2020-03-19

EFFECTS OF SOIL AND WATER CONSERVATION PRACTICES ON HYDROLOGICAL RESPONSES IN ALEKT WENZ WATERSHED NORTHWESTERN ETHIOPIAN HIGHLAND.

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Simir Birihan Atanaw

A thesis submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, Bahir Dar University in partial fulfillment of the requirements for the degree of Master of Science in Engineering Hydrology in the Faculty of Civil and Water Resource Engineering.

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Bahir Dar, Ethiopia

July 3, 2017

Declaration

I, the undersigned, declare that the thesis comprises my own work, which was done under the supervision of Seifu Admassu Tilahun (Ph.D.) and co-supervision of Anwar Assefa Adem (Ph.D. candidate). In compliance with internationally accepted practices and work, I have dually acknowledged and referred all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea /data/fact/ source will constitute sufficient ground for disciplinary action by the university. This can also evoke penal action from the sources that have not been properly cited or acknowledged.

Name of the student_____________________________ Signature ______________

Date of submission: _________________

Place: Bahir Dar

This thesis has been submitted for examination with my approval as a university advisor.

Advisor Name: ____________________________________

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Bahir Dar University

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To my sister

Biographical sketch

Simir Birihan Atanaw was born in 1990 in the Amhara Regional State, North Gondar province Dembiya District, Ethiopia. He went to Salj Elementary School at the age of nine and studied for eight years. Then, he went to Kolladiba General Secondary School. After stayed four years at Kolladiba and completed his natural science preparatory study, He has joined Wollega University to study Agricultural Science in December-2012 E.C. He studied Bachelor degree of Water Resources and Irrigation Management. Then, luckily, he has the chance to study master's degree in hydrology engineering at Bahir Dar University Institute of Technology in Novemeber-2015. He has a broad interest to study surface water, groundwater hydrology, and flood frequency analysis. Thus, he has a dream to specialize in water resources, hydrology or hydraulics engineering in the future career.

ACKNOWLEDGEMENT

My deepest and maximum respect and special thanks go to Dr. Seifu Admassu Tilahun offered a chance, funding the whole work, initiation and providing an excellent advice and his patience when I worked through this. I would like to say thank you my sponsor ERA sincerely for providing the entire educational fee.

I would like to extend my heart full gratitude to my co-advisor Anwar Assefa Adem (Ph.D. candidate) for his critical and constructive comment, and trained software like ArcGIS /Arc SWAT/ for watershed delineation, and Endnote X6 and Google Scholar for reference organization and citation.

To my family, Grace, thanks for all the support and encouragement you provided. Words are impossible to find that adequately express my gratitude.

My gratitude extends to my colleagues, Kassaye Gurebiyaw Legese for his support and advice to using Mendeley Desktop for reference organization, Habtamu Muche for his advice, comment. Abebe Yohannes, for his encouragement, supporting and staying with me during data collection of X.Y.Z coordinate by GPS for watershed delineation and characterization, Alemsha Getaneh for his aiding during sediment sample oven drying and balancing.

During my fieldwork, Dejen Dagnew helped me during construction of gauging stations, and data collectors (Endager Beza, Eyasu Tigabie, Keleb Getnet, and Yalie Lakew) for collecting relevant data in day and night by resisting frost and cold. I would like to use this opportunity to thank them all.

The research for this MSc thesis was made possible through the CGIAR Research Program on Water, Land and Ecosystem’s East Africa focal regional program. The research was implemented under a collaborative partnership between the Amhara Regional Agricultural Research Institute, International Water Management Institute, Bureau of Agriculture and Bahir Dar University. The contents of the paper are the responsibility of the authors and do not necessarily reflect the views of CGIAR-WLE.

ABSTRACT

Land degradation by soil erosion and its induced threat is a serious problem in the world specifically in northwestern Ethiopian highland. To control this adverse impact different soil and water conservation (SWC) practices were implemented in the food for work program through government-led and with the help of NGOs. However, there is no substantial scientific research on the effects of SWC practices on hydrological responses. In this study, two watersheds that are situated in the northwestern Ethiopian highland were selected. One has sufficient SWC practices since 2012 with a total drainage area of 87.6ha and the second one has limited conservation practices with a total drainage area of 234.7ha. The adjacent watersheds are comparable in their overall characters of geology, soil type, climate, and relief. The treated and the untreated watersheds have an average slope of 8.9^0 and 9.4^0 respectively. The study was conducted by installing rectangular cross-sectional weir on the treated and staff gauge on the untreated watershed. Data of Rainfall, Streamflow, Sediment Concentration, and Sediment-associated and Dissolved nutrient of N and P for 2015 and 2016 rainy periods were collected. The watersheds received an annual rainfall of 665 mm in 2015 and 795 mm in 2016. The median infiltration rates for treated and untreated watershed were 22 mm hr^{-1}, and 19 mm hr^{-1} respectively. The runoff responses from treated watershed were 8.5 mm yr^{-1} for 2015 and 9.6 mm yr^{-1} for 2016. This is lower than untreated watershed which responded17.3 mm yr^{-1} for 2015 and 15.3 mm yr^{-1} for 2016. The implemented conservation practices had a capacity of enhanced base flow in the treated watershed as compared to the untreated watershed. The runoff coefficients of the treated and untreated watersheds were nearly 0.04 and 0.1 in both periods of 2015 and 2016 respectively. The runoff and base flow were higher in 2016 than 2015. This is due to the higher rainfall were recorded in 2016. This figure shows that the implemented SWC practices reduced the runoff responses by two fold. Similarly, the practices reduced sediment yield from treated watershed, which delivered 2.4 ton $ha^{-1}yr^{-1}$ and 2.1 ton $ha^{-1}yr^{-1}$ for 2015 and 2016 of the rainy period respectively. This is lower than the untreated watershed that lost 6 ton $ha^{-1}yr^{-1}$ and 8.5 ton $ha^{-1}yr^{-1}$ in 2015 and 2016 respectively. The adopted SWC activities able to reduce the sediment yield by reducing the runoff volume and trapping the soil losses. The difference between runoff volume and sediment yield within the two watersheds were statistically significant at 5% significance level. This study examined that SWC practices can diminish soil and essential nutrient losses. However, it is important to investigate the long-term effects of SWC in the reduction of soil and nutrient losses.

Keywords: Nutrient depletion, Runoff, Sediment Yield, Treated, Untreated.

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ACRONYMS AND ABBREVIATIONS

DN	Dissolved Nitrogen
DP	Dissolved Phosphorus
ES	Ecosystem
FFW	Food For Work
H	Depth of Flow
Hcl	Hydrochloric Acid
IC	Infiltration Capacity
IR	Infiltration Rate
N	Nitrogen
Nc	Nutrient Concentration
N_{los}	Nutrient Losses
P	Phosphorus
Q	Discharge
RI	Rainfall Intensity
SSC	Suspended Sediment Concentration
SWC	Soil And Water Conservation
Sy	Sediment Yield
V	Volume

CHAPTER ONE

1 INTRODUCTION

1.1 Background

The degradation of land, which declines the quality of land, will remain a global challenge for the 21st century due to its negative impact on agricultural productivity (Tan, Lal, & Wiebe, 2005) and the quality of the environment. It has adverse effects on food security and the quality of life (Gashaw, Bantider, & Silassie, 2014). According to Eswaran et al. (2001) 3.6 billion hectares of land was lost annually due to adverse degradation in a global scale. Overall, the depletion of nutrients in the soil has been estimated at an average rate (kg/ha/year) 18.7, 5.1 N, P, and 38.8 K, which covers 59%, 85% and 90% of harvested areas respectively (Tan et al., 2005). According to Tan et al. (2005) total annual deficit of nutrients was 5.5Tg (1Tg = 10^{12}g) N, 2.3TgP, and 12.2Tg K, associated with global production losses of 1136Tg yr^{-1}. When the degradation occurs onsite where the soil erosion, nutrients losses and lots off site when the sediments are deposited (Eswaran, Lal, & Reich, 2001). Land degradation happens all over the world but it is a particular problem in parts of South Africa, and sub-Saharan Africa (Lal, 1998).

