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Master Thesis

ASSESSMENTS ON THE IMPACT OF STONE BUNDS ON WATER EROSION IN THE GUMARA MAKSEGNIT WATERSHED, NORTHERN ETHIOPIA

for attainment of the academic degree of

Diplomingenieur

presented by

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Abstract

Soil erosion due to heavy rain events during the rainy season from June to September is a big threat to the Ethiopian highlands. About 85 % of the total population of Ethiopia, live from agriculture and therefore sound soils are crucial for the country´s nutrition supply and they act as a backbone for development and progress. In order to reduce water erosion on sloped acres in the experimental site, embankments of stones were built along the contour lines during the last years. These stone bunds reduce downslope surface runoff and therefore also soil erosion decreases. This thesis assesses the effectiveness of stone bunds as a soil conservation measurement. The project was carried out from the middle of June until the beginning of September in 2013 in the Gumara – Maksegnit watershed, with an area of 54 km², in the Amhara region in Northern Ethiopia. At the beginning of the field work two erosion plots, each with an area of 60 m², were installed in the field next to each other. The only difference between both plots was, that one plot had a stone bund on its´ slope toe and the other on was without a stone bund. Slope, soil texture, rock fragment cover and canopy cover were equal on both plots. Samples were taken of the surface runoff of both plots and through laboratory analysis, soil erosion rates of both plots could be determined and compared with each other. Also the influence of the maintenance of a stone bund on soil erosion was assessed. Additionally other important parameters, which influence soil erosion, like slope, canopy cover, and rock fragment cover were determined.

Zusammenfassung

Bodenerosion durch Wasser stellt im Äthiopischen Hochland aufgrund der Intensiven Regenereignisse während der ausgeprägten Regenzeit zwischen Juni und September ein großes Problem dar. In einem Land, in dem 85% der gesamten Bevölkerung von der Landwirtschaft leben, ist ein intakter Boden eine der wichtigsten Ressourcen zur Gewährleistung der Ernährungssicherheit des gesamten Landes und unerlässlich im Bezug auf Entwicklung und Fortschritt. Zur Reduktion der Wassererosion an geneigten Hängen wurden in den vergangenen Jahren im Untersuchungsgebiet hangparallele Stone Bunds errichtet, die den Oberflächenabfluss in der Falllinie reduzieren und somit den Bodenabtrag verringern sollen. Die Wirksamkeit dieser Bodenschutzmaßnahme soll im Rahmen dieser Arbeit untersucht werden. Im Zuge der Feldarbeit von Mitte Juni bis Anfang September 2013 in dem ca. 54 km² großen Gumara – Maksegnit Einzugsgebiet in der Amhara Region in Nord – Äthiopien, wurden zwei Erosionsplots mit je 60 m² Fläche nebeneinander errichtet. Der einzige Unterschied zwischen den Plots ist, dass am Fuße der einen Plotfläche ein Stone Bund zum Erosionsschutz eingebaut war und beim anderen nicht. Hangneigung, Bodenart, Steinbedeckung und Bepflanzung waren ident. Oberflächenabfluss der Plotflächen wurde beprobt und im Zuge von Laboruntersuchungen konnten die Bodenerosionsraten von beiden Plots ermittelt und miteinander verglichen werden. Des Weiteren wurde auch der Einfluss einer Erhöhung und einer Erneuerung des Stone Bunds auf das Bodenerosionsverhalten untersucht. Nebenbei wurden auch noch andere wichtige Einflussfaktoren für Bodenerosion, wie Hangneigung, Pflanzenbedeckungsgrad und Steinbedeckungsgrad ermittelt.

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1 Introduction

Due to the fact that about 85% of Ethiopia´s population live from agriculture, soil erosion and ongoing land degradation is a big threat to Ethiopian society. This thesis is a part of the in 2009 started project “Unlocking the potential of rain fed agriculture in Ethiopia for improved rural livelihood”, which investigates strategies to prevent further degradation of the soil and enhance productivity of rain-fed agriculture in the Amhara region of Ethiopia. During the project also the availability of water resources for different watersheds and settlements is estimated and advices for irrigation, water harvesting and for agronomic measurements are made. The project was initiated by the Austrian Development Agency (ADA) which holds a project partnership with the University of Natural Resources and Life Science, Vienna (BOKU), the International Centre for Agricultural Research in the Dry Areas (ICARDA) and the Amhara Regional Agricultural Research Institute (ARARI).

The experimental work was carried out in the Gumara – Maksegnit watershed, Amhara Region. The field work and all the practical work were carried out in cooperation with the Gonder Agricultural Research Center (GARC).

This master thesis deals with a part of this project. It describes the process and the results of soil erosion measurements on experimental plots as well as the impact of a stone bund as a soil conservation method on soil erosion. The experimental site is representative for cultivated land in this region. The data were generated from 04.07.2013 until 03.09.2013. At the beginning, the construction of two erosion plots was necessary. In order to assess the impact of stone bunds on soil erosion, one plot without a stone bund and one with a stone bund have been installed in the watershed. Surface runoff from the plots, caused by precipitation events was collected into ponds and samples were taken. Surface runoff (l), solid concentration in the runoff (g/l) and soil erosion (t/ha) were monitored and determined. Canopy and rock fragment cover were analyzed in order to estimate their influence on soil erosion processes.

2 Hypothesis and Objectives

This thesis is about assessments of the impact of stone bunds on surface runoff and soil erosion. Before starting with the experimental work, some general hypothesis about the effect of stone bunds on soil erosion have been defined.

- Stone bunds act as a barrier for surface runoff, leading to a higher soil water content in the vicinity of the stone bunds compared to areas without and farther away from stone bunds.
- Because of a slight grade, stone bunds increase lateral surface runoff.
- Stone bunds prevent soil loss, because eroded soil accumulates behind the bund.
- Soil accumulation, which is caused by stone bunds, leads to a formation of terraces. Therefore the slope length decreases by time.

Based on these hypotheses the objectives of this study are defined as follows:

1. Assess the quantity of soil erosion of both plots and compare them with each other.
2. Make investigations about the quantity of surface runoff of both plots and compare them with each other.
3. Figure out the impact of the maintenance of a stone bund on soil loss.
4. Determination of the impact of stone bunds on the quantity of soil erosion, soil loss and surface run off.

3 Soil erosion and soil conservation

3.1 Land degradation in Ethiopia and soil conservation methods

Ethiopia is one of the most well endowed countries in Sub-Saharan Africa regarding natural resources (Gete et al., 2006), even though degradation of resources in Ethiopia has been going on for centuries (Hurni et al. 2010). Nowadays soil and land degradation is the most immediate environmental problem facing Ethiopia. Soil loss and degradation in fertility, moisture store capacity and structure of the remaining soils, reduce the country´s agricultural productivity (Hurni, 1988). Due to Ethiopia´s high population of 92 million people (2013) and its high growth rate of 2.9% (2013) (Auswärtiges Amt Deutschland, 2014), the pressure on environment and natural resources increases every year. In 2003 around 85% of the total population worked in the agricultural sector which is mainly contributing for increasing soil degradation. Beside that the main drivers are severe soil loss, deforestation, low vegetative cover and unbalanced livestock and crop production (Gashaw et al., 2014). During his assessments on soil erosion in the Ethiopian highlands, Hurni (1988) found out that the annual average soil loss is highest on cultivated land with 42 t/ha in comparison to 5 t/ha from pastures. As a result, almost 50% of the total annual soil loss comes from cultivated land even though only 13% of the country´s area are cultivated.

During several decades scientists observed a wide range of negative effects of land degradation in Ethiopia. Berry (2003) found out that land degradation causes different problems: Increasing scarcity of vegetation, water courses dry up, predomination of thorny weeds result in the loss of rich pastures and soils become thin and stony. Desta et al. (2000) reported that land degradation leads to increased runoff and reduced infiltration which can finally lead to flooding problems. Mulugeta (2004) found out that land degradation is threatening biological resources and agricultural productivity. Besides environmental and ecological side effects, there are also financial and social problems which are caused by land degradation. It is estimated, that land degradation causes losses in productivity in the extent of minimally 3% of Ethiopia's agricultural GDP (Berry, 2003) every year. Other modeling work estimates that between 2000 and 2010 the loss of agricultural value could be around seven billion USD (Berry, 2003). Furthermore the loss of soil productivity is worsening and continuing the poverty, leading to food insecurity and a reduction of farm income, especially among the rural poor (Shibru, 2010).

Coxhead and Oygard (2008) pointed out some principles for reducing land degradation: Maximizing vegetation cover to prevent soil erosion, replacement of removed nutrients, installation of soil conservation structures like terraces, vegetation strips and stone bunds.

3.2 Soil erosion

Soil erosion is one of the biggest environmental and public health problems for human society. Humans acquire more than 99.7% of their food (calories) from the land and only 0.3% from the oceans and other aquatic ecosystems. Each year estimated ten million ha of cropland are lost because of soil erosion, leading to a reduction of cropland available for food production (Pimentel, D., 2006).

Soil erosion is a process that attacks the most productive top soil layer at first and may lead to decreasing productivity which is perceptible over extended periods. Erosion, caused by human activities, may first have occurred by burning of vegetation in order to acquire new grazing land for game animals. During the agricultural revolution, soil erosion has been intensified and geographically spread with new technologies like tillage, tractors, plows, bulldozers, motor scrapers and front loaders. Any activity that disrupts the vegetation cover on the land usually leads to increasing erosion rates (Terrence J. Toy et al., 2002).

Without the usage of commercial fertilizers the loss of top soil can cause a yield reduction of more than 50%, compared to yields from soils with little topsoil loss (Weesies et al., 1994). Follett and Steward (1985) found out that the decline of soil productivity is often masked by using high yield crop breeds and and increasing application of fertilizers and pesticides, what cannot be considered as a sustainable way of doing agriculture.

Watts, Nick et al. (2012) revealed that over-cultivation leads to a permanent change of vegetative cover, water content and soil organic matter. The logical consequence is erosion and loss of fertile topsoil, decreasing productivity and a loss of biodiversity.

3.2.1 Water erosion

Water erosion is the removal from surface soil by water from rain, snow melt, runoff and irrigation. The main driver in water erosion is rainwater in the form of runoff. It leads to the movement of organic and inorganic soil particles along the soil surface and their deposition in lower landscape areas or in water bodies. Water erosion occurs in all types of soil to different degrees. Slight erosion contributes to soil formation but accelerated erosion effects soil and environment in a negative way (Blanco-Canqui & Lal, 2008). On a global scale there is a high variation in soil erosion vulnerability between the different regions in the world. The United States Department for Agriculture published a world - map about water erosion vulnerability in 1998, see figure 1, which shows that especially the Sub Sahara region is moderately – highly threatened by precipitation caused soil erosion

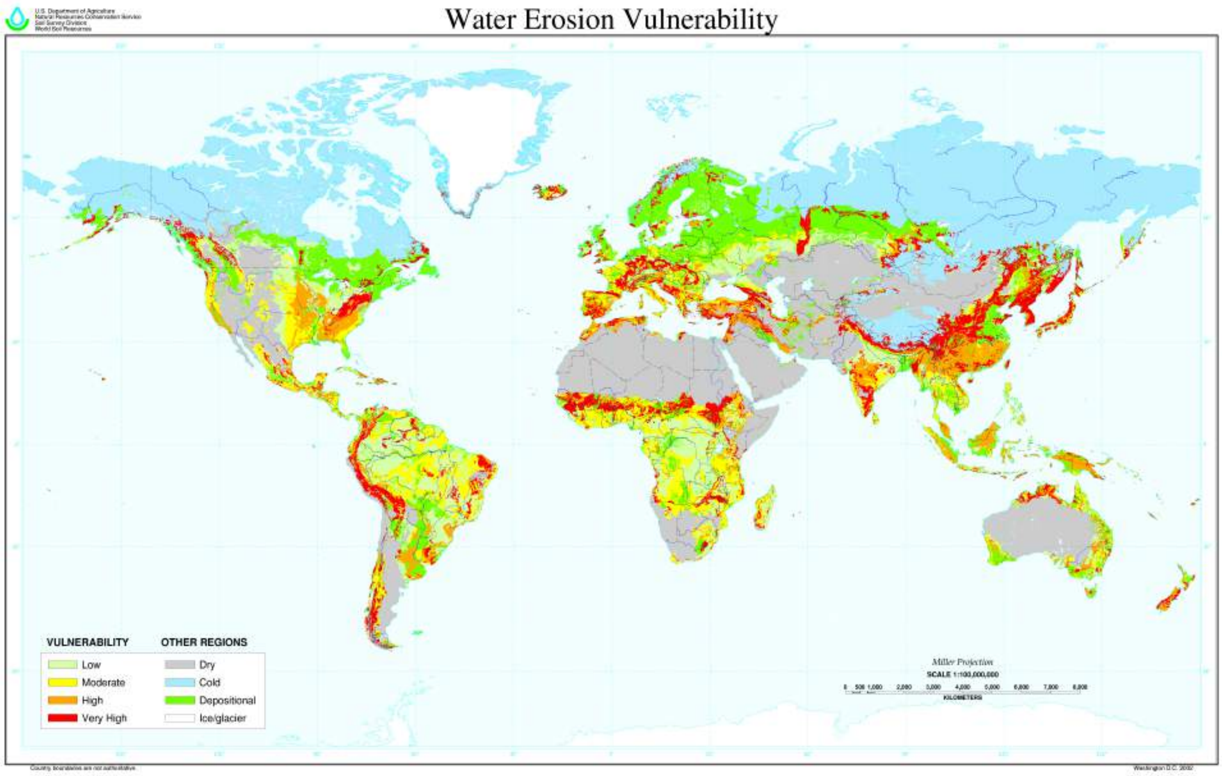

Figure 1: Erosion vulnerability worldwide (USDA, 1998)

3.2.2 Splash erosion

Splash erosion occurs at the beginning of a rainfall event. Raindrops hit the soil surface like small bombs and form crates or cavities of different shapes and sizes (Blanco-Canqui & Lal, 2008).

