UTP 2	35	40.8	69.172	38.429	2.44	0.07	0.93

General Remarks:

- Weather: cloudy but still very hot
- Soil condition: dry and cracked
- Precipitation previous day: 0 mm

* Problems and Solutions:

- TP 1 - OF: No problem
- TP 1 - SF: No problem
- TP 2 – SF: Still very little water underneath the foil.
    - ➔ Foil was not removed due to small amount of water.
- TP 2 – OF: No problem
- UTP 1: No problem
- UTP 2: No problem

Table A.1-8: 8th Sampling on 26th of August 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	Sediment$_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
26.08.2015	TP 1 - OF	62	116.8	2.47	1.372	6.64	0.11	0.10
	TP 1 - SF	62	109.8	5.408	3.004	6.54	0.11	0.20
	TP 2 - SF	62	43.8	4.858	2.699	2.61	0.04	0.07
	TP 2 - OF	62	38.3	5.372	2.984	2.14	0.03	0.07
	UTP 1	62	66.8	100.881	56.045	4.02	0.06	2.23
	*UTP 2	62	95.8	42.567	23.648	5.72	0.09	1.35

General Remarks:

- Weather: cloudy
- Soil condition: very moist
- Precipitation previous day: 17 mm

* Problems and Solutions:

- TP 1 - OF: No problem
- TP 1 - SF: No problem
- TP 2 – SF: Still very little water underneath the foil.
  - ➔ Foil was not removed due to small amount of water.
- TP 2 – OF: No problem
- UTP 1: A lot of soil was detected in the pond.
- UTP 2: Collection pipe was blocked again with sediments.
  - ➔ Sediment was removed, but pipe was left in place.

Table A.1-9: 9th Sampling on 1st of September 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	$Sediment_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
01.09.2015	TP 1 - OF	35	31.3	0	0.000	1.78	0.05	0.00
	TP 1 - SF	35	32.3	5.351	2.973	1.92	0.05	0.06
	TP 2 - SF	35	14.3	0	0.000	0.85	0.02	0.00
	TP 2 - OF	35	6.8	5.082	2.823	0.38	0.01	0.01
	UTP 1	35	9.8	34.559	19.199	0.59	0.02	0.11
	UTP 2	35	6.3	45.561	25.312	0.38	0.01	0.09

General Remarks:

- Weather: sunny
- Soil condition: moist, slightly sticky
- Precipitation previous day: 15 mm

* Problems and Solutions:

- TP 1 - OF: No problem
- TP 1 - SF: No problem
- TP 2 – SF: Still very little water underneath the foil.
  - ➔ Foil was not removed due to small amount of water.
- TP 2 – OF: No problem
- UTP 1: No problem
- UTP 2: No problem

Table A.1-10: 10th Sampling on 9th of September 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	$Sediment_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
09.09.2015	TP 1 - OF	48	97.8	1.333	0.741	5.56	0.12	0.04
	TP 1 - SF	48	66.3	4.115	2.286	3.95	0.08	0.09
	TP 2 - SF	48	75.8	1.936	1.076	4.51	0.09	0.05
	TP 2 - OF	48	23.8	3.309	1.838	1.33	0.03	0.03
	UTP 1	48	9.8	17.971	9.984	0.59	0.01	0.06
	UTP 2	48	16.3	8.09	4.494	0.97	0.02	0.04

General Remarks:

- Weather: sunny
- Soil condition: slightly moist
- Precipitation previous day: 4 mm

* Problems and Solutions:

- TP 1 - OF: No problem
- TP 1 - SF: No problem
- TP 2 – SF: No problem
- TP 2 – OF: No problem
- UTP 1: No problem
- UTP 2: No problem