Ethiopia is one of the most endowed countries with an abundant natural resource from the horn of sub-Saharan Africa (Gashaw et al., 2014). However, the country visited by continuous natural resources degradation in a century (Berry, 2003; Temesgen Gashaw, 2014). The rate of land degradation exacerbated in the northwestern Ethiopian highland where almost 85-90% of the population depend on agriculture with 12million hectares of cultivated land (Amsalu & de Graaff, 2006; Grepperud, 1996). Its consequences can be affecting people and wildlife in different aspects (Desta, 2000; Temesgen Gashaw, 2014). When this happens, the plants and animals that live on the land are also harmed, or even wiped out, and people suffer due to low productivity (Taddese, 2001). Land degradation which is induced by soil erosion is the major factors responsible for the recurrent malnutrition and famine problems in Ethiopia (Bekele, 2003).

Soil erosion is the fundamental global problem of environmental quality and economic sustainability (Bewket & Teferi, 2009). About 55% approximately 2billion hectares of degraded soil in the world were caused by water erosion and thereby creates a threat to global food security (Senti, Tufa, & Gebrehiwot, 2014). Because of erosion, the yield of the world rain-fed agriculture decrease by about 29% over the next 25 years (Vlek, 2008). The value of annual production losses for some selected crops could over US$400 million in a global scale. Also, it is the bottlenecks for Ethiopian economic development (Stoorvogel & Smaling, 1998). Arable land reduction due to gully formation and expansion (Poesen, Vandaele, & Van Wesemael, 1996) resulted in crop yield depletion from time to time. The problems accelerated by rapid population growth, cultivation on the steep slope, expansion of production to marginal and fragile land, clearing of vegetation, and overgrazing (Amsalu & de Graaff, 2006; Eswaran et al., 2001). Half of the agricultural land affected and accounts 1.5-2 billion tons in an annual soil losses rate (Brhane & Mekonen, 2009; Taddese, 2001; Vlek, 2008). This resulting 1.5 million tons of grain reduction for each production period (Vlek, 2008). Ethiopia lost 137 tons ha^{-1} $year^{-1}$ top soil through soil erosion by water (Jan Nyssen et al., 2009).

Since, soil erosion is a natural hazard (Hyndman & Hyndman, 2010), which is difficult to stop and avoid for last. It is possible to control and reduce its adverse impact through the implementation of an appropriate soil and water conservation (SWC) measures. In Ethiopia, after the declaration of wildlife conservation and development policy, the government initiated to various studies and capacity building programs for massive SWC intervention (Herweg & Ludi, 1999). Various SWC measures have been adopted and implemented by the program of food for work (FFW) through government led a national campaign to control soil erosion by water (Z Adimassu, Mekonnen, Yirga, & Kessler, 2014; Nyssen et al., 2010).

Similarly, a series of SWC practices have been implemented in *Alekt Wenz* watershed by farmers through governmental led of a national campaign since 2012 (Birhanu & Meseret, 2014; Demelash & Stahr, 2010).

As the kebele experts and local farmers explained that, the practices were used to recover degraded land, improved pastureland, reduce soil erosion, sustain land productivity, and improve environmental quality in the northwestern Ethiopian highland of *Alekt Wenz* watershed.

The practice includes physical structures (terraces, stone-bund, check dam, and arc weir) and biological (native tree plantations, the establishment of pasturelands with a fence, Sesbania (Sesbania grandiflora), Vetiver grass (Chrysopogon zizanioides), and Elephant grass (Pennistum purpureum). In the study watershed, there is a limited scientific study to assess the extent in the effectiveness of implemented SWC activities on hydrological responses. However, Soil degradation impact in terms of soil losses, nutrient depletion, runoff generation in rate and volume were not investigated in the study watershed.

SWC practices could have a capability in reducing runoff generation in a rainy season (Z Adimassu et al., 2014), increase base flows of a catchment by improving infiltration rate of the soil, and as a result increase dry season stream flow (Huang & Zhang, 2004) and prevent Rivers from drying up earlier. Those practices reduced the problems of soil nutrient depletion and enhance the productivity of land (Khanna, 1997). Generally, it is believed that the impact of conservation practices on hydrological responses are control surface runoff (Z Adimassu et al., 2014), decrease soil erosion and reservoir sedimentation (Chakela, 1981; Ngetich et al., 2014) improving soil fertility of farmland, and improving agricultural production (Bewket, 2007; Wolka, 2014). Therefore, understanding the effects of conservation practices on the hydrological responses is play a crucial role either sustainability of existing conservation measures or providing a new intervention measure in a selected watershed. A scientific research was conducted on the effectiveness of SWC practices on hydrological responses in *Alekt Wenz* watershed using two experimental nested watersheds under different degree of treatments. In addition, this scientific study was examined stream flow response, suspended sediment concentrations, and dissolved and sediment-associated nutrient depletion in the study watershed under different degree of treatments.

1.2 Statement of the problem

One of the global environmental and economic problem is land degradation and its induced threat (Bewket & Teferi, 2009; Wang, Hapuarachchi, Ishidaira, Kiem, & Takeuchi, 2009). Land resources in the Ethiopian highlands are facing intense degradation (Abiy, 2009), which is largely a consequence of deforestation, agricultural land expansion and overgrazing (Z. Adimassu, Langan, Johnston, Mekuria, & Amede, 2017). This result significant environmental degradation, losses of biodiversity, reductions in agricultural productivity and services derived from ecosystems (Z Adimassu et al., 2014). The government of Ethiopia launched ecological restoration programs to restore degraded ecosystems services (ES) and mitigate human pressures on natural ecosystems, thereby improving the ES they provide as well as reversing biodiversity losses.

The ecological restoration program mainly focused on the construction of soil and water conservation (SWC) structures such as terraces and bunds on the hill slope and cultivated lands, gully treatments and stabilization as well as establishing enclosures on communal grazing lands (Demelash & Stahr, 2010). Accordingly, considerable soil and water conservation (SWC) measures have been adopted and implemented in Ethiopia including the study watershed with 87.6ha to arrest soil erosion by water. Even though those selected actions are undertaken, there is a major gap was observed during field visit about implementation, monitoring and investigating the long-term impact of the adopted SWC activities. Most studies almost focused on impacts of selected conservation practices on soil losses from a single selected watershed (Z Adimassu et al., 2014; Khanna, 1997)

However, there is a limited significant comparative study in relation with hydrological responses to SWC practices between treated and untreated watershed. Therefore, scientific research is crucially important to alleviate these problems. This scientific study realized the effectiveness of SWC activities on the hydrological response, by collecting hydrological data of streamflow, dissolved and sediment-associated soil nutrient, and suspended sediment yield for two data-recording periods (2015-2016).

The study was quantified soil and nutrient losses and compared hydrological variables between treated and untreated watershed by conducting a student t-test with 5% of significance level.

1.3 Significance of the study

Conservation of natural resources such as land, soil, and water has been a fundamental concern of Ethiopians to improve rural development strategy starting from the 20th century (Nyssen, Poesen, Moeyersons, Haile, & Deckers, 2008). Due to inappropriate implementation and poor sustainable management of SWC practices led to alarming rates of land degradation, soil erosion, environmental imbalance, and low production of feed, fiber, food, and fuel. Therefore, to eradicate degradation of natural resource and environmental imbalance understanding the effects of SWC practice on the hydrological responses of a given watershed is crucially important for the concerned body.