Splash erosion mainly occurs in two steps:

After the raindrop hits the soil surface, it breaks up soil clods and aggregates and it leads to a soil – water dispersion. In the second step, the solid particles are transported down slope and those particles resettle on the soil surface or become retained by crop parts or other obstacles (FAO, 2012).

3.2.3 Interrill erosion

When runoff starts, it immediately builds small rills in the top soil layer. Some particles are carried away by runoff and some concentrate in small rills. Interrill erosion is the most common type of soil erosion. It occurs simultaneously with splash erosion and together they make up about 70% of total soil erosion (Blanco-Canqui & Lal, 2008).

3.2.4 Rill erosion

This type of soil erosion occurs, because of concentrated runoff streams in small rills or channels. Due to higher concentration of runoff water in rills, mostly the erodibility at rill erosion is much higher than at interrill erosion. Increasing runoff mixed with soil particles can enlarge the channels and rills (Blanco-Canqui & Lal, 2008).

3.2.5 Gully erosion

Gully erosion creates either V- or U- shaped channels with a minimum width of 0.3 m and a minimum depth of 0.3 m. Runoff that accumulates at a lower point of the field, can lead to the formation of gullies. Gullies can be classified in ephemeral gullies and permanent gullies. Ephemeral gullies are smaller gullies that can be corrected by routine tillage operation. Permanent gullies are too large to get corrected by tillage operations (Blanco-Canqui & Lal, 2008).

3.3 Stone bunds

Stone bunds can be defined as embankments of stones built along the contour lines across sloping land in order to reduce the velocity of overland flow and soil erosion (Nyssen et al., 2009). The usage of stone bunds has short - term and long - term effects. In the Gumara – Maksegnit watershed, stone bunds are a widely spread soil conservation method and its installation along the contour lines is shown in Figure 2 and 3. Optimally they are slightly graded in order to induce lateral runoff along the stone bunds.

Figure 3: Representative stone bund in the Gumara – Maksegnit watershed

Figure 2: Sequence of stone bunds in the Gumara – Maksegnit watershed

The stone bunds in the Gumara – Maksegnit watershed are made out of rocks which are equally distributed over the cultivated lands. At first local farmers construct a stone bund – skeleton with stones of a size between 10 and 20 cm. Afterwards the holes and gaps become filled up with smaller stones. The height of a typical stone bund in that region ranges from 0.15 to 0.4 m. Nyssen et al. (2009) show that short - term effects of stone bunds are the reduction of the slope length and the creation of small retention basins for runoff and sediment. Short – term effects reduce the volume and erosivity of the overland flow and lead to a decrease of soil loss. The reduction of soil erosion rates due to the reduction of slope length by stone bund building can be compensated by an increase of soil erosion due to rock fragment removal (Nyssen et al., 2007).

Middle – and long – term effects are mainly the reduction of the slope gradient of the soil surface by forming bench terraces and the development of vegetation cover on the stone bund itself (Nyssen et al., 2007). Nyssen et al. (2007) show in their study, that due to the construction of stone bunds, the average slope of 202 erosion plots could be decreased from 14.1% to 11.2% within three to 21 years. This means an average slope reduction of 0.33 (±0.21)% per year. Figure 4 shows the development of accumulation zones above the stone bund which leads to a formation of terraces:

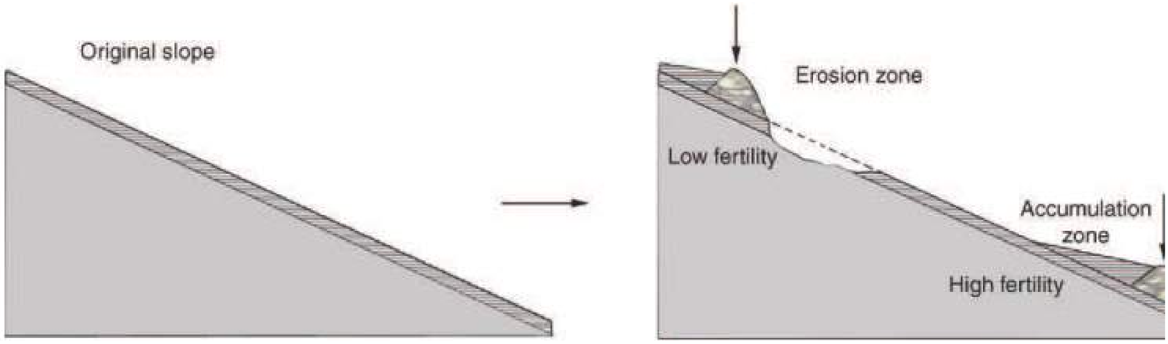

Figure 4: Development of an erosion zone and an accumulation zone on a plot between two stone bunds (Vancampenhout et al., 2006)

Desta et al. (2005) found out that stone bunds can reduce annual soil loss caused by sheet and rill erosion by 68%. The trapping efficiency decreases when the depression behind the stone bund gets filled, therefore regular maintenance and an increase of height are necessary in order to ensure the positive effect of a stone bund.

Figure 5: Accumulation of sediments in front of the stone bund

Nyssen et al (2007) found out during his experiments in Tigray, Northern Ethiopia, that on plots with stone bunds of an average age between three and 21 years, there is an average increase in grain yield of 53% in the lower part of the plot in comparison to the middle and upper part of the plot, as a result of sediment accumulation. Even though stone bunds require some extra space, their positive effects can lead to an increase of yield. In the study of Nyssen et al. (2007) they could prove an increase of yield from 0.58 to 0.65 t ha^{-1} which compensates the stone bund – construction costs to almost 100%.

There are also negative side effects of stone bunds like direct damage to crops due to accumulation of sediments and the concentration of runoff by the structures. Also rats and other rodents can be attracted by the stone bund, because they use the bunds as their shelter and den (Nyssen et al., 2007).

4 Materials and methods

4.1 Description of the study area

The study area is the Gumara-Maksegnit watershed in the Amhara Region in Northern Ethiopia. The exact location of the experimental sites is shown in figures 6 and 7. The watershed is situated about 35 km southeast from the city Gonder and it covers an area of 54 km². Altitudes range between 1923m and 2851 m a.s.l (Addis H. et al., 2013). The climate is semi – humid and the average precipitation in that area is about 1320 mm per year (data from 1997 - 2011) of which 90% fall in the time from the beginning of June until the end of September. The average monthly maximum temperature is 31.8°C for March and the average minimum temperature is 10.8° for January, based on climate data from 1997 until 2013 (Addis H., unpublished). Approximately 75% of the study area is used as crop land, mainly planted with sorghum, tef, faba bean, lentil, wheat, chickpea, linseed, fenugreek and barley. The watershed is populated by approximately 4250 people in about 1150 households (ICARDA, 2015). 23% of the watershed area is covered by forests and the rest is covered by villages and traffic areas. The villages and settlements in the watershed are widely scattered from the low until to the upper parts of the watershed. The study area is located in the Ayaye sub-catchment where since some years stone bunds are widely used as a soil conservation measurement. As it is shown in figure 6, loam soils predominate in the higher parts of the watershed and clay soils occur more in the downstream area. In the upper stream, loam soils are shallow with a rooting depth of about 15 cm. The clay soils in the lower stream are well developed and their depth reaches out to 80 cm (Addis H., unpublished).

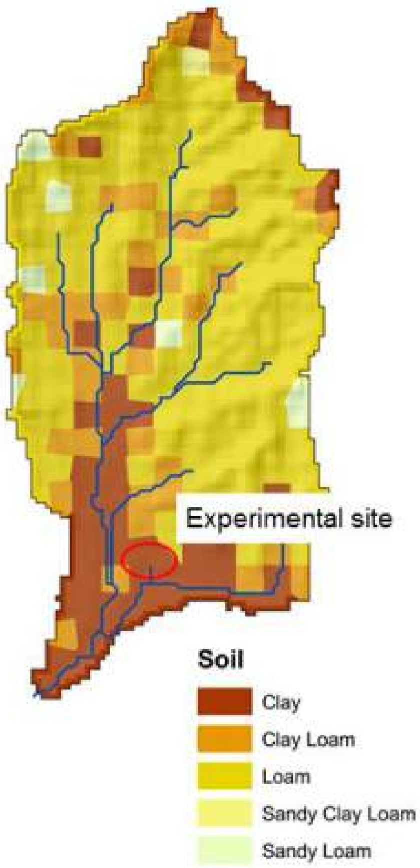

Figure 6: Soil map of the Gumara - Maksegnit watershed; the red circle indicates the experimental site (Addis H. et al., 2013)

Figure 7 shows the horn of Africa and the Amhara Region, where the watershed is located. It is close to lake Tana, the biggest lake in Ethiopia and the origin of the Blue Nile. The map of the watershed shows the locations of all three automatic rain gauging stations. The location of the experimental site is marked by a yellow circle.

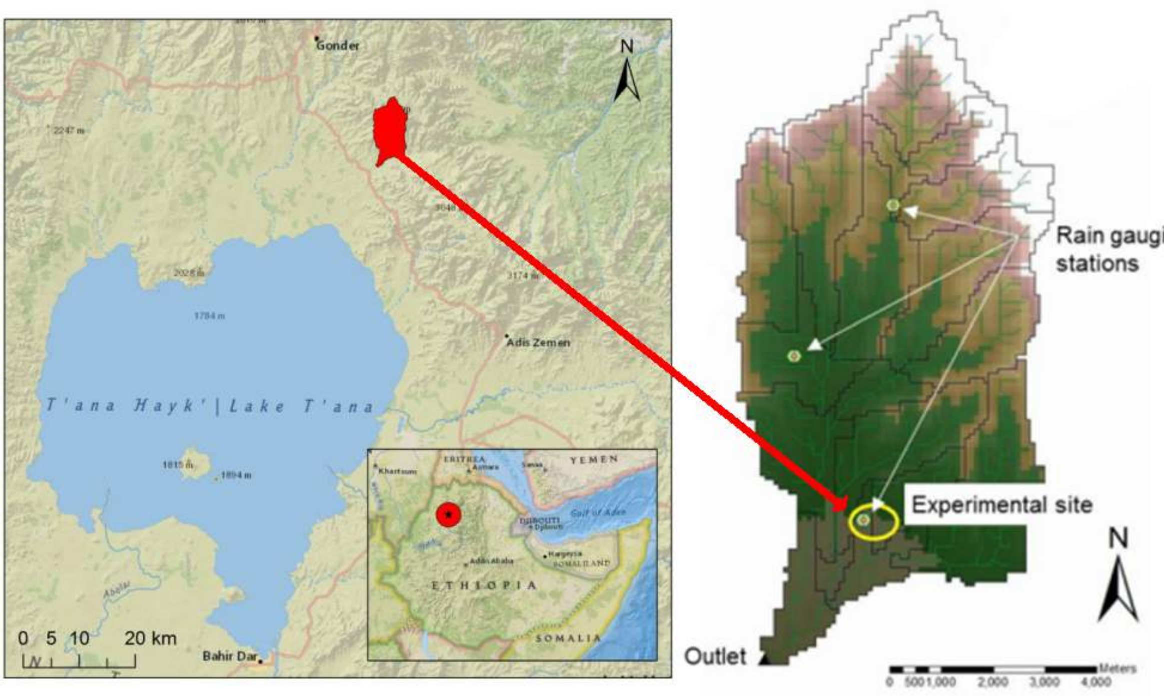

Figure 7:

Left: Amhara region, northeast of lake Tana (Addis H. et al., 2013)

Right: Map of the Gumara-Maksegnit watershed (Brenner Claire, 2013)

4.2 Erosion Plots

In order to generate erosion data for this thesis, the construction of two erosion plots was necessary. Both plots have the same linear dimensions and the same area. There are also equal or very similar conditions between both plots in stone cover, soil texture, inclination and crop cover. The main difference between both plots is, that one plot is with a stone bund (treated) on its slope toe and one without a stone bund (untreated). These two plots were necessary in order to compare the influence of stone bunds on surface soil erosion. The plots were situated on a field where normally crops are cultivated by local farmers. Main crops in this area are sorghum, tef, faba bean, lentil, wheat, chickpea, linseed, fenugreek and barley. During the whole construction and monitoring period the plot areas were left fallow. The area of both plots was overgrown accidently during the monitoring period mainly by different crops, grass and weeds.