Table A.1-11: 11th Sampling on 16th of September 2015

Date	Plot	Rainfall Sum mm	Sampling Volume liter	Sediment$_{dry}$ g/1,8 l	Sed. Concentr. g/l	Surface Runoff mm	Runoff Coeff.	Soil Loss t/ha
16.09.2015	TP 1 - OF	66	242.8	3.689	2.049	13.81	0.21	0.30
	TP 1 - SF	66	98.8	9.73	5.406	5.88	0.09	0.32
	TP 2 - SF	66	143.8	4.801	2.667	8.56	0.13	0.23
	TP 2 - OF	66	46.8	7.856	4.364	2.62	0.04	0.12
	UTP 1	66	172.8	37.147	20.637	10.41	0.16	2.12
	UTP 2	66	165.8	31.186	17.326	9.90	0.15	1.71

General Remarks:

- Weather: cloudy
- Soil condition: very moist
- Precipitation previous day: 16 mm

* Problems and Solutions:

- TP 1 - OF: No problem
- TP 1 - SF: No problem
- TP 2 – SF: No problem
- TP 2 – OF: No problem
- UTP 1: No problem
- UTP 2: No problem

A.2 Precipitation Data

Table A.2-1: Date and Order of Sampling including Precipitation Data; green ellipses mark situations, where two rainfall events >10 mm happened after each other

Date	Precipitation in mm	Order of Sampling
24.06.2015	20	
25.06.2015	0	
26.06.2015	27	
27.06.2015	0	
28.06.2015	5	
29.06.2015	0	
30.06.2015	0	
01.07.2015	2	
02.07.2015	3	
03.07.2015	2	Sampling Start
04.07.2015	0	
05.07.2015	0	
06.07.2015	9	
07.07.2015	19	
08.07.2015	10	1st Sampling
09.07.2015	0	
10.07.2015	0	
11.07.2015	5	
12.07.2015	0	
13.07.2015	18	
14.07.2015	15	2nd Sampling
15.07.2015	8	
16.07.2015	3	
17.07.2015	7	
18.07.2015	6	
19.07.2015	0	
20.07.2015	6	Sampling Attempt
21.07.2015	10	
22.07.2015	16	
23.07.2015	15	3rd Sampling
24.07.2015	30	3rd Sampling
25.07.2015	5	
26.07.2015	10	
27.07.2015	0	
28.07.2015	6	
29.07.2015	0	4th Sampling
30.07.2015	0	
31.07.2015	13	
01.08.2015	7	
02.08.2015	6	
03.08.2015	2	
04.08.2015	0	
05.08.2015	2	
06.08.2015	19	5th Sampling
07.08.2015	5	
08.08.2015	0	
09.08.2015	2	
10.08.2015	20	
11.08.2015	6	
12.08.2015	0	
13.08.2015	2	
14.08.2015	14	6th Sampling
15.08.2015	0	
16.08.2015	17	
17.08.2015	18	
18.08.2015	0	
19.08.2015	0	7th Sampling
20.08.2015	0	
21.08.2015	0	
22.08.2015	0	
23.08.2015	5	
24.08.2015	6	
25.08.2015	34	
26.08.2015	17	8th Sampling
27.08.2015	0	
28.08.2015	5	
29.08.2015	9	
30.08.2015	0	
31.08.2015	6	
01.09.2015	15	9th Sampling
02.09.2015	16	
03.09.2015	10	
04.09.2015	3	
05.09.2015	0	
06.09.2015	0	
07.09.2015	9	
08.09.2015	10	
09.09.2015	0	10th Sampling
10.09.2015	16	
11.09.2015	39	
12.09.2015	7	
13.09.2015	0	
14.09.2015	0	
15.09.2015	0	
16.09.2015	4	11th Sampling

Table A.2-2: Monthly and yearly rainfall data (in mm) from the Maksegnit weather station