This scientific study will pay a contribution in providing technical information for sustainability of the existing SWC practices with some additional measure to treated watershed, and remark suitable and cost-effective conservation practice for the untreated watershed. Generally, this study will serve to provide information for other researchers who are interested in making a future study about the effect of soil and water conservation practices on hydrological responses to be undertaken.

1.4 Objectives of the study

1.4.1 General Objective

The general objective of the study was to investigate the effectiveness of soil and water conservation practices on hydrological responses in *Alekt Wenz* watershed found in northwestern Ethiopian highland.

1.4.2 Specific objectives

1) To compare the hydrological responses in the study watershed under treated and untreated sub-watersheds.

2) To quantify suspended sediment yield as a result of treated and untreated watersheds.

3) To quantify dissolved and sediment-associated nutrient losses and estimate the corresponding nutrient replacement costs.

1.5 Research questions

1. In what extent the adopted SWC practices affect the hydrological response in the study watershed?
2. Do SWC practices are effective in terms of runoff and soil loss reduction?

1.6 Scope of the study

Since it is impossible to cover the whole aspect of the study area with the given available time and resource and limit the boundary study area and scope of the problem to a manageable fashion. Hence, the study focused on the representative site of one watershed with treated and untreated nested watersheds from *Alekt Wenz* watershed found in *Farta* district. The two adjacent watersheds were assumed comparable in their overall characters of geology, soil type, climate, and relief. However, they are treated differently, one has intensive SWC practices and the other has limited in conservation measures. This scientific research was a concern mainly on the effect of SWC practices to the hydrological response particularly infiltration capacity, Streamflow, suspended sediment concentration, and dissolved and sediment-associated soil nutrients (P, N). In addition, the study compared the hydrological response between treated and untreated watersheds.

1.7 Limitation of the study

Obviously, due to the financial, labor, transport cost and accessibility during data collection, the study was not quantified the total soil and nutrient losses due to difficulties of bed load sediment transport measured. Constructing masonry weir instead of staff gauge for the untreated site is very important. It is better to see social part of the SWC practice for the study watershed. This study was conducted only in two-year data recording period to shows the effectiveness of conservation practices in *Alekt Wenz* watershed. This study did not consider the linkage between watershed characteristics and hydrological responses.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Hydrological responses

The way a watershed reacts when it was subjected to a rainfall event is called hydrological response or it is a reaction of any watershed to an input of precipitation according to its physical characteristics like infiltration, runoff, and sediment yield. Precipitation may be moving into a stream from overland flow or as a groundwater flow. The stream flow, which gauged at a particular point, is a function of integrated response to temporal and spatial variation and result in hydrograph. Studying the hydrological response of the watershed to different treatment is very important to understand the hydrological cycle processes (Hewlett & Hibbert, 1967), quantifying soil losses, nutrient losses, and the corresponding economic crisis.

2.2 Infiltration capacity

Infiltration is the process by which water enters into the soil from the ground surface and it was governed by two forces: gravity and capillary action. The rate of infiltration is determined by characteristics of the soil including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity all play a role in controlling infiltration rate and capacity (Watson et al., 1995). For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly (Horton, 1941). Vegetation creates more porous soils by both protecting the soil from raindrop impact, which can close natural gaps between soil particles, and loosen soil through plant root action. This is why forested areas have the highest infiltration rates of any vegetative types. Soil infiltration measurement is estimating the rate of water such as rainfall moves from ground surface to the soil through gravity action and measured by single or double infiltrometer in relation to the purpose (Saleem, 1997).

Single ring infiltrometer has maintained the nature of the lateral flow of water while double ring infiltrometer is restricted lateral flow. During conducting the measurement the operator records how much water goes into the soil for a given five-minute time interval period for ten-rounds.

2.3 Suspended sediment yield

Sediment-discharge measurements usually are available on a discrete or periodic basis to estimate sediment yield from suspended sediment concentration–discharge rating curve. With a known volume of a water-sediment mixture, SSC data are produced by measuring the dry weight of all the sediment (B. J. R. Gray, Glysson, Turcios, & Schwarz, 2000; Yusop, Okuda, Hashim, Kondo, & Said, 2005). There are two approaches to obtaining values describing sediment loads in streams. One is based on direct measurement of the quantities of interest, and the other on relations developed between hydraulic parameters and sediment transport curve formulation (J. R. Gray & Simões, 2008). Sediment concentration and runoff velocity have a linear relationship during the rainy season, but the base flow is sediment free. In Ethiopia, most cultivated fields are plowed during rainy season sediment concentration is transport limited later in the non-rainy season sediment concentration is sourced limited (Tilahun, 2012). Also, most models which assume the source of erosion is of all portion of the steep watershed and rainfall intensity is a driving force. Models are inapplicable to estimate sediment yield in a humid area with well-structured soil, rainfall intensity is less than infiltration capacity, and erosion is obtained from degraded land (Tilahun, 2012). The degraded and saturated area losses higher sediment, but the saturated area with vegetation deliver lower sediment than the degraded area that is bare (Steenhuis et al., 2012).

2.4 Nutrient concentration–Discharge relationship (C-D)

The nutrient concentration highly variable in a seasonal pattern in relation to discharges fluctuation, in time and space as the discharge increase there is an increase in concentration and it may decrease (Z Adimassu et al., 2014).

There is a positive strong correlation between NO_3-N to the corresponding discharge of the stream, and suggest that low discharge results in low NO_3-N concentrations, while high discharge also results in high nitrate concentrations (Roland Stenger1, 2014).

However, point sources of nutrient concentration affect the positive relationship through resulting high NO_3-N concentration with low discharge. Phosphorus and discharge related negatively, i.e. increasing discharge with decreasing concentration due to ground water contribution and higher affinity of suspended sediment to absorbs phosphorus nutrients (Bertol et al., 2003).

Separating base flow from storm flow is very important to explore the link in discharge and concentration of nutrients. The base flow of the rivers characterizes the relatively steady with the contribution of the groundwater system. Whereas the dynamic quick flow is mainly due to near-surface flows, like surface runoff, interflow, and artificial drainage, but can also contain contributions from the groundwater system (Haileslassie, Priess, Veldkamp, Teketay, & Lesschen, 2005). Obviously, response quick flow in nutrient concentrations to land management or land use changes more quickly than those in base flow (Bertol et al., 2003; Ngetich et al., 2014).

2.5 Soil erosion and fertility depletion status in Ethiopia

Soil fertility depletion particularly affected by soil erosion and as the main biophysical limiting factor for rising per capita food production in the majority of an African country (Yusop et al., 2005). Ethiopian small farmers, whose livelihood is dependent mostly on agriculture with unchecked soil fertility decline results in a major threat to economic development. The higher demographic pressure, poor planning and use of land, the dependence on agriculture as a source of subsistence, and deforestation, over-grazing, expansion of the agriculture to marginal land and steep slopes, results in the decline of the agricultural productivity and degradation of the environment (Steenhuis et al., 2012). Nutrient mining means the net losses of plant nutrients from the soil or production system due to a negative balance between nutrient inputs and outputs through soil erosion (Stoorvogel & Smaling, 1998).

Guzman (2011) estimates annual sediment yields during run-off events were 5.4ton ha^{-1} yr^{-1} for Andit Tid, 22.5ton ha^{-1} yr^{-1} for Anjeni and 8.8 $tonha^{-1}$ yr^{-1} for Maybar watersheds. Ethiopia loses 1.5 billion tons of soil per year from the Highland by soil erosion, which resulting 1.5 million of crop production losses in each year (Taddese, 2001).