In the plot areas, heavy soils with high clay content predominate. Claire Brenner (2013) described the soil composition in the area of the erosion plots in her studies about monitoring and soil erosion in the Ethiopian highlands carefully. According to her, the analysis of samples from the soil surface, show a clay content of 42%, a silt content of 36% and a sand content of 22%. Figure 8 shows a soil texture triangle with the percentages for clay, silt and sand, as described above. The soil of the experimental site is marked there with a red dot.

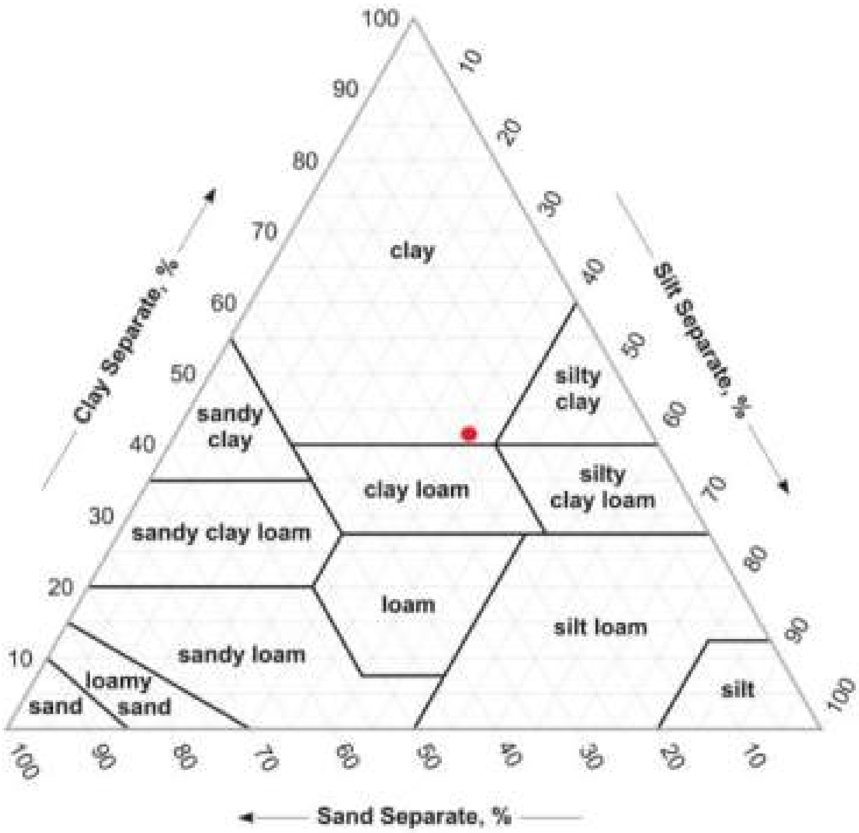

Figure 8: Soil texture triangle; the red dot represents the soil at the experimental site (Brenner Claire, 2013)

The main measurements of both plots:

- Width: 3 m
- Length: 20 m
- Area: 60 m²

The plot area was bordered with metal sheet pieces of 3 – 5 m length, a thickness of 3 mm and a height of approximately 30 cm. These metal pieces were hammered carefully below soil surface for 15 cm. Therefore the plot border was reaching 15 cm over the ground level.

The main components of both erosion plots were:

- Metal sheets: In order to create the borders of the plot
- Tubes: Tubes with 10 cm of diameter in order to collect surface runoff and to transfer it to the sample dividers
- Sample-divider: Divided the total runoff into 30 or 31 equal parts and transferred only about 10% of the total runoff into a pond.
- Pond: The runoff comes over the sample-divider into the pond. From the pond samples for laboratory analysis were taken.

The construction of the treated plot, which is shown at figure 9, started in the middle of June. It was very important to construct the plot fast, since the first big precipitation events of the annual rainy season occurred already in the beginning of June. Once the treated plot was constructed, the decision was made to construct the untreated plot in order to have reference data to compare with. On 4th of July the first samples from the treated plot could be taken and on 13th of July the first samples could be taken from both plots.

Figure 9: Construction works for the plots

Tubes

Tubes were necessary at the slope toe of each plot, in order to collect surface runoff and to transfer it to the sample-divider. At first, runoff and eroded soil material is collected by a collection pipe. This pipe has big openings for collecting the runoff. In order to prevent bigger stones or crop parts of reaching the inside of the pipe and clogging it, a metal mesh with a mesh size of 3 cm was installed before the openings of the collection pipe. Connected to the collection pipe, there is a conduit pipe, through which the surface runoff is transferred to the sample divider. The tubes for both plots were made out of Pvc and had a diameter of 125 mm. In total at the treated plot there were 20 m of Pvc tubes necessary and at the construction of the untreated plot, there were 8 m of Pvc tubes used. Figure 14 and 15 show the arrangement of both tube types at one plot.

Sample-divider

Because of very high expected surface runoff, caused by high precipitation events, there was the idea of dividing the runoff into equal parts and transferring only a part of it to the sampling ponds. For that reason, the decision was made to use sample dividers. The possibility of building well working sample dividers was strongly limited. As material for building the dividers, there were only old iron barrels from a local market with a height of 90 cm and a diameter of 50 cm available. With an iron saw, one barrel was manually cut into two equal sized parts with a height of 45 cm. Then, at the open side of the barrel half, there were 30 (at the untreated plot) or 31 (at the treated plot) equal sized V - shaped apertures cut in similar distances along the circumference. As it is shown in figure 10, at every 10th opening there was a connection part installed, in order to connect a tube of 25 mm diameter with one aperture of the sample-divider. In total there are three connections for a tube per sample-divider in the same distance. With that system the transfer of 10.0% or respectively 9.7% of the total surface runoff from the plots to the ponds was possible.

Figure 10: Sample-divider

Figure 11 shows the sample-divider installed at a plot. Three tubes of 25mm diameters transfer 10.0% or respectively 9.7% of the surface runoff from the erosion plots to the ponds. The sample divider is set up on a concrete foundation which is circuited by a concrete pan. The other 90% of the surface runoff, which are not transferred to the pond, flow through the apertures of the sample-divider into the pan and finally they flow via an outlet into a draining ditch. It took the first precipitation events to fill the divider with sediments. After that, all the sediments which came with new surface runoff went through the apertures of the divider equally.

Figure 11: Sample-divider installed at the plot

Ponds

In order to store surface runoff after precipitation events, the construction of sample ponds was necessary. With those ponds the total runoff volume of every precipitation period and its sediment load could be determined. At the treated plot there was one pond constructed for the downslope runoff and one for the lateral runoff. At the untreated plot there was only one pond for the total surface runoff necessary. In order to find out the proper size of the ponds, some calculations were necessary. It was assumed, that samples will be taken minimum once per week. Another assumption was made with 110 mm of maximum precipitation during seven days with a maximum surface runoff coefficient of 0.7. With a plot area of 60 m^2, this results in a required minimum pond - volume of 0.46 m^3 in order to store the total runoff in this very extreme case. Therefore the ponds dimensions are 1.2 m of length, 0.75 m of width and 0.5 m of depth. In total, one pond was able to store about 0.47 m^3 of surface runoff, which is more than the expected amounts.

The ponds were digged manually and their bottom was covered with a plastic foil to make it water proof. In order to prevent rainwater falling directly into the pond, it was covered by big corrugated iron pieces. In order to close every opening where water from the soil surface could enter, which is not coming from the sample-dividers, a final cover with a plastic foil over the corrugated iron pieces was used. For the purpose of stopping surface runoff from the outside of the plots to enter the ponds, a ditch was created around the ponds as a barrier for that water. Figure 12 shows the ponds of the treated plot when they were covered with corrugated iron sheets and with a plastic foil. In figure 13 you can see a full pond after heavy precipitation events, before taking samples and determining the total volume of stored runoff.

Figure 12: Covered ponds

Figure 13: Full pond after heavy precipitation events

4.2.1 Treated Plot (T)

This plot is treated (T) because it has a stone bund at its slope toe. The runoff is divided into two fractions, the down slope runoff (TD) and the lateral runoff (TL). In order to collect the lateral runoff separately, an extra tube, an extra sample divider and an extra sample pond were necessary. At the beginning of the accumulation zone, which is about four meters uphill the stone bund, there is a small salient which leads lateral runoff to its corresponding tube in order to get transferred into the pond. The salient has an area of approximately 4 m² but in this thesis it is assumed to be negligible, since it´s area is very small and it is in the accumulation zone where generally less soil erosion is expected.

The lateral runoff results from the existence of stone bunds. Runoff gets forced to flow along the stone bunds until its flowing velocity decreases in a way that it partly percolates instead of surpassing the stone bund. The downslope runoff fraction could not be prevented of surpassing the stone bund and therefore it shows the part of the runoff that was not effected enough by the stone bund in its flowing direction and velocity. It either flowed over the stone bund or the suspension found it´s way through the stones. Once it surmounted the stone bund, the downslope runoff got collected in a collection pipe from where it was transferred it into a corresponding pond.

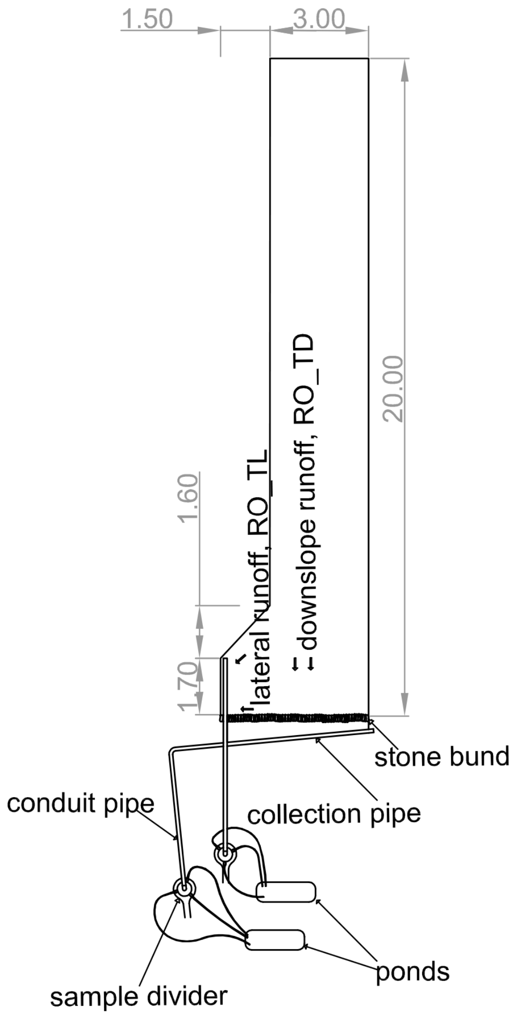

Figure 14: Sketch of the treated plot

Figure 15: Treated plot, ready for operation

4.2.2 Untreated Plot (UT)

This plot is considered to be untreated (UT) because there is no stone bund in order to influence runoff in any way. This plot is constructed next to the treated plot under the same conditions like same soil texture, same inclination, same crop cover and same precipitation. It is not necessary to separate downslope from lateral runoff, because there is no stone bund inducing lateral runoff. In order to investigate the impact of stone bunds on the surface runoff and the resulting soil erosion, generated data from the untreated plot are compared with the generated data from the treated plot.

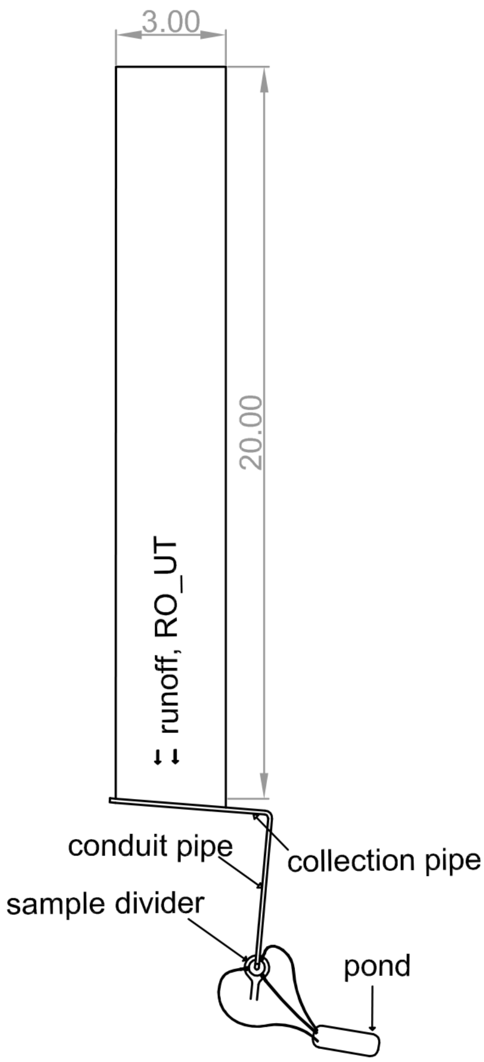

Figure 16: Sketch of the untreated plot

Figure 17: Untreated plot, ready for operation

4.3 Maintenance of a stone bund

In order to get data for the treated plot, which show the effect and the importance of the maintenance of a stone bund, the stone bund was maintained in the middle of the sampling period. On the 9th of August 2013 a team of three people spent two to three hours in order to maintain the stone with a length of 4.5 m. For that purpose, stones of 10 – 20 cm of diameter were collected in the field area and mainly used for the maintenance work. At first the width of the bund and it´s ground area were increased. Finally, it´s height was raised from 30 cm before maintenance to 50 cm after maintenance. After finishing the work, the bund was higher and also it´s permeability of surface runoff and eroded soil particles was much less than before maintenance. Figure 18 and 19 show the stone bund in two different conditions: Before and after maintenance.