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1997	0.0	0.0	55.2	82.9	175.0	55.2	369.9	346.5	54.7	188.2	33.1	1.2	1362
1998	12.6	0.0	46.4	0.0	109.4	176.0	370.9	518.1	76.9	50.4	0.0	0.0	1361
1999	4.2	0.0	0.0	6.1	57.6	239.8	543.5	487.2	134.4	106.9	19.4	9.7	1609
2000	0.0	0.0	0.0	81.2	37.7	168.2	410.9	437.6	117.1	67.5	5.7	6.4	1332
2001	0.0	0.0	11.2	23.1	125.2	262.5	557.2	555.6	65.0	56.8	19.1	2.1	1678
2002	0.0	0.2	12.4	30.2	38.8	125.4	271.5	266.4	42.5	0.0	1.0	0.0	788
2003	25.3	15.2	29.5	56.6	101.8	197.1	365.1	352.2	104.4	68.9	37.5	19.4	1373
2004	4.6	2.7	7.9	43.1	5.0	118.6	319.6	309.3	80.1	8.9	40.7	1.1	942
2005	0.0	0.0	39.3	56.6	17.5	145.5	290.3	241.9	104.4	68.9	37.5	19.4	1021
2006	0.0	2.9	16.5	42.2	125.1	257.4	310.8	277.2	219.7	65.1	40.4	30.0	1387
2007	25.3	11.1	41.1	43.8	73.9	343.9	355.4	278.0	160.3	39.1	70.0	0.0	1442
2008	7.2	0.0	0.0	36.4	182.2	145.8	330.9	357.5	84.4	48.2	8.3	0.0	1201
2009	25.3	15.2	3.5	56.6	101.8	73.7	348.7	352.2	29.5	68.9	0.9	0.0	1076
2010	0.9	0.0	35.2	22.6	43.1	89.3	308.8	312.8	63.2	8.2	12.8	0.0	897
2011	0.9	0.0	35.2	76.3	291.4	457.6	556.4	631.2	178.4	18.8	84.8	0.0	2331
Average	7.1	3.1	22.2	43.8	99.0	190.4	380.7	381.6	101.0	57.7	27.4	6.0	1320

Table A.2-3: Precipitation Data from Manual Rain Gauge and Ombrometer

Date	Ayaye Manual Gauge	Aba-K'aloye Ombrometer	Diversion in mm	Diversion in %	Manual Gauge Precip. Sum	Ombrometer Precip. Sum
06.08.2015	19	13.6	-5.4	-40		
07.08.2015	5	3	-2	-67		
08.08.2015	0	0	-	-		
09.08.2015	2	4.8	2.8	58		
10.08.2015	20	17.6	-2.4	-14		
11.08.2015	6	4.6	-1.4	-30		
12.08.2015	0	3.6	3.6	-		
13.08.2015	2	1.4	-0.6	-43		
14.08.2015	14	6.4	-7.6	-119	49	41.4
15.08.2015	0	1.6	1.6	-		
16.08.2015	17	17.6	0.6	3		
17.08.2015	18	1.8	-16.2	-900		
18.08.2015	0	0	-	-		
19.08.2015	0	0	-	-	35	21
20.08.2015	0	0	-	-		
21.08.2015	0	0.4	0.4	-		
22.08.2015	0	0	-	-		
23.08.2015	5	2.6	-2.4	-92		
24.08.2015	6	3.6	-2.4	-67		
25.08.2015	34	25.2	-8.8	-35		
26.08.2015	17	8.2	-8.8	-107	62	40
27.08.2015	0	1.6	1.6	-		
28.08.2015	5	3.6	-1.4	-39		
29.08.2015	9	9	0	0		
30.08.2015	0	0	-	-		
31.08.2015	6	4.2	-1.8	-43		
01.09.2015	15	9.4	-5.6	-60	35	27.8
02.09.2015	16	6.6	-9.4	-142		
03.09.2015	10	1.6	-8.4	-525		
04.09.2015	3	1.2	-1.8	-150		
05.09.2015	0	0	-	-		
06.09.2015	0	6	6	-		
07.09.2015	9	10	1	10		
08.09.2015	10	0.8	-9.2	-1150		
09.09.2015	0	9.8	9.8	100	48	36
10.09.2015	16	26	10	38		
11.09.2015	39	5.2	-33.8	-650		
12.09.2015	7	1.8	-5.2	-289		
13.09.2015	0	0.2	0.2	-		
14.09.2015	0	0	-	-		
15.09.2015	0	2.2	2.2	-		
16.09.2015	4	0	-4	-	66	35.4