2.6 Soil and water conservation practices in Ethiopia

In Ethiopia Soil and water conservation practices are very old as evidenced by the existence of traditional measures in some parts of the country such as *Konso* region (Sauerborn, 2001). Different structural like, terracing was developed in *Tigray*, North *Shewa*, and highland of Konso, and stone bund also used as water harvesting technology (Nyssen et al., 2010; Sauerborn, 2001), biological like agroforestry, intercropping for increasing of farm yield used to reduce raindrop impact results low soil detachment and runoff generation (Gizaw Desta Gessessea, 2009; Sauerborn, 2001). Recently different SWC practices are implemented in the northwestern Ethiopian highland including the study watershed. Soil conservation refers to the protection of fertile top soil from erosion by wind and water and the replacement of nutrient in the soil by means of cover crops, terracing, contour farming crop rotation etc. (Karlen et al., 1997; Stamey & Smith, 1964). SWC can be defined as the combination of the appropriate land use and management practices that promotes the productive and sustainable use of land and control erosion and other forms of land degradation (Bekele, 2003; Unger & Agassi, 1995). Generally, soil-water conservation includes all forms of human action to prevent and treat soil degradation (Rasmussen et al., 1998). The aim of soil-water conservation is to facilitate optimum level of production from a given area of land while keeping soil losses below a critical value and protections of the life-supporting capacity of soils such as, soil quality, soil depth, soil structure, water holding capacity and soil productivity (Arshad & Martin, 2002; Habtamu, 2014).

2.7 Impact of conservations on runoff and soil losses

It is believed that the hydrological impact of soil conservation practices is to reduce and delay surface runoff, and hence, decrease soil erosion (Nyssen et al., 2010). The soil and water conservation practice resulted in a clear decreasing trend in annual surface runoff and increase soil moisture content (Huang & Zhang, 2004). The impact of construction of terraces and dams on hydrological behavior is to reduce overland flow and alter the temporal distribution of stream flow.

Terraces can significantly reduce overland flow and increase soil moisture (Haith & Loehr, 1979; Herweg & Ludi, 1999). The soil and water conservation measures resulted in a significant reduction of runoff volume and sediment loads (Dagnew et al., 2015). Maintain existing measure is essential for the long-term sustainability of the practices. This is because the constructed ditches of bunds were trapped sediment losses. Due to the expansion of gully formation, the watershed delivers high sediment concentration to the watershed. Gully erosion controlling and treatment must be a part of concern in large-scale soil and water conservations program (Dagnew et al., 2015).

Soil and water conservation practices have an impact on reducing runoff generation, soil and nutrient losses (Z Adimassu et al., 2014; Ngetich et al., 2014). As Dagnew et al. (2015) studied that implementation of SWC practices had a capacity to reduce the volume of runoff during the study period. According to Dagnew et al. (2015), 32% and 20% of runoff have occurred from 2010 and 2011 monsoon of rainfall, but the values were diminished to 10% and 11% after the implementation of SWC during 2012 and 2013. This was happened due to a large amount of rainwater infiltration in the furrow, which improved the base flow response of a watershed.

Sediment concentrations were higher in the beginning of rainy monsoon because during this time new rills formed from plowing of land. Sediment load was decreased after the implementation of SWC activities. The average flow suspended sediment concentrations were 22g/l before SWC implemented while 14g/l after SWC practices were implemented (Dagnew et al., 2015). As Adimassu et al. (2017) stated that SWC practices have an ability in reducing the losses of soil organic matter (OM), and soluble and sediment associated soil nutrients.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Description of study area

3.1.1 Location

The *Alekt Wenz* watershed found in *Farta* district, South *Gondar*, *Amhara* Regional state, between 38°7'0"E to 38°8'0"E Longitude and 11°46'0"N to 11°48'0"N Latitude. The watershed has an area of 532.44ha and it nested sub-watershed of Ribb, Lake Tana Basin, Ethiopia. The *Alekt Wenz* watershed has two adjacent nested watersheds. The adjacent watersheds were treats differently. The one with intensive SWC works and closure area called treated. The other watershed with sparse SWC activities and enclosure called untreated (*Figure 3-1*).

3.1.2 Climate

Based on the agro-climatologically classification, the area characterized by *Dega* climate type. In terms of climatic condition the study area has an average annual minimum, maximum and mean temperatures of 9.7, 22, 15.5°C respectively. The rainfall pattern is unimodal and ranges from May to September. The annual rainfall ranges between 856.8 and 1569.9 mm with a long-term average of 1301mm. (source: Debre-Tabor-Gassay meteorological station).

3.1.3 Topography

The study area topography characterized by extremely high relief and over 70% of the land extends from gently to hills landscape (*Figure 3-2*). The elevation ranges from 2,779m to 3000m above sea level (m.a.s.l). This landscape was exposed for serious soil erosion in the past period until the soil and water conservation practiced adopted and implemented. *Table (3-1)* shows that the drainage density and form factor have equal value for both watersheds. Even though the length of flow path, area, and the slope was higher for the untreated watershed, their difference was not significant.

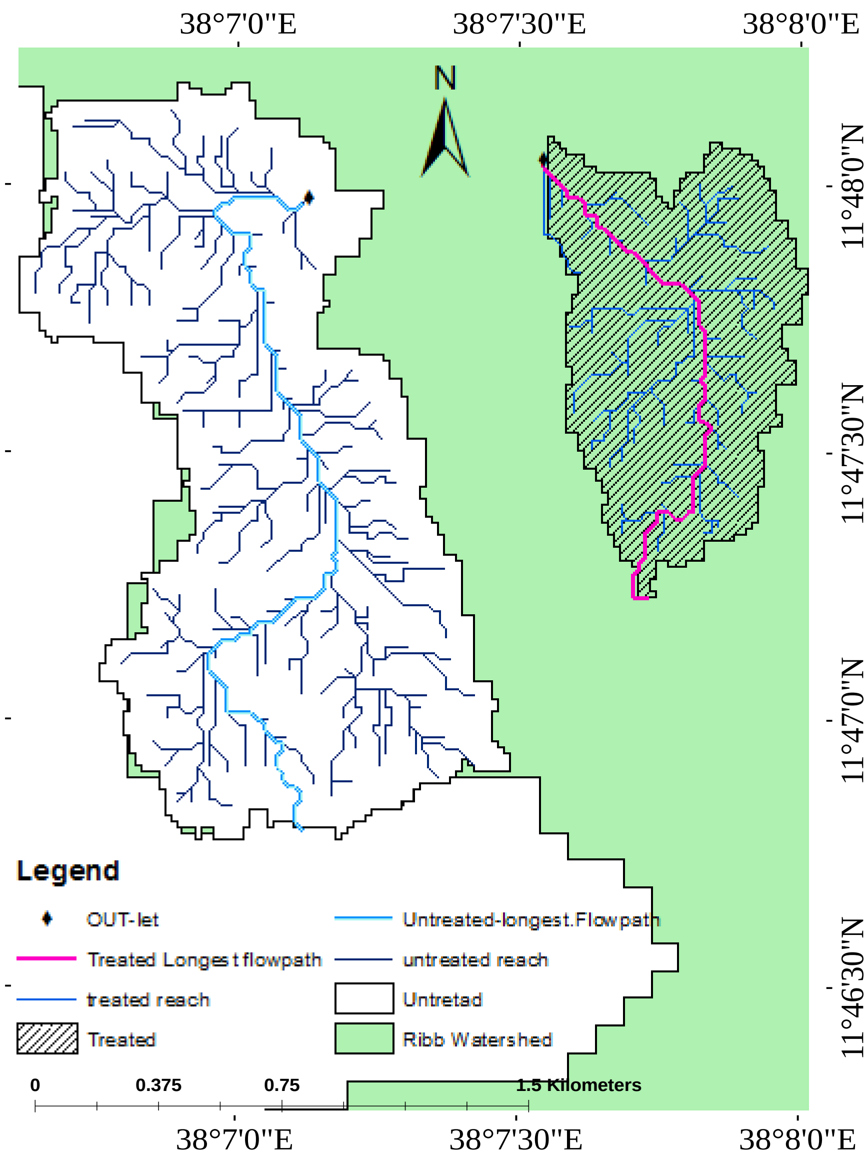

Figure 3-1: Hydrological setting and location of the *Alekt Wenz* watersheds.