Figure 19: Stone bund before maintenance

Figure 18: Stone bund after maintenance

4.4 Precipitation data collection

At the beginning of the construction of the erosion plots, several manual rain gauges have been installed in the whole watershed. The precipitation amount of the prior 24 hours was recorded daily at 7:00 am manually. After recording the precipitation amount, the rain gauge was emptied in order to be ready for the next measurement period. Figure 20 shows the gauging station, which delivered precipitation data for this thesis. It was located about 50 m far away from the plots.

Figure 20: Manual rain gauge (photo: Christoph Schürz)

4.5 Topographic survey of the study area

In order to get information about the slope of both plots a survey of the study area was conducted. At first the coordinates of the upper and the lower point of one length side of each plot were determined with a hand – GPS. Then, every three to four meters the relative altitude of a point of the plot length had been measured. For that purpose a tube water level was used. It was made out of a plastic tube with a diameter of 3 cm and a length of 6 m. As it is shown in Figure 21, it was bonded to an iron stick of 1 m length at both endings. The tube was filled with water for about 80% while both endings were held highly over ground, so that the water could not get out of the tube. In order to start surveying, one corner point of the treated plot was used as a reference point with an assumed reference elevation of 0 m. Beginning from that point, every three to four meters along the boundary of the plots, the difference of the water level height at the tube water level was measured. All the water level differences were noted down in a sketch and the profiles of the plots could be drawn later in AutoCAD as it is visible in chapter 5.4.

Figure 21: Surveying with a tube balance

4.6 Assessment of canopy and rock fragment cover

The determination of canopy and rock fragment cover was done by two different ways of a photo image classification. In order to assess the canopy and rock fragment cover, two general assumptions were taken:

1. The canopy and rock fragment cover on the untreated and on the treated plot are assumed to be the same, since both plots are next to each other on the same acre with the same conditions.

2. The rock fragment cover is constant during the whole rainy season.

The assessment of the canopy cover is based on photo series of two different zones of the treated plot, zone 1 and zone 2. As it is shown in figure 22, zone 1 is located 5 m uphill from the stone bund and zone 2 is located 10 m uphill from the bund. Both zones are marked by a square with the dimensions of 1 m x 1 m, made out of a nylon string and wooden sticks in its corners. Photos from both zones were taken from the same height and perpendicularly during the monitoring period, starting from 2013.06.16 until 2013.08.28 in total 18 times. The chronological gap between two photos is minimum two and maximum nine days.

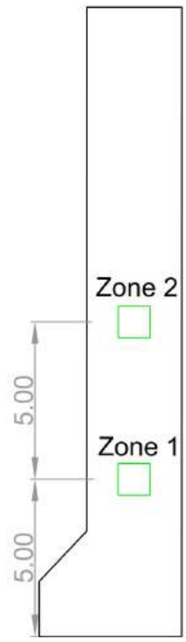

Figure 22: Arrangement of Zone 1 and 2 at the treated plot for the investigation of canopy and rock fragment cover. Distances are in meters

There was a problem with the evaluation of the photos of both zones from the 20th of August 2013. That is why for this day the crop cover is interpolated between the determined cover from 2013.08.14 and 2013.08.24. Each photograph of a series is evaluated with an image classification tool of the software ArcGis 10.3. As you can see in figure 23 and figure 24, a photo is divided into two classes: a canopy and a none-canopy class. At first a calibration is necessary, where different colors are referred to different types of categories like soil, stone and leaf. In a next step the total area for each category can be calculated. The areas are given in pixels and their percentage is evaluated by dividing them through the total image area. The result of this evaluation is a trend of the development of canopy cover during the observation period.

Figure 24: Photo of zone 1, ready for canopy cover determination

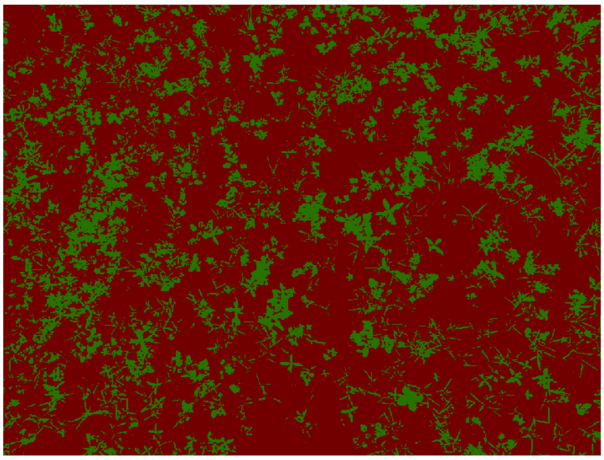

Figure 23: Same photo as in figure 21. After zonal classification, 2 different classes are visible: Green: Canopy; Brown: No canopy

The stone fragment cover was assessed by using a different method than for the assessment of the canopy cover. Because of the assumption that the stone cover does not change during the observation period, only one photo was evaluated of each of both zones. In order to have a good visibility of the stone cover, both photos were taken on 2013.06.16, before the start of the vegetative period of growth. The photos were taken from the same height and perpendicularly. The evaluation was also done with the software ArcGis 10.3, but with a different method. Every single stone > 1 cm on the photo is framed with the polygon function by hand. This method is very time consuming but necessary, because a classification by colors is not possible, since the colors of the soil and of some stones are too similar and it would result in too big errors. After framing the stones manually, the software calculates the area of each stone automatically in pixels. The rock fragment cover was finally determined by dividing the sum of the different partial areas by the total area of the image.

4.7 Sampling and laboratory work

Generally the samples of both plots were always taken at the same time, which usually was between 9:00 and 11:00 o´clock am. At the beginning of the sampling period (beginning of July), samples were taken from the ponds approximately once per week. It was considered to be more useful to make the frequency of taking samples dependent from the occurrence of heavy precipitation events. In late July and August samples were taken even two or three times per week. Before taking samples, the ponds had to be discovered from the plastic foil and the metal coverage, which should prevent the direct entrance of rainwater, the entrance of runoff from areas outside the plots, as well as the entrance of all kinds of animals.

Basically two different ways of taking samples have been used during this field work:

Method 1:

This method was the most common one and it was used on twelve out of 13 times of taking samples. After discovering the ponds, the sediment on the bottom of the ponds had to be mixed with the water by stirring it up with a wooden or a plastic stick for approximately five to ten minutes, like it is shown in figure 25.

Figure 25: Stirring up the soil – water suspension in a pond before taking samples

After transforming into a homogenous suspension consisting of soil particles and rainwater, samples could be taken. Depending on the amount of totally stored water in the ponds, samples with volumes between 0.5 and 1.8 l were taken with empty plastic bottles and their sample volume was determined later exactly in the laboratory. After taking one up to three samples, the remaining volume of the ponds was emptied manually with plastic buckets of ten to 20 l like it is shown in figure 26. In that way the total volume of surface runoff in the ponds could be determined.

Figure 26: Estimating the water volume in a pond by emptying it with a bucket

Once the volume of the samples was determined exactly in the laboratory, the volume of samples was added to the total volume of stored water of the corresponding pond. After the ponds were emptied, they were cleaned and finally covered again with the corrugated sheet and the plastic foil.

The evaluation of the sediment concentration in the samples was conducted in the laboratory. At first the volume of the runoff sample is evaluated with a 1000 ml measuring cup. Then the sample was transferred into a 1000 ml plastic bottle which is suitable for laboratory issues, like it is shown in figure 27. In order to ensure the sedimentation even of the smallest particles (silt, clay) the addition of a flocculation agent is necessary. For that reason 10 ml of a KCl – solution was added per a liter of runoff sample. The concentration of the KCl solution was 74.6 gram of KCl per 1000 ml.

After wards the sedimentation of the suspended particles took up to twelve hours. Once the particles were fully settled, most of the water could be decanted carefully by not disturbing the sediments on the bottom of the bottle. After the decantation, the sediments were spilled into a 150 ml – 250 ml measuring glass. Those soil particles, which remained on the bottom and on the inner surface of the plastic bottle, were washed out by using a wash bottle and transferred into the measuring glass, until the plastic bottle was totally clean. After another ten to twelve hours, the soil particles in the measuring glass settled again and the majority of the water could be removed by decantation.

Now the highly concentrated sample in the measuring glass was dried into the dry oven on 105° C until constant weight was reached, which lasted around twelve hours. After a short cooling period the dry sample was weighted on a laboratory balance and the weight of the measuring cup was reduced, in order to know the dry weight of the solids in the sample. Referring it to the total surface runoff, it´s sediment concentration could be determined in g/l.

Method 2:

This method for taking samples was only used once on 2013.08.09. On that day, the stored volume in the treated ponds was in total 13.6 l and 16.4 l in the untreated pond. Because of this relatively small volumes, the total soil – water suspension including sediments from the ground of all three ponds have been sampled with 1.00 l – 1.8 l plastic bottles and without mixing the volume before. In total there were 30 samples required. The analysis of the sample volume and the sediment concentration was done in the same way as in method 1.

Extra Samples:

Extra samples were taken especially at the beginning of the sampling period. In the first weeks the collection pipes or the conduit pipes of both plots were clogged with sediments from time to time. Further adjustments like an increase of the tubes' inclination were necessary in order to prevent sedimentation in the tubes. When clogged tubes were detected, they became emptied and cleaned and if possible, also attempts in order to refer the sediments in the tubes to the total soil erosion on the plots were done. Therefore the sediments were put into a bucket and some water was added. Then it was mixed and stirred up with a wooden stick until the total volume changed into a homogenous soil – water mixture. This process could last up to 20 minutes. In the next step, the whole mixture was weighed and then a sample was taken. The volume and the weight of the sample have been detected. Depending on the volume of the sample and on the availability of the materials, either a filtration was made, using paper- or textile filters, or the measuring glass – method like in method 1 was applied. After removing the major part of the water from the sample, either through filtration or decantation, the sample was dried in the dry oven at 105° Celsius until constant weight. After recording the dry mass of the sample, the mass of the total sediment which clogged the tubes could be determined. Then the mass of the sediments could be referred to the total surface runoff from the whole plot area in g/l and finally it was added to the solid concentration results from the analysis of the samples from the ponds. A detailed description of those events where extra samples were taken can be found in the chapter A1 of the Annex.

Figure 27: Soil samples in the laboratory before analysis

The results of the sediment concentration analysis in the laboratory in combination with the runoff information allow the evaluation of soil erosion at both plots during the monitoring period. Before determining soil loss data, the results of the sample analysis have been compared with the Dixon test in order to detect outliers.

It is assumed that errors in taking samples follow a normal distribution. For that reason the data of the sample analysis could be tested for outliers. The Dixon test is applicable for small amounts of data (n < 30). Streck Georg (2004) describes the requirements for the application of this test as follows:

- Minimum amount of data: $n \geq 3$
- The data have to be in an ascending order $x_1, x_2, \ldots, x_{n-1}, x_n$

Since during the field work for this thesis sometimes only one or two samples have been taken, the Dixon test cannot be applied at every sample. Only those events, where three samples out of one pond have been taken, can be assessed by this test. Those measurement events with only one or two samples are assumed not to be outliers. Of course the low amount of samples may cause errors and uncertainty of the results. The test confirms and/or denies both hypothesis H0 and H1.

- H0: The maximum or minimum value is not an outlier.
- H1: The maximum or minimum value is an outlier.

At first a test value $D_{exp} = D_{max,min}$ is calculated. Then D_{exp} is compared with a standard value D_{tab} which is dependent from the amount of data n and the level of significance α. D_{tab} is listed in test tables and can be taken from literature. The value is not an outlier, if $D_{exp} < D_{tab}$ The calculation method of the test value D_{exp} differs depending on the amount of data n. For $3 \leq n \leq 7$ the following equation has been used:

$$D_{\min} = \frac{(x_2 - x_1)}{(x_n - x_1)}$$

Equation: 2 (Streck G., 2004)

$$D_{\max} = \frac{\left(x_n - x_{(n-1)}\right)}{(x_n - x_1)}$$

Equation: 1 (Streck G., 2004)

$D_{tab} = 0.999$ for n = 3 and α = 0.001. Table A.3.1 in the Annex shows the results of the solid concentration analysis of all samples, their D_{min} and their D_{max} and also if they are outliers or not.

5 Results and discussion

5.1 Precipitation

Figure 28 shows the precipitation at the erosion plots for every day during the fieldwork. Daily rainfall data was recorded on 65 successive days from the 1st of July 2013 until the 3rd of September 2013. The precipitation sum during this period was 533.6 mm and the different events varied between 0.1 mm and 41.0 mm of precipitation per day. The average precipitation during this period was 8.3 mm per a day. There were ten days without any precipitation, 22 days with precipitation below 5 mm and 33 days with precipitation over 5 mm. The precipitation data from the weather station in Maksegnit show, that between 1997 and 2011 the average rainfall was 772.3 mm during the time between 1st of July and 3rd of September. This leads to the assumption that the rainfall during the monitoring period in 2013 was below average. The precipitation data from the weather station in Maksegnit are listed in table A1.1 in the Annex.

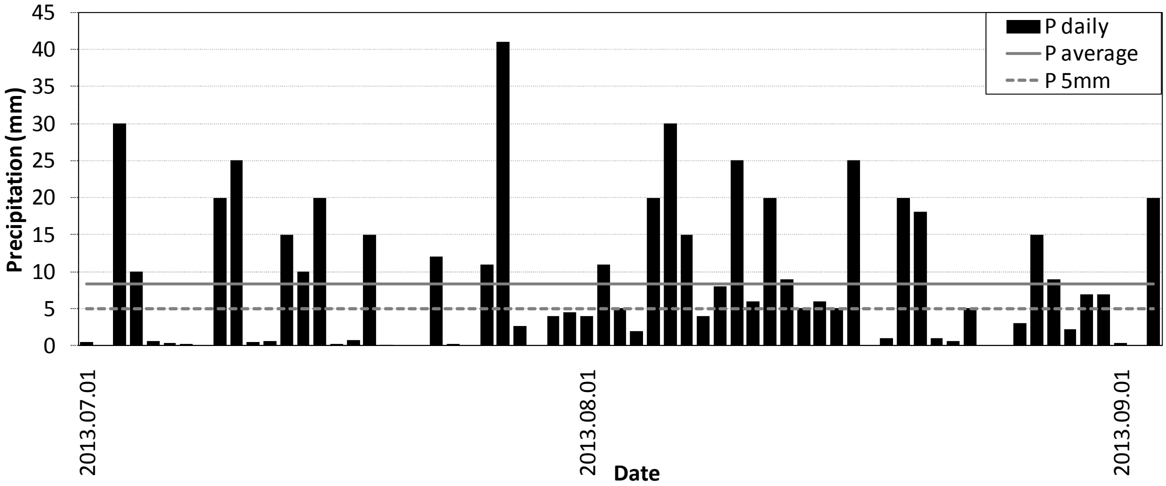

Figure 28: Precipitation at the erosion plots during the field work from 1st of June until 3rd of September 2013. P stands for precipitation

5.2 Runoff

During the monitoring period run off was monitored 16 times. Figure 29 shows Runoff of the treated and untreated plot during the monitoring period and it's corresponding precipitation during the monitoring period. There was 0 mm of runoff detected on the 25th and 30th of July 2013 and on the 23rd of August 2013. There was only one day with a precipitation of 11 mm influencing the runoff, which was recorded on the 25th of July. In that case 11 mm of precipitation per a day was not enough to cause detectable surface runoff. On the 30th of July, only 4.5 mm of rainfall did not cause any runoff on the same day. On the 23rd of August and two days before, in total 6.6 mm of precipitation occurred, of which 5 mm happened on the monitoring day, leading to zero runoff. The smallest detectable runoff was noted on the 8th of August 2013. Within two days, precipitation of 12 mm, of which 8 mm occurred on the monitoring day, lead to a small runoff of 2.3 mm (T) and 2.7 mm (UT). The precipitation on the monitoring day, which probably caused the runoff, was smaller than the precipitation on the 25th of July. During the four days before the 8th of August, it was raining 77 mm. Because of that, the soil was already more saturated than on the 25th of July, leading to noticeable surface runoff by a smaller amount of precipitation.

At the first monitoring event on the 3rd July 2013, the plastic foil of the untreated pond had a huge hole, therefore runoff data for the untreated plot (RO_UT) could not be monitored, only those of the treated plot (RO_T). In order to compare runoff data between the both plots, the runoff data from the 3rd of July 2013 have to be excluded from the data series. In all the following comparisons between both plots, only data after the 3rd of July 2013 are taken into consideration.

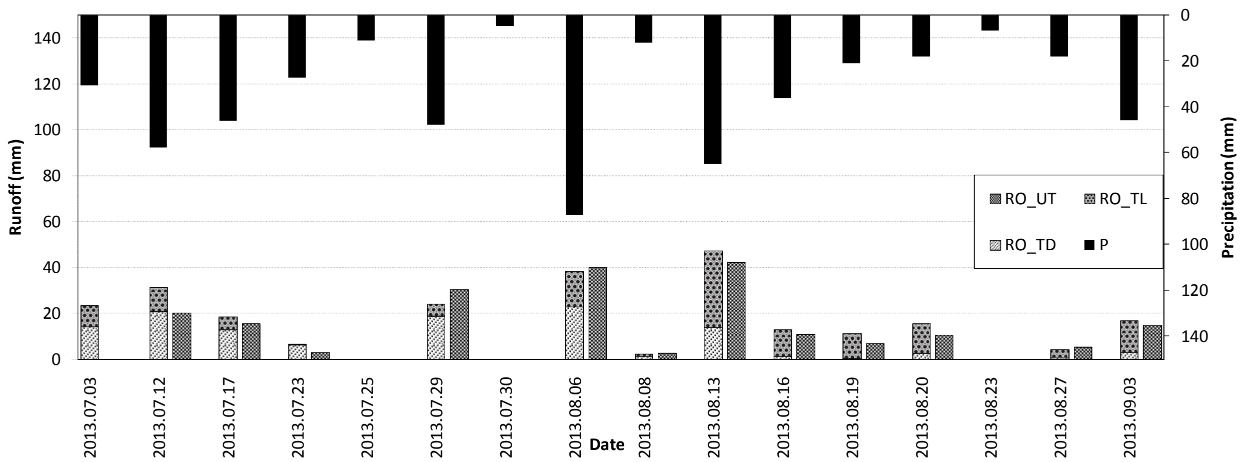

Figure 29: Runoff of the treated and untreated plot during the monitoring period and it's corresponding precipitation. RO_UT = Runoff of the untreated plot; RO_TL = Lateral runoff of the treated plot; RO_TD = Downslope runoff of the treated plot; P = Precipitation

During 4th of July and 3rd of September in 2013, the total precipitation was 503.1 mm. During the same period the total surface runoff of the treated plot was 230.4 mm and the total surface runoff of the untreated plot was 203.7 mm.

Figure 30 shows the runoff coefficients of both plots during the monitoring period in comparison to it´s runoff. The runoff coefficients describe the ratio between surface runoff and precipitation and they range from 0.1 to 0.85 with an average value of 0.46 for the treated plot and 0.40 for the untreated plot. Looking at figure 30, there is a general pattern about the relationship between runoff coefficient and surface runoff noticeable. High runoff leads most of the time to higher coefficients and smaller runoff leads most of the time to smaller coefficients. The coefficients from the 20th of August are remarkably high in comparison to the corresponding runoff data. This is, because there were only 18 mm of precipitation on the monitoring day recorded, which was high enough to cause surface runoff. 20 mm of precipitation on the day before are assumed to keep the soil saturated enough in order to increase surface runoff additionally.

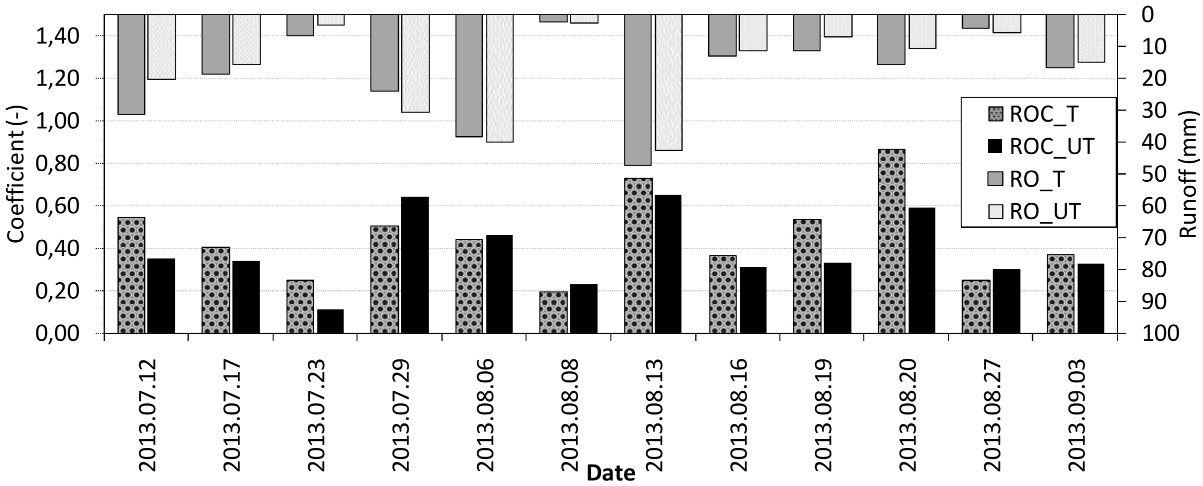

Figure 30: Runoff coefficients of the treated and untreated plot and its' corresponding runoff during the monitoring period. ROC_T = Runoff coefficient of the treated plot; ROC_UT = Runoff coefficient of the untreated plot; RO_T = Runoff of the treated plot; RO_UT = Runoff of the untreated plot

Figure 31 shows the ratio between downslope runoff and total runoff, as well as between lateral runoff and total runoff of the treated plot and it gives evidence about the impact of the maintenance of the stone bund on the distribution of lateral and downslope runoff. Before the maintenance, the average ratio between downslope runoff and total runoff of the treated plot is 73% and the same ratio is 17% after the maintenance.

This means, that proper maintenance of a stone bund can reduce downslope runoff by 77 % and therefore it is a suitable measurement to increase the efficiency of stone bunds. At the same time, the average ratio between lateral runoff and total runoff of the treated plot is 27 % before and 83 % after the maintenance. After the maintenance, the lateral runoff is 307 % of the same runoff before maintenance, which leads to a higher accumulation of eroded soil particles behind the stone bund and a lower erosion rate as a long term effect.

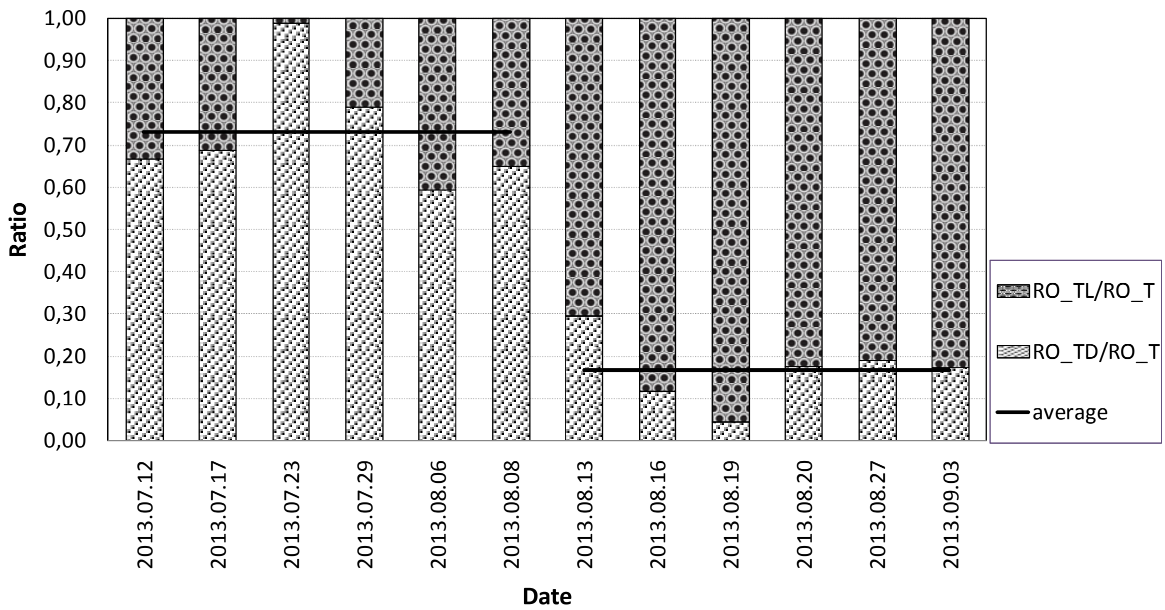

Figure 31: Share of down slope – and lateral runoff in the total runoff of the treated plot during the monitoring period. RO_T = Total runoff of the treated plot; RO_TL = Lateral runoff of the treated plot; RO_TD = Downslope runoff of the treated plot

5.3 Soilloss

The results of the sediment concentration analysis in the laboratory in combination with the runoff information allow the evaluation of soil erosion at both plots during the monitoring period. Before determining soil loss data, the results of the sample analysis have been compared with the Dixon test in order to detect outliers. The test provides the information, that there is no outlier in the data series.