Table 3-1: Watershed Characteristics of the study area.

	Watershed parameters						
watersheds	Area (ha)	Slope (Degree)	Longest flow path (km)	Elevation difference (m)	Drainage density L_{st}/Area (m^{-1})	Form factor (Area/L^2)	Specific catchment area (m2/m)
Treated	87.6	5-35	2.12	116	0.012	0.2	413.96
untreated	234.7	5-42	3.38	157	0.012	0.2	684.62

Most scholars agreed that slope, form factor, specific catchment area (SCA), and drainage density has a linear relationship with runoff generation, but the flow path length and the area have inversely correlated (Zhang, Shi, Fang, & Guo, 2015). The variation of slope between treated and untreated watershed is insignificance because the average slope is 8.9^{o} and 9.4^{o} respectively

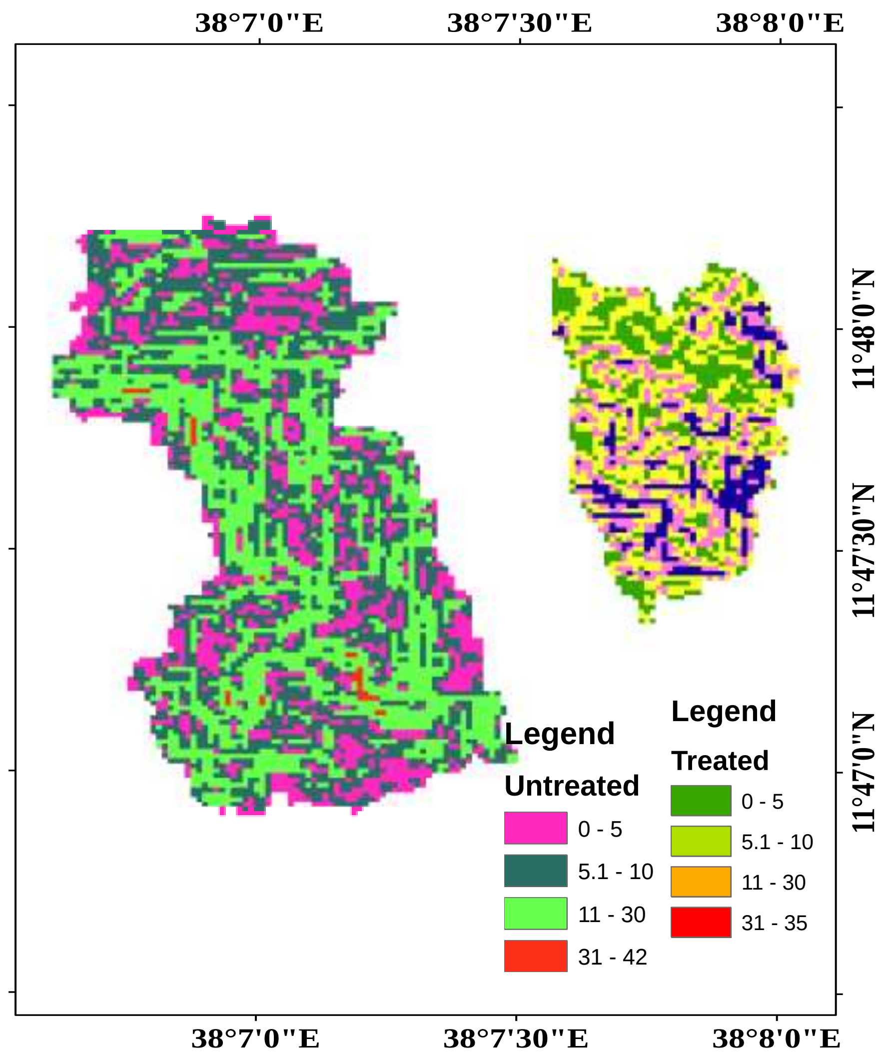

Figure 3-2: Slope class of the study watershed.

3.1.4 Land use land cover

The land use/land cover is one of the factors that control soil erosion in different aspects. The study watersheds have cultivated, enclosed-pastureland, grazing, and forest area are the dominant land uses and land cover. Cultivated and grazing land facilitated erosion, while forest and enclosed-pastureland reduce runoff generation and soil erosion. As *Table 3-2)* shown that the percentage of land use/land cover of the two sub-watersheds. Even if there are difference value of area coverage, but the difference of percentage coverage is insignificant at 5% level of significance level t-test *(Table 3-3).*

Table 3-2: land uses/land covers distribution of study watersheds.

Land use land cover	Treated(ha)	%	Untreated(ha)	%
Cultivated	29.4	34	126.7	54
Grassland /enclosed/	19.8	23	1.7	1
Forest	26.3	30	70.9	30
Grazing	11.4	13	35.4	15

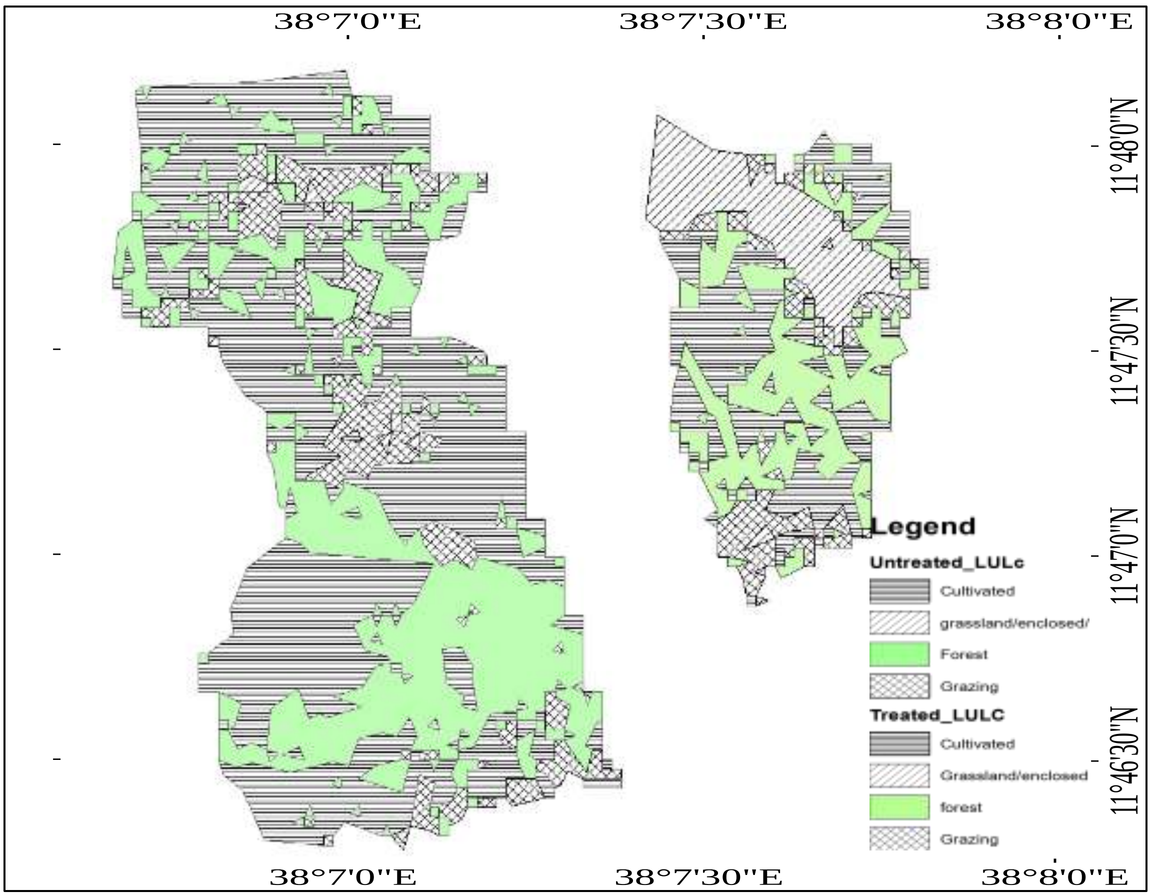

Figure 3-3: Land use/land covers map of the study watersheds.