As shown in figure 32, there were 15 monitoring days during the whole monitoring period between 4th of July and 3rd of September 2013. On three out of 15 monitoring days there was no soil erosion noticeable, because on these days only 0 mm of runoff was recorded. Table 3 shows the result of the soil erosion measurement for every single runoff fraction as well as the total erosion values for both plots before and after the maintenance of the stone bund. The total soil erosion of the untreated plot with 23 t/ha is significantly smaller than the soil erosion of the treated plot with 33 t/ha. The difference in results is mainly because of strong inequalities between soil erosion results from the treated and untreated plot during the first three monitoring days, which is clearly visible in figure 32. The reason for that is not totally clear, since both plots have the same conditions in soil type, inclination, stone- and crop cover and precipitation. But during the first events, sedimentation of eroded soil particles in the collection- and conduit pipe of the untreated plot was noticed. These sediments clogged the pipes and probably led to wrong results. For example on the 17th of July there were erosion values of about 8.1 t/ha at the treated plot and 1.7 t/ha at the untreated plot determined. Just by this measurement day, the results of total soil erosion of both plots differ by more than 6 t/ha.

Before maintenance the downslope fraction of the soil erosion of the treated plot was more than five times as high as the lateral erosion of the same plot. After maintenance, the lateral erosion was four and a half times as high as the downslope erosion. This shows clearly how stone bunds influence soil erosion.

Table 1: Soil erosion before and after the maintenance and the total soil erosion during the monitoring period from 4th of July until 3rd of September 2013

Origin of erosion	Before maintenance (t/ha)	After maintenance (t/ha)	Total (t/ha)
UT	10.68	12.32	**23.00**
T	23.13	10.17	**33.30**
TD	19.39	1.85	21.24
TL	3.74	8.32	12.06

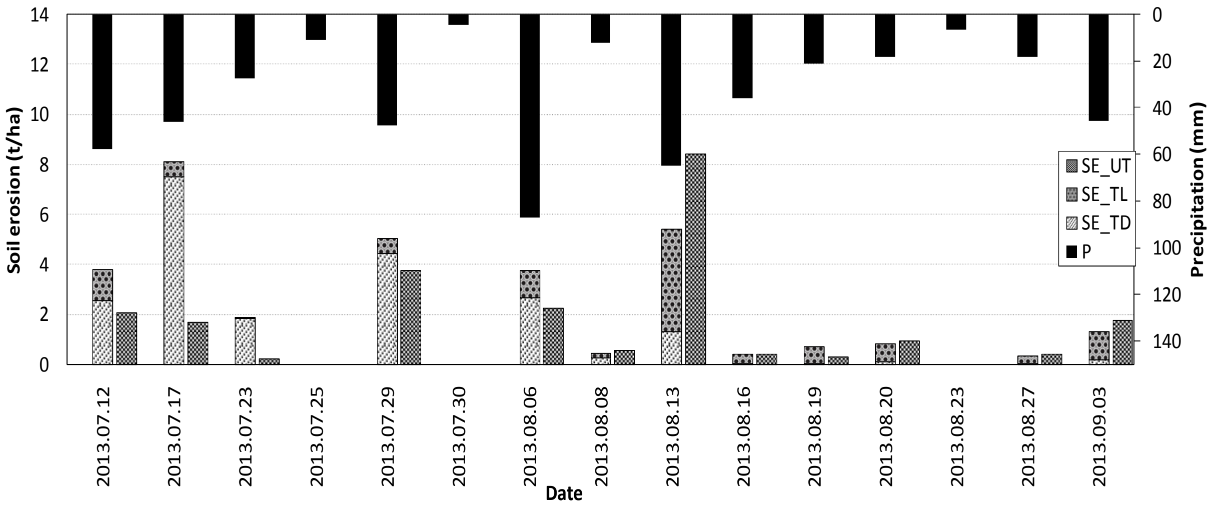

Figure 32: Soil erosion on the treated and on the untreated plot during the monitoring period and its' corresponding precipitation. SE_UT = Soil erosion on the untreated plot, SE_TL = Lateral soil erosion on the treated plot, SE_TD = Downslope soil erosion on the treated plot

Figure 33 gives further evidences for errors in the soil erosion results. On the 17th of July the runoff from both plots was almost equal with about 20 mm, while the corresponding soil erosion differs heavily like mentioned above. Another evidence for errors is the erosion result from the 13th of August. The runoff at the untreated plot was slightly smaller than the runoff of the treated plot, but it's corresponding soil erosion was about one and a half times as high as the one of the treated plot.

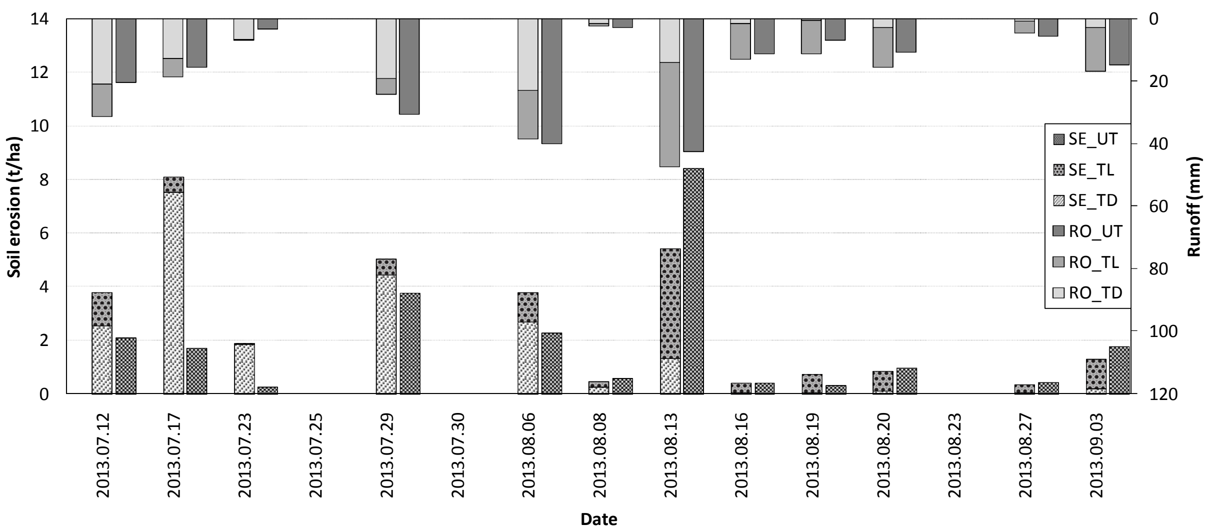

Figure 33: Soil erosion on the treated and untreated plot and its' corresponding runoff during the monitoring period. SE_UT = Soil erosion on the untreated plot; SE_TL = Lateral soil erosion on the treated plot; SE_TD = Downslope soil erosion on the treated plot; RO_UT = Runoff of the untreated plot; RO_TL = Lateral runoff of the treated plot; RO_TD = Downslope runoff of the treated plot

5.4 Topographic survey of the study area

In the length – profile of the treated plot it is possible to see the accumulation zone up to 4.16 m before the stone bund where the inclination of 6% is lower than the average slope of 9%. The inclination uphill the accumulation zone is almost equal over the whole lope length and it is at 10%.

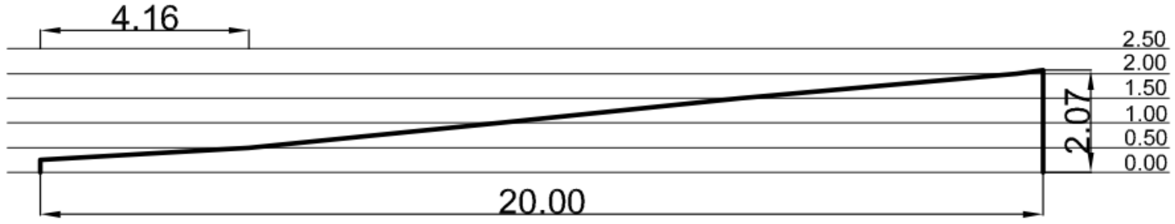

Figure 34: Length - profile of the treated plot

The length – profile of the untreated plot is more uniform in comparison to the profile of the treated plot, because an accumulation zone does not exist. The slope is about 9% and is equal to the slope of the treated plot.

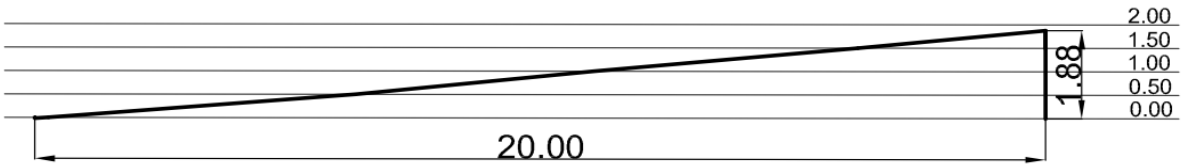

Figure 35: Length - profile of the untreated plot

5.5 Assessment of canopy and rock fragment cover

The determination of the canopy cover was conducted with an image classification tool of the software ArcGIS. Figure 37 shows the development of the canopy cover during the observation period. At the beginning, the canopy cover is equal to 0%. After the first precipitation events in the end of June, vegetation starts to grow. It grows almost constantly until the middle of August, when the canopy cover increases from 27.5% to 39.8% within only five days. At the end of the observation period, the canopy covers 46.4% of the plot area.

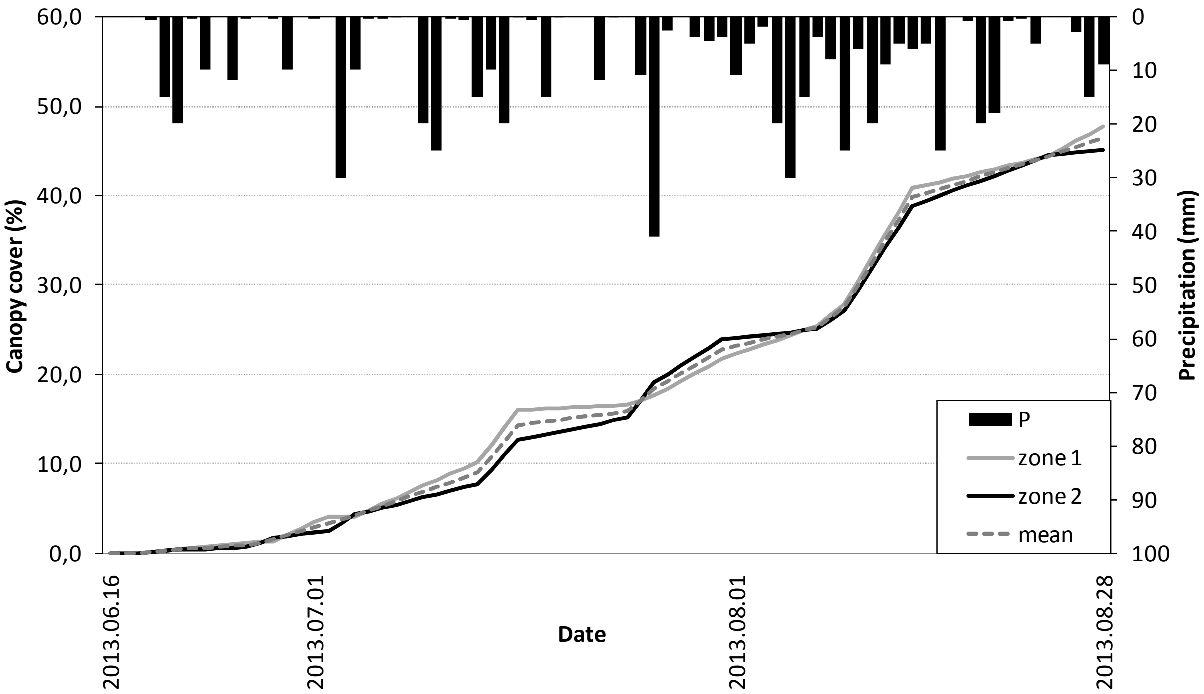

Figure 36: Development of the canopy cover during the observation period

While the canopy cover was increasing during the observation period, the rock fragment cover was assumed to be constant during the same time span. Table 2 shows the results of the manually determined rock fragment cover in the different zones and it´s mean value.

Table 2: Rock fragment cover

Zone	Rock fragment cover (%)
Zone 1	10.74
Zone 2	11.79
Mean	11.27

6 Summary and conclusion

During the rainy season 2013 soil erosion measurements were carried out on two different plots. In order to assess the impact of stone bunds on soil erosion, one plot without a stone bund (untreated) and one with a stone bund (treated) have been constructed. The surface runoff of both plots was collected into ponds, from where samples have been taken. The runoff of the treated plot was collected separately as a downslope fraction and as a lateral fraction of the total runoff. The runoff of the untreated was not divided into different fractions. In the laboratory sediment concentrations of the runoff samples were determined and then the soil loss rates could be calculated. Both plots showed comparable soil erosion rates. Some errors in the sample taking process occurred at the beginning of the monitoring period at the untreated plot, which probably distorted the erosion results. A maintenance of the stone bund at the treated plot in the middle of the monitoring period showed clearly, that well constructed stonebunds have an decreasing effect on downslope runoff and downslope soil erosion. In order to point out the results and findings of this thesis, the four hypothesis are discussed as follows:

1.) Assess the quantity of soil erosion of both plots and compare them with each other.

During the monitoring period from 4th of July until 3rd of September 2013 the total soil erosion was 23.0 t/ha at the untreated plot and 33.3 t/ha at the treated plot. These results are partly affected by errors in the plot arrangement or in the sample taking process. That is why the determined soil erosion rates of both plots cannot really be compared with each other in order to get information about the impact of stone bunds on soil erosion. The results can only give an idea about the order of magnitude of the soil erosion in that area.

2.) Make investigations about the quantity of surface runoff of both plots and compare them with each other.

During the monitoring period, the total surface runoff of the treated plot was 230.4 mm and the total surface runoff of the untreated plot was 203.7 mm, while the total precipitation was 503.1 mm. The average runoff coefficients are 0.46 at the treated plot and 0.40 at the untreated plot. The impact of the maintenance of the stone bund on surface runoff is clearly noticeable. Due to an increase of the stone bund´s height, the downslope runoff on the treated plot decreases by 77 % and the lateral runoff increases by 307 %.

3.) Figure out the impact of the maintenance of a stone bund on soil loss.

Before the maintenance of the stone bund, the downslope soil erosion of the treated plot was more than five times as high as the lateral erosion of the same plot. After maintenance, the lateral erosion was four and a half times as high as the downslope erosion. The results show, that due to maintenance a major part of the eroded sediments can be forced to flow laterally along the stone bund with a higher likelihood to settle down along the way instead of going through the stone bund.

4.) Determination of the impact of stone bunds on the quantity of soil erosion and surface run off.

It is not possible to conclude with reliable information about the influence of stone bunds on the quantity of soil erosion and surface runoff. This is because the erosion data of both plots cannot be compared with each other and plot replications or reference data are not available. But a reduction of downslope erosion and runoff due to the maintenance of the stone bund is suggested by the determined erosion and runoff data. Therefore a positive effect of stone bunds on soil erosion can be assumed.

7 Bibliography

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8 Annex

A1. Precipitation Data

Table A1.1: Precipitation data from the manual rain gauger. P = Precipitation;

Date	P (mm)
2013.07.01	0.5
2013.07.02	0
2013.07.03	30
2013.07.04	10
2013.07.05	0.6
2013.07.06	0.4
2013.07.07	0.3
2013.07.08	0
2013.07.09	20
2013.07.10	25
2013.07.11	0.5
2013.07.12	0.7
2013.07.13	15
2013.07.14	10
2013.07.15	20
2013.07.16	0.2
2013.07.17	0.8
2013.07.18	15
2013.07.19	0.1
2013.07.20	0
2013.07.21	0
2013.07.22	12
2013.07.23	0.2
2013.07.24	0
2013.07.25	11
2013.07.26	41
2013.07.27	2.6
2013.07.28	0
2013.07.29	4
2013.07.30	4.5
2013.07.31	4
2013.08.01	11
2013.08.02	5
2013.08.03	2
2013.08.04	20
2013.08.05	30
2013.08.06	15
2013.08.07	4
2013.08.08	8
2013.08.09	25

2013.08.10	6
2013.08.11	20
2013.08.12	9
2013.08.13	5
2013.08.14	6
2013.08.15	5
2013.08.16	25
2013.08.17	0
2013.08.18	1
2013.08.19	20
2013.08.20	18
2013.08.21	1
2013.08.22	0.6
2013.08.23	5
2013.08.24	0
2013.08.25	0
2013.08.26	3
2013.08.27	15
2013.08.28	9
2013.08.29	2.2
2013.08.30	7
2013.08.31	7
2013.09.01	0.4
2013.09.02	0
2013.09.03	20

Table A1.2.: Monthly precipitation data from the weather station in Maksegnit from 1997 - 2011

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

A2. Sample data

During the sample period from 4th of July until 3rd of September 2013 some problems in generating data occurred. Especially during the first measurement events there was a lack of experience with this kind of plot arrangement and potential sources of errors have not been identified by this time. This testing period was affected by clogged tubes through sediments, holes in the plastic foils of the ponds or by local kids putting stones into the plots' tubes. All in all, different happenings resulted in distorted or simply wrong measurement results. Especially the first data about soil erosion are not reliable and shall be considered as results of necessary test runs in order to identify the areas, which are worthy of improvement.

This chapter should give an overview about the composition and detailed data of each sample of each monitoring day. Furthermore it should give explanations about problems or events, which probably disturbed the measurement results.

2013.07.03

Table A2.1a.: Volume, sediment mass and soil erosion rates, determined for the 3rd of July 2013. M = Mass; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	83.85	52.84	0.00
M sediment per pond (g)	1216	824	0.00
Soil erosion (t/ha)	2.03	1.37	0.00

Table A2.1b.: Results of the sample analysis for the 3rd of July 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Sample	Sample volume (l)	M-solids (g)	S.c. (g/l)	S.c. average (g/l)
TD1	0.95	12.45	13.11	
TD2	0.94	14.48	15.40	**14.50**
TD3	0.96	14.39	14.99	
TL1	0.96	15.25	15.89	
TL2	0.83	12.63	15.22	**15.59**
TL3	1.05	16.45	15.67	

Note:

At the first measurement day the plastic foil of the pond of the untreated plot had a hole. This is why for that day, data for runoff and soil erosion from the untreated plot could not be generated. In order to compare data from the untreated with data from the treated plot, data from that day are not taken into consideration. During the analysis of the TD2 sample, there were mistakenly some solid residuals in the sample bottle after putting the major part of the sample into a glass beaker for the drying process. The weight of the residual solids has been dried after a filtration with a paper filter and finally it has been accounted for the determination of the sediment concentration of TD2.

2013.07.12

Table A2.2a.: Volume, sediment mass and soil erosion rates, determined for the 12th of July 2013. M = Mass; TD = downslope fraction of the treated plot; TL = lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	121.42	60.48	121.76
M sediment per pond (g)	1486	726	1879.97
Soil erosion (t/ha)	2.48	1.21	3.13

Table A2.2b.: Results of the sample analysis for the 12th of July 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Sample	Sample volume (l)	M-solids (g)	Sediment concentration (g/l)	S.c. average (g/l)
TD1	1.67	21.96	13.15	**12.24**
TD2	1.75	19.82	11.32	
TL1	1.75	22.69	12.96	**12.01**
TL2	1.73	19.12	11.05	
UT1	1.76	18.18	15.44	**15.44**

Note:

The collection tube of the untreated was totally clogged by sediments. The sediments have been removed and collected. After mixing them with water into a plastic bucket, they were stirred up manually with a wooden stick for approximately 20 minutes until they converted more and more in a thick homogenous soil – water mixture of high density. The total weight of the mixture was 8.61kg. After taking a sample with a certain volume from the mixture in the bucket, it´s sediment concentration could be determined and finally a total sediment weight of 6.22kg could be calculated. This sediment has been referred to the total surface runoff at the untreated plot and it was also accounted for the determination of the solids concentration of the UT1 sample.

2013.07.17

Table A2.3a.: Volume, sediment mass and soil erosion rates, determined for the 17th of July 2013. M = Mass; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	74.74	33.96	93.61
M sediment per pond (g)	4382	331	1025.42
Soil erosion (t/ha)	7.55	0.55	1.71

Table A2.3b.: Results of the sample analysis for the 17th of July 2013. S.c. = Sediment concentration; S.c. av. new = New average sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Sample	Sample volume (l)	M-solids (g)	S.c. (g/l)	S.c. average (g/l)	S.c. av. new (g/l)
TD1	0.93	32.43	34.87		
TD2	0.89	26.39	29.65	32.15	**58.63**
TD3	0.92	29.37	31.92		
TL1	0.96	9.076	9.45		
TL2	0.96	9.908	10.32	**9.76**	-
TL3	1.04	9.871	9.49		
UT1	1.35	15.013	11.12		-
UT2	1.76	18.986	10.79	**10.95**	

Note:

The collection tube of the downslope fraction of the treated plot was partly clogged by sediments. Because of lots of sediment on the ground of the treated pond, the sediments have been collected separately and it´s dry weight was determined. Finally it was referred to the total runoff volume, which was collected in the ponds and it was accounted for the determination of the average solids concentration of the TD pond. The final average sediment concentration of the TD samples is listed in Table A2.3b at S.c. av. new.

2013.07.23

Table A2.4a.: Volume, sediment mass and soil erosion rates, determined for the 23rd of July 2013. M = Mass; TD = downslope fraction of the treated plot; TL = lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	38.84	0.5	19.20
M sediment per pond (g)	1091	15	153.37
Soil erosion (t/ha)	1.88	0.03	0.26

Table A2.4b.: Results of the sample analysis for the 23rd of July 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Sample	Sample volume (l)	M-solids (g)	Sediment concentration (g/l)	S.c. average (g/l)
TD1	0.93	26.78	28.80	
TD2	0.96	25.94	27.02	**28.09**
TD3	0.95	27.02	28.44	
TL1	0.59	18.11	30.69	**30.69**
UT1	1.7	13.56	7.98	**7.99**
UT2	1.5	12	8.00	

Note:

The conduit pipe of the untreated plot, which transfers the surface runoff to the sample divider was clogged totally by sediments until up to approximately 50% of its height as it is shown in figure 38. The tube was cleaned and freed from sediments totally. It is assumed that until that day, the runoff data and the soil erosion data from the untreated plot are not reliable, because the clogging of the conduit pipes was not realized for the first 20 days of measurement and therefore it could be the main reason for huge differences between data from the treated and the untreated plot.

Figure 37: Clogged tube of the untreated plot

<u>2013.07.25</u>

Note:

Between the last monitoring day and this day no surface runoff and no soil erosion occurred.

2013.07.29

Table A2.5a.: Volume, sediment mass and soil erosion rates, determined for the 29th of July 2013. M = Mass; TD = downslope fraction of the treated plot; TL = lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	110.78	29.36	182.98
M sediment per pond (g)	2579	358	2259.36
Soil erosion (t/ha)	4.44	0.62	3.77

Table A2.5b.: Results of the sample analysis for the 29th of July 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Sample	Sample volume (l)	M-solids (g)	Sediment concentration (g/l)	S.c. average (g/l)
TD1	0.91	20.56	22.59	
TD2	0.94	21.61	22.99	**23.28**
TD3	0.93	22.55	24.25	
TL1	1.42	19.66	13.85	**12.18**
TL2	0.94	9.88	10.51	
UT1	1.53	18.40	12.03	**12.35**
UT2	1.45	18.37	12.67	

2013.07.30

Note:

No surface runoff and soil erosion could be detected.

2013.08.06

Table A2.6a.: Volume, sediment mass and soil erosion rates, determined for the 6th of August 2013. M = Mass; TD = downslope fraction of the treated plot; TL = lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	133.00	90.50	239.50
M sediment per pond (g)	1560.09	639.84	1365.64
Soil erosion (t/ha)	2.69	1.10	2.28

Table A2.6b.: Results of the sample analysis for the 6th of August 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Sample	Sample volume (l)	M-solids (g)	S.c. (g/l)	S.c. average (g/l)	S.c. average new (g/l)
TD1	0.89	8.75	9.83	9.57	**11.73**
TD2	0.98	9.42	9.61		
TD3	0.94	8.72	9.28		
TL1	1.48	9.22	6.23	6.54	**7.07**
TL2	0.92	6.18	6.72		
TL3	0.95	6.34	6.67		
UT1	1.64	9.08	5.54	5.70	**5.70**
UT2	1.66	9.74	5.87		

Note:

There was almost no sediment in the collection and conduit pipes of both plots. One of the three connection parts between the sample divider and the small tubes to the TL pond was clogged. This may have caused an error of the data. After emptying the ponds, there was extra sediment on the bottom of the TD and TL pond. This sediment was collected and analyzed separately in the laboratory. Afterwards the results of it´s sediment concentration have been added to the sediment concentration results of the corresponding pond – samples. The final average sediment concentrations of the TD, TL and UT samples are listed in Table A2.6b at S.c. average new.

<u>2013.08.08</u>

Table A2.7a.: Volume, sediment mass and soil erosion rates, determined for the 8th of August 2013. M = Mass; TD = downslope fraction of the treated plot; TL = lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	8.82	4.74	16.41
M sediment per pond (g)	161.23	114.38	347.62
Soil erosion (t/ha)	0.28	0.20	0.58

Table A2.7b.: Results of the sample analysis for the 8th of August 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT

Sample	S.c. average (g/l)
TD1	**18.28**
TL1	**24.13**
UT1	**21.19**

Note:

Because of the small amounts of collected surface runoff in all three ponds, the total amount of collected runoff has been sampled and it´s sediment concentration had been determined. In the conduit pipe of the untreated plot one big stone could be found and removed. It was obvious that the stone was put inside the tubes by humans, maybe by some local kids which wanted to play a prank. This may caused an error of the data.