This land use/land cover map was prepared by image classification, which downloading image from earth explorer, and taking ground truth from google earth to check the real land use/land cover in the field.

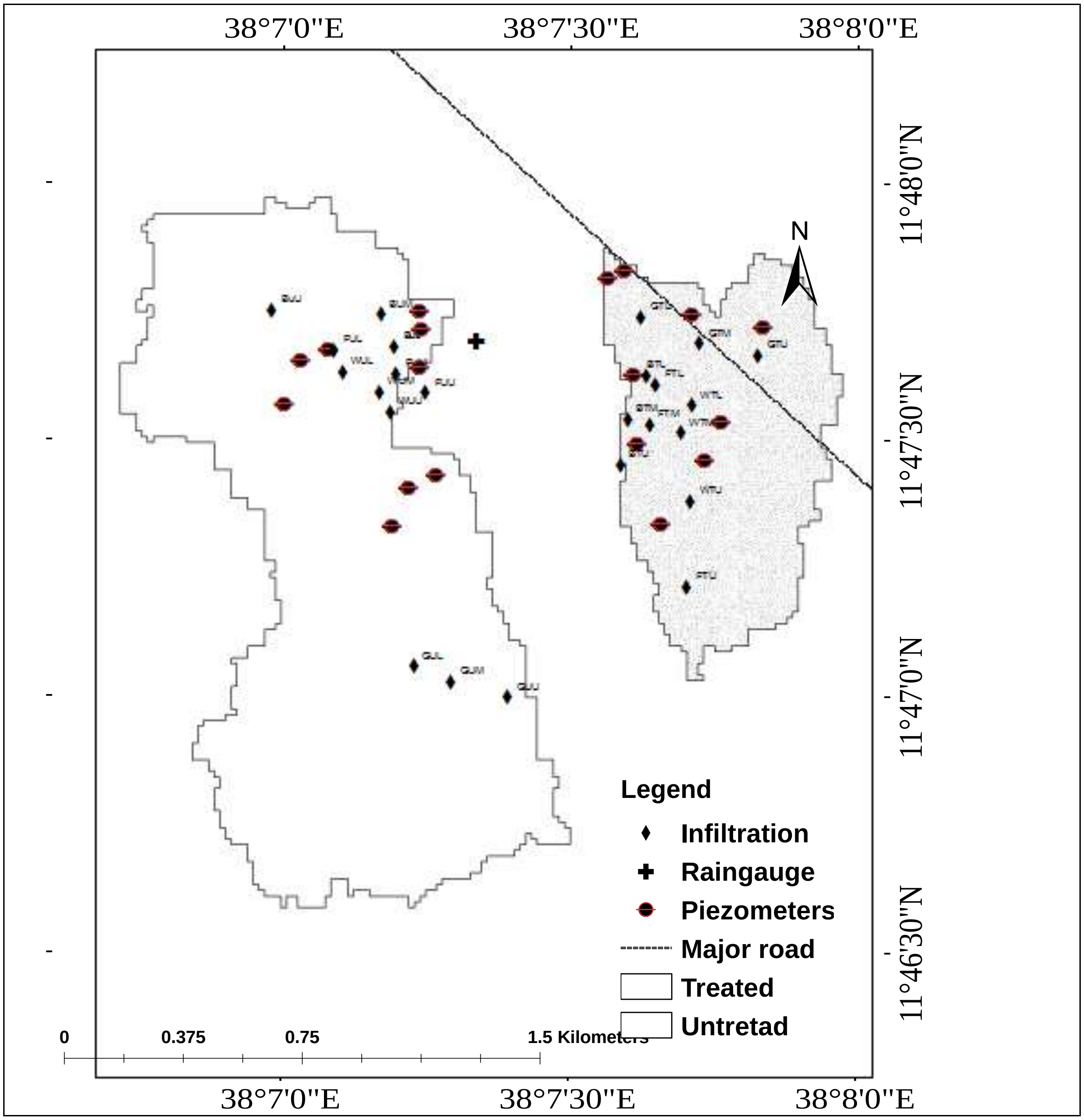

Figure 3-4: Location of rain gauge, piezometer, and infiltration on *Alekt Wenz* watersheds.

Table 3-3: T-test on the ratio of variances on land use/land cover.

Ratio	0.165
F (Observed value)	0.165
F (Critical value)	15.439
DF1	3
DF2	3
p-value (Two-tailed)	0.173
alpha	0.05

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0. The risk to reject the null hypothesis H0 while it is true is 17.27%. Therefore, the study was assumed the effects of land use/land cover on the hydrological response on the two sub-watersheds were comparable. This is because the variation of land use/land cover is insignificant.

3.1.5 Farming system

The farming system is a mixed farming (growing crops and rearing animals). Crop production is mostly rain fed and subsistence-oriented. Livestock plays a significant role in the farming system as a source of plowing/draft/ power, food, and cash. Most of the upper and middle parts of the untreated watershed are used for cultivation and grazing. The lower part of the watershed is mostly saturated during the rainy season. It is also covered with grass. These areas of the watershed serve as grazing land in untreated and cutting-carrying practice is applying in treated one. The areas at the upper and middle slope are continuously cropped with cereal crops and are dominant. Most of the cultivated fields are commonly planted with bean, wheat, pea, potato, and barley is grown in study watershed.

3.1.6 Soil and water conservation practices on the study watershed.

This scientific research was the longitudinal type of research design in which frequently data collection for extending time duration of two years (2015-2016). It was also experimental due to the study conducted on a comparison of two adjacent watersheds under deferent SWC practices.

To apply this design the study select two experimental sub-watersheds by checking the variation of land use/land cover and geomorphological characteristics. By employed t-test on the ratio of variance on land use/land cover, which results insignificant variation between treated and untreated watersheds. To earn the specific objectives, the study was designed two adjacent watersheds, which are treated differently.

Treated Watershed**:** This watershed treated with different SWC activities. Physical structures including stone /soil/ bund, gabion, arc weir, and terrace. Biological measures including, pastureland improvement, Sesbania (Sesbania grandiflora), Vetiver grass (Chrysopogon zizanioides), and Elephant grass (Pennistum purpureum), fencing /closure/ and applying cutting and carrying method in order to reduce animal disturbance of the treated watershed.

Untreated watershed**:** The 'untreated' watershed has been practiced with a smaller amount of SWC practices with a sparse proportion of native grasses. Intensive agriculture was practiced from upstream to downstream, and it is the enclosure. Overgrazing and animal trumping are a common problem as compared to treated watershed. Both catchments are instrumented to measure rainfall, runoff and soil losses, infiltrations capacity, and dissolved and sediment-associated nutrient.