Figure 38: A big stone blocking a tube of the untreated plot

2013.08.13

Table A2.8a.: Volume, sediment mass and soil erosion rates, determined for the 13th of August 2013. M = Mass; TD = downslope fraction of the treated plot; TL = lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	81.51	193.65	255.11
M sediment per pond (g)	774.23	2382.62	5054.74
Soil erosion (t/ha)	1.33	4.10	8.42

Table A2.8b.: Results of the sample analysis for the 13th of August 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT

Sample	Sample volume (l)	M-solids (g)	S.c. (g/l)	S.c. average (g/l)	S.c. average new (g/l)
TD1	1.66	15.73	9.48	**9.50**	-
TD2	0.95	8.59	9.04		
TD3	0.9	8.98	9.98		
TL1	1.7	20.46	12.04	**12.30**	-
TL2	0.99	12.18	12.30		
TL3	0.96	12.07	12.57		
UT1	1.61	29.89	18.57	18.51	**19.81**
UT2	1.73	32.47	18.77		
UT3	1.77	32.23	18.21		

Note:

One of the three connection tubes between the sample divider and the pond of the untreated plot was removed because of an unknown reason, as it is shown in figure 40. Also the collection tube of the untreated plot was clogged by sediments, which could be removed and analyzed separately. After referring its' sediment concentration to the collected runoff amount in the UT pond, the sediment concentration was added to the before determined average sediment concentration, resulting in the S.c. average new value, as it is shown in Table A2.8b.

Figure 39: Removed connection tube between the sample divider and the pond of the UT plot

2013.08.16

Table A2.9a.: Volume, sediment mass and soil erosion rates, determined for the 16th of August 2013. M = Mass; TD = downslope fraction of the treated plot; TL = lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	8.96	267.08	66.35
M sediment per pond (g)	34.74	820.95	246.66
Soil erosion (t/ha)	0.06	1.41	0.41

Table A2.9b.: Results of the sample analysis for the 16th of August 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT

Sample	Sample volume (l)	M-solids (g)	Sediment concentration (g/l)	S.c. average (g/l)
TD1	0.98	3.84	3.92	**3.88**
TD2	0.98	3.76	3.84	
TL1	1.74	5.2	2.99	**3.07**
TL2	1.62	5.03	3.10	
TL3	1.72	5.38	3.13	
UT1	1.77	6.9	3.90	**3.72**
UT2	1.67	6.94	4.16	
UT3	0.91	2.82	3.10	

Note:

There is a tremendous difference in the volume of the collected runoff of both plots.

2013.08.19

Table A2.10a.: Volume, sediment mass and soil erosion rates, determined for the 19th of August 2013. M = Mass; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	3.00	62.20	41.45
M sediment per pond (g)	38.52	392.49	285.52
Soil erosion (t/ha)	0.07	0.68	0.48

Table A2.10b.: Results of the sample analysis for the 19th of August 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT

Sample	Sample volume (l)	M-solids (g)	Sediment concentration (g/l)	S.c. average (g/l)
TD1	1.00	12.84	12.84	**12.84**
TL1	1.78	11.38	6.39	
TL2	1.67	9.61	5.75	**6.31**
TL3	1.75	11.87	6.78	
UT1	1.74	11.71	6.73	**6.89**
UT2	1.71	12.05	7.05	

2013.08.20

Table A2.11a.: Volume, sediment mass and soil erosion rates, determined for the 20th of August 2013. M = Mass; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	15.79	74.54	63.71
M sediment per pond (g)	69.55	428.71	578.98
Soil erosion (t/ha)	0.12	0.74	0.96

Table A2.11b.: Results of the sample analysis for the 20th of August 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT

Sample	Sample volume (l)	M-solids (g)	Sediment concentration (g/l)	S.c. average (g/l)
TD1	0.93	3.90	4.19	**4.40**
TD2	0.86	3.97	4.62	
TL1	1.63	9.37	5.75	
TL2	0.97	5.64	5.81	**5.75**
TL3	0.94	5.35	5.69	
UT1	1.78	12.13	6.81	
UT2	0.98	11.89	12.13	**9.09**
UT3	0.95	7.90	8.32	

2013.08.23

Note:

Between the last monitoring day and this day no surface runoff and no soil erosion occurred.

2013.08.27

Table A2.12a.: Volume, sediment mass and soil erosion rates, determined for the 27th of August 2013. M = Mass; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	4.93	21.10	32.88
M sediment per pond (g)	35.36	129.88	301.78
Soil erosion (t/ha)	0.06	0.22	0.50

Table A2.12b.: Results of the sample analysis for the 27th of August 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT

Sample	Sample volume (l)	M-solids (g)	Sediment concentration (g/l)	S.c. average (g/l)
TD1	0.93	6.67	7.17	**7.17**
TL1	1.44	7.96	5.53	**6.16**
TL2	1.66	11.26	6.78	
UT1	0.93	8.83	9.49	**9.18**
UT2	0.98	8.89	9.07	
UT3	0.97	8.70	8.97	

2013.09.03

Table A2.13a.: Volume, sediment mass and soil erosion rates, determined for the 3rd of September 2013. M = Mass; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT = Untreated;

Pond	TD	TL	UT
Volume (l)	16.92	80.75	88.97
M sediment per pond (g)	127.43	633.21	1067.45
Soil erosion (t/ha)	0.22	1.09	1.78

Table A2.13b.: Results of the sample analysis for the 3rd of September 2013. S.c. = Sediment concentration; TD = Downslope fraction of the treated plot; TL = Lateral fraction of the treated plot; UT

Sample	Sample volume (l)	M-solids (g)	Sediment concentration (g/l)	S.c. average (g/l)
TD1	1.02	7.00	6.86	**7.53**
TD2	0.9	7.38	8.20	
TL1	1.43	11.27	7.88	**7.84**
TL2	1.45	10.40	7.17	
TL3	0.87	7.37	8.47	
UT1	1.38	14.76	10.70	**12.00**
UT2	1.24	16.37	13.20	
UT3	1.35	16.33	12.10	

Table A.2.14: Results of the solid concentration analysis of each sample including standard deviation and the standard error of mean. C_solid = Solid concentration; C_s_av = Average solid concentration;

Date	Sample	C_solids (g/l)	C_s_av (g/l)	standard deviation	standard error of mean
2013.07.03	TD1	13.11	14.50	1.23	0.71
	TD2	15.41			
	TD3	14.99			
	TL1	15.88	15.59	0.34	0.20
	TL2	15.22			
	TL3	15.66			
2013.07.12	TD1	13.15	12.24	0.91	0.65
	TD2	11.32			
	TL1	12.96	12.01	0.95	0.67
	TL2	11.05			
	UT1	10.33	10.33	-	-
2013.07.17	TD1	58.19	58.63	4.68	2.70
	TD2	52.97			
	TD3	55.24			
	TL1	9.45	9.76	0.49	0.28
	TL2	10.32			
	TL3	9.49			
	UT1	11.12	10.95	0.17	0.12
	UT2	10.79			
2013.07.23	TD1	28.79	28.09	0.94	0.54
	TD2	27.02			
	TD3	28.44			
	TL1	30.69	30.69	-	-
	UT1	7.99	8.00	0.00	0.00
	UT2	8.00			
2013.07.25	TD	0.00	0	-	-
	TL	0.00	0	-	-
	UT	0.00	0	-	-
2013.07.29	TD1	22.59	23.27	0.86	0.50
	TD2	22.99			
	TD3	24.25			
	TL1	13.85	12.18	1.67	1.18
	TL2	10.51			
	UT1	12.03	12.35	0.32	0.23
	UT2	12.67			
2013.07.30	TD	0.00	0	-	-
	TL	0.00	0	-	-
	UT	0.00	0	-	-
2013.08.06	TD1	9.83	9.57	0.28	0.16
	TD2	9.61			
	TD3	9.28			

	TL1 TL2 TL3	6.23 6.72 6.67	6.54	0.27	0.16
	UT1 UT2	5.54 5.87	5.70	0.16	0.12
2013.08.08	TD	18.28	18.28	-	-
	TL	24.13	24.13	-	-
	UT	21.19	21.19	-	-
2013.08.13	TD1 TD2 TD3	9.5 9.0 10.0	9.50	0.47	0.27
	TL1 TL2 TL3	12.0 12.3 12.6	12.30	0.27	0.16
	UT1 UT2 UT3	18.6 18.8 18.2	18.51	0.28	0.16
2013.08.16	TD1 TD2	3.92 3.84	3.88	0.04	0.03
	TL1 TL2 TL3	2.99 3.10 3.13	3.07	0.08	0.04
	UT1 UT2 UT3	3.90 4.16 3.10	3.72	0.55	0.32
2013.08.19	TD1	12.84	12.84	-	-
	TL1 TL2 TL3	6.39 5.75 6.78	6.31	0.52	0.30
	UT1 UT2	6.73 7.05	6.89	0.16	0.11
2013.08.20	TD1 TD2	4.19 4.61	4.40	0.21	0.15
	TL1 TL2 TL3	5.75 5.81 5.69	5.75	0.06	0.04
	UT1 UT2 UT3	6.81 12.13 8.32	9.09	2.74	1.58
2013.08.23	TD	0.00	0	-	-
	TL	0.00	0		
	UT	0.00	0		
2013.08.27	TD1	5.74	5.74	-	-
	TL1 TL2	6.52 9.60	8.06	1.54	1.09

	UT1 UT2 UT3	7.90 7.91 7.73	7.85	0.10	0.06
2013.09.03	TD1 TD2	6.86 8.20	7.53	0.67	0.47
	TL1 TL2 TL3	8.02 7.17 8.47	7.88	0.66	0.38
	UT1 UT2 UT3	10.70 13.20 12.02	11.97	1.25	0.72

A3. Dixon test data

Table 1 shows the results of the outlier test as well as the sediment concentration of each sample. D_{min} and D_{max} is always below D_{tab} (D_{tab} = 0.999). Since that, no outliers are beyond the measured data and all of them can be used. N in the outlier column means no. Table 2 gives an overview of all measurement events and the results of each measurement, including mean values and standard errors of mean.

Table A.3.1: Dixon outlier test of solid concentration results; n = no; C_solids = Solids concentration;

Date	Sample	C_solids (g/l)	Dmin	Dmax	Outlier
2013.07.03	TD1	13.11	0.82		n
	TD3	14.99			
	TD2	15.41		0.18	n
	TL2	15.22	0.67		n
	TL3	15.66			
	TL1	15.88		0.33	n
2013.07.17	TD2	52.97	0.43		n
	TD3	55.24			
	TD1	58.19		0.57	n
	TL1	9.45	0.04		n
	TL3	9.49			
	TL2	10.32		0.96	n
2013.07.23	TD2	27.02	0.80		n
	TD3	28.44			
	TD1	28.79		0.20	n
2013.07.29	TD1	22.59	0.24		n
	TD2	22.99			
	TD3	24.25		0.76	n
2013.08.06	TD3	9.28	0.61		n
	TD2	9.61			
	TD1	9.83		0.39	n
	TL1	6.23	0.90		n
	TL3	6.67			
	TL2	6.72		0.10	n
2013.08.13	TD2	9.0	0.46		n
	TD1	9.5			
	TD3	10.0		0.54	n
	TL1	12.0	0.50		n
	TL2	12.3			
	TL3	12.6		0.50	n
	UT3	18.2	0.64		n
	UT1	18.6			

	UT2	18.8		0.36	n
2013.08.16	TL1	2.99	0.84		n
	TL2	3.10			
	TL3	3.13		0.16	n
	UT3	3.10	0.76		n
	UT1	3.90			
	UT2	4.16		0.24	n
2013.08.19	TL2	5.75	0.62		n
	TL1	6.39			
	TL3	6.78		0.38	n
2013.08.20	TL3	5.69	0.48		n
	TL1	5.75			
	TL2	5.81		0.52	n
	UT1	6.81	0.28		n
	UT3	8.32			
	UT2	12.13		0.72	n
2013.08.27	UT3	7.73	0.92		n
	UT1	7.90			
	UT2	7.91		0.08	n
2013.09.03	TL2	7.17	0.66		n
	TL1	8.02			
	TL3	8.47		0.34	n
	UT1	10.70	0.53		n
	UT3	12.02			
	UT2	13.20		0.47	n

Table A.3.2: Table of D_{tab} values for the Dixon test in dependence of N and α. N = Number of data; α = level of significance. The orange color marks the D_{tab} value which was used in the thesis (Lohninger, 2010).

N	α=0.001	α=0.002	α=0.005	α=0.01	α=0.02	α=0.05	α=0.1	α=0.2
3	0.999	0.998	0.994	0.988	0.976	0.941	0.886	0.782
4	0.964	0.949	0.921	0.889	0.847	0.766	0.679	0.561
5	0.895	0.869	0.824	0.782	0.729	0.643	0.559	0.452
6	0.822	0.792	0.744	0.698	0.646	0.563	0.484	0.387
7	0.763	0.731	0.681	0.636	0.587	0.507	0.433	0.344
8	0.716	0.682	0.633	0.591	0.542	0.467	0.398	0.314
9	0.675	0.644	0.596	0.555	0.508	0.436	0.370	0.291
10	0.647	0.614	0.568	0.527	0.482	0.412	0.349	0.274
15	0.544	0.515	0.473	0.438	0.398	0.338	0.284	0.220
20	0.491	0.464	0.426	0.393	0.356	0.300	0.251	0.193
25	0.455	0.430	0.395	0.364	0.329	0.277	0.230	0.176
30	0.430	0.407	0.371	0.342	0.310	0.260	0.216	0.165