3.2 Methods of data collection

To address the specific objectives, rainfall, infiltration capacity, streamflow, suspended sediment concentration (SSC), dissolved and sediment-associated nutrient were directly collected for the rainy months of the monsoon (June to September) during 2015 and 2016. The other months of rainfall and erosion are insignificant and irrelevant for evaluating the hydrological responses because of SWC practices implementation. Spatial information of watershed outlet location, rainguage, piezometers, and soil and water conservation structures, and location of infiltration measurement were conducted using Garmin-76 GPS. Data like temperature, rainfall except 2015 and 2016, and soil type were taken from the secondary source.

Digital elevation model (DEM) 20mX20m resolution was used to delineating the study watershed and extract slope, SWC implementation layout, area coverage by SWC activities.

3.2.1 Rainfall Measurement

During 2015 and 2016 of data recording period, five-minute resolution rainfall data was collected with the automatic recording tipping bucket type rain gauge (*Figure 3-4*). It was installed on the common border of the two nested watersheds during the rainy season (early June to late November). The rainfall data were analyzed in terms of depth (mm), duration (hr.), and intensity (mm/hrs.) and it is important to calculate the weighted runoff coefficient of the treated and the untreated watershed. This data was used to compare daily runoff depth with daily rainfall event and the same time to compute corresponding runoff coefficients.

3.2.2 Infiltration Measurement

In this study, infiltration rate was measured in September 13/2015 at different land use/land cover on upper, middle, and lower portion of the study watershed (*Figure 3-4*). Using single ring 25cm diameter infiltrometer to allow lateral flow and approach the natural state of the watersheds. The constant infiltration rate at the end of the test was used as the infiltration capacity (IC) of the watershed. The result of IC was statistically analyzed with t-test to realize and compare the infiltration rate of the watershed under different treatments.

Figure 3-5: Infiltration conducting in the study watersheds.

3.2.3 Perched groundwater level measurements

The perched groundwater levels were monitored below the surface of the earth. The perched groundwater fluctuation measurement conducted by installing 18 piezometers (Φ=5cm) with six transects. The piezometers were installed by considering slope (lower, middle, and upper) class of the *Alekt Wenz* watersheds (*Figure 3-4)*. The measurement is done everyday morning (9:00). The readings were told us the position of the water table below the earth surface. This data is important to shows the saturation state of the watersheds under different degree of treatments.

3.2.4 Streamflow (Discharge) Measurement

Measurement of flow depth and surface velocity with a floating method was conducted on the two gauging stations.

The gauging stations were instrumented by rectangular weir for treated and staff gauge for the untreated watershed. The untreated watershed has large depth and width. Due to this, it is not economical to installed weir. The runoff may over turn and wiped away the weir. The discharges were computed by using area-velocity measurement method. The method was inserted 31m and 21m for 2015 and 8m and 5m for 2016 upstream from the outlet of the staff gauge and masonry rectangular notch weir respectively. The cross sections were defined by 30cm depth and 60cm width for weir. The staff gauge cross section was defined using area divided method. The method, divided the width of the stream with 10cm interval and measures each corresponding depth. The elapsed time required for the float to reach the outlets was recorded.

The process was conducted by two pairs of data collectors at the staff gauge and at the weir outlet. The measurements were done every 20 minutes following the commencement of rainfall-runoff events to the end of storm period. Storm period commonly understood as the time elapsed between the beginning and the ending of a single rainfall-runoff event (Tilahun, 2012). The data recording continue until the runoff become sediment free. The stream discharge computed by using the defined cross-section area (A) and measured stage (H). A power function of stage-discharge rating curves developed to get continuous discharge data from treated and untreated watersheds.

3.2.5 Suspended Sediment Concentration (SSC) Measurement

Quantification of the total sediment yield from the watershed computed through suspended sediment concentration (SSC) analysis. That means storm samples fetched every 20 minutes until the flow dropped and the flowing water turned clear. Between three and seven samples of one-liter bottles collected during most of the storm event. By using standard filter paper with the 18cm diameter to filter the SSC and mass of sediment per liter of discharge were determined by weighing the mass of oven drying sediment with electronics balance after drying in oven dry by $105^{\mathbf{0}}$c over 24 hours.

3.2.6 Nutrient losses Measurement

Time-integrated sampling technique was conducted which made by mixing equal volumes of water collected at a sampling station at regular time intervals. The soluble nutrients that are lost during the rainy time were measured in water quality laboratory. The nutrient data particularly dissolved phosphorus (DP) and dissolved nitrogen (DN) organized by making a composite of one storm's samples and taking 100ml after preserving with 2ml Hydrochloric acid (HCl) to conserve transport losses. Sediment-associated nutrients extracted in Amhara Regional Agricultural and Research Institute (ARARI) laboratory. One-month composite sediment data taken and extract the associated nutrient by ppm for P and percent for N.

3.3 Method of data analysis

The collected data was organized, analyzed, and made a descriptive statistics. It was used to establish best-fit stage-discharge and sediment-discharge rating curve. Also, it used during quantifying losses and comparing treated and untreated watersheds by t-test to show their statistical significance with 5% significance level. To develop best fit stage-discharge rating curves the surface velocities (multiplied by two-third to compute the mean velocity) and multiplied by the defined cross-sectional area for both gauging stations of all the 20-minute flow depths. A stage-discharge rating curve with a power function was employed to develop the relationship between flow depth (H), suspended sediment concentration (SSC) and storm discharge (Q).

3.3.1 Stage-discharge rating curve

To get a continuous recording of hydrological data, and reduce the time for organizing data from both gauging stations the following power function stage-discharge rating curve was employed for the two nested watersheds.

$$Q = aH^b \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots eq3.1$$

Where: Q = discharge (m^3/sec)

H= stage or depth of flow (cm) a, and b are constants

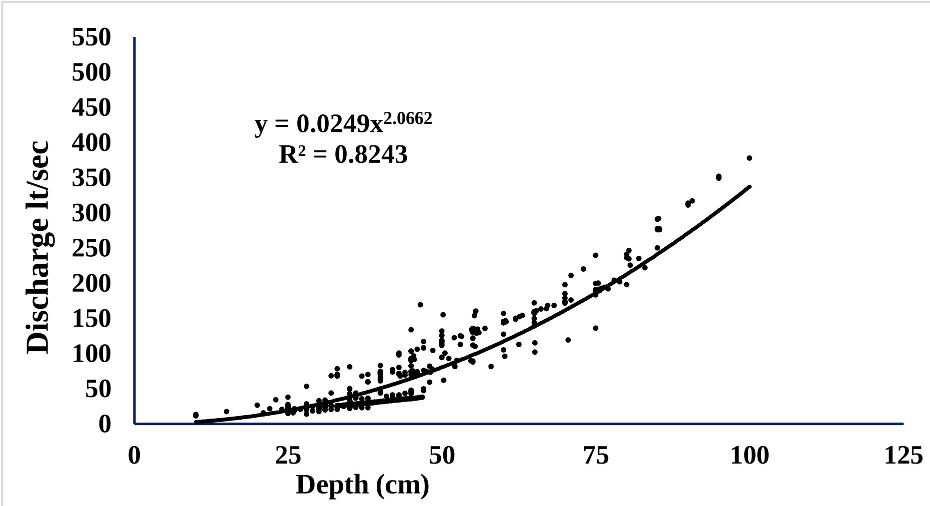

Figure 3-6: Stage-Discharge rating curve for the untreated watershed.

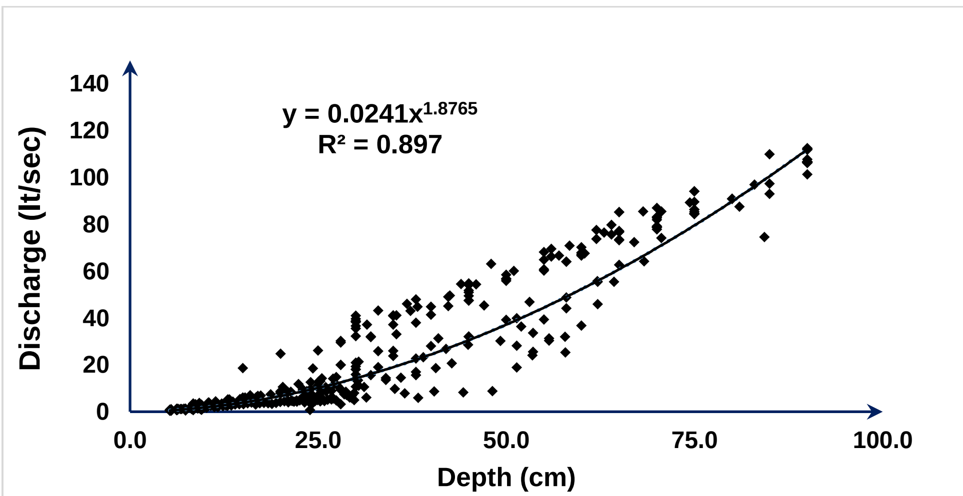

Figure 3-7: Stage-Discharge rating curve for the treated watershed.

The developed stage-discharge rating curve has a higher coefficient of correlation (R^2) which described a high degree of linearity between stage and discharge of a watershed. In a rainy season, the higher runoff occurs during higher rainfall time.

3.3.2 Suspended sediment concentration (SSC)-discharge (Q) rating curve

Suspended sediment concentration (SSC)-discharge (Q) rating curve was developed from the collected data during rainfall. When there was no rain, the recession flow was small and discharge and sediment measurements were taken as base flow. The 20-munite storm data converted into the daily flow by using Microsoft Excel add-on and XLSTAT-2017 and sediment yield (mg) was computed through multiplying SSC (mg/l) by the corresponding storm discharge (lit), the same method was used for and nutrient losses from both watersheds (kg/ha).

$$Sy = SSC * V$$

Where:

$Sy = sediment\ yield$

$SSC = suspended\ sediment$ concentration (mg/l)

$V = volume\ of\ runoff\ (liter)$

3.3.3 Nutrient losses

In the study watershed, artificial fertilizer applied at the beginning of the rainy season for wheat, barley, potato, bean, and pea to increase their production.

During rainfall period, the dissolved nutrients washed-out from different parts of the watershed, convey by surface runoff and reached the streams. The dissolved nutrient losses from the watershed under different treatment was quantified, and to get a number of nutrient losses multiplying nutrient concentration (mg/l) by volume of runoff (l), and divided by the watershed area (ha). The procedure is undertaken during testing of dissolved nutrient (P and N) as follows:

Test procedure for dissolved phosphorus

Agricultural fertilizers normally contain phosphate minerals and phosphates. Also, arise from the breakdown of plant materials and from animal wastes.

Phosphates can enter watercourses through a variety of routes-particularly domestic and industrial effluents and run-off from agricultural land. The Palintest phosphorus-phosphate LR test provides a simple method of measuring phosphorus-phosphate levels. In the Palintest phosphate LR method, the phosphate reacts under acid conditions with ammonium molybdate to form phospho-molybdic acid. This compound reduced by ascorbic acid to form the intensely colored 'molybdenum blue' complex.

A catalyst incorporated to ensure complete and rapid color development, and the inhibitor used to prevent interference from silica. The reagents provided in the form of two tablets for maximum convenience. The test simply carried out by adding one of each tablet to a sample of the water. During dissolved phosphorus testing, 10ml of runoff sample was used. Phosphate LR-1 tablet was added. By using spatula crushed the tablet and mix to dissolve. Then phosphate LR-2 tablet added, crushed, and mixes to dissolve again. Stand 10minute to allow the full-color development of the test sample. After full-color development, select phot28 on photometer and taking the reading in mg/l of phosphorus and phosphate.

Test procedure for dissolved Nitrogen

Nitrates enter water system from the breakdown of natural vegetation, the use of chemical fertilizers in agriculture and from animal manures. The Palintest nitrate test method provides a simple test for the nitrate-nitrogen nutrient. In the Palintest nitrate test method, nitrate first reduced to nitrite, the resulting nitrite then determined by a diazonium reaction to form a reddish dye. The reduction stage carried out using the unique zinc-based nitrate test powder, and nitrate test tablet that aids rapid flocculation after the one-minute contact period. The test conducted in a special nitrate test tube of graduated sample container with hopper bottom to facilitate settlement and decanting of the sample. Fill the nitrate test tube with the sample to the 20ml mark. The nitrite was resulting from the reduction stage, which determined by reaction with sulphanilic acid in the presence of N-(1-naphthyl)-ethylene diamine. This forms a reddish dye. The reagents provided in a single Nitricol tablet that simply added to the test tube with the 10ml solution. The intensity of the color produced in the test is proportional to the nitrate concentration and is measured using a Palintest Photometer. Stand for 10 minutes to allow full-color development and select Phot23 on Photometer for result as mg/l of N-NO3.

Sediment-associated nutrient extracted from the total sediment load of the monthly composite.

$$Nlos = Nc * Sl \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. eq\ 3.2$$

Where:

$Nlos$ = nutrient los (mg)

Nc= nutrient concentration (mg/ton)

Sl= sediment load (ton)

To compute the amount of nutrient extract from sediment, multiplied phosphorus content (ppm) and nitrogen content (percent) by their corresponding sediment load. The data was important to realize and quantified nutrient losses from the watersheds under different treatments.

The economic value that the farmers incurred to replace a number of nutrient losses due to runoff computed based on the price of commercial fertilizers from the local distribution agency see (*Table 4-3 and Table 4-4*). The context of the distribution system, farmers purchase commercial fertilizer from the distribution agency. There is two commonly used the payment system that the farmers and supplier agreed, which is payment of 50% at the time of acquisition, and the remainder with credit of earning an interest rate of 12.5% per annum (Ayele et al., 2015).

Mostly the farmers used UREA and DAP with the proportion of N and P for UREA, (46:0:0) and Diammonium Phosphate (DAP), (18:46:0) in fertilizer analysis system of (N: P: K) ratio, the ratio indicates that 46% of N in UREA and DAP contain 18% N, 46% P_2O_5 and 20% available P. The economic cost value per 1Kg of N and P were computed as follow:

$$Cost\ of\ Nitrogen = \frac{Price\ of\ 1kg\ UREA}{N\ content\ in\ UREA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots eq\ 3.3$$

$$Cost\ of\ Phosphorus = \frac{[\boldsymbol{priceof1kgDAP} - (\boldsymbol{priceof1kgN} * \boldsymbol{Ncontent})]}{\boldsymbol{AvailableP}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots eq\ 3.4$$

The average direct purchase price of 100kg of UREA $70 and DAP $100 in the study period (2015). The local distribution system provided 50% of the purchase cost and 50% on credit. Also, the price of UREA and DAP including the credited cost were $74.4 UREA and $132.5 DAP per 100kg. Depending on the value the estimated replacement cost for 1kg N was $1.6and available P $5.2.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Rainfall intensity and infiltration rate

The study watershed received an annual rainfall of 665 mm for 2015 and 795 mm for 2016. The maximum rainfall intensity was 93.6 mm hr^{-1} for 2015 and 91.2 mm hr^{-1} for 2016. The largest number of rainfall intensity occurs in July for both data recording periods that is 549 for 2015, 775 for 2016. To show the relationship between rainfall intensity and infiltration rate, spatial average infiltration rate and exceedance probability of rainfall intensity were used (*Figure 4-1*). The steady state infiltration rate for treated watershed ranges from 7 mm hr^{-1} to 122 mm hr^{-1} and for untreated watershed ranges from 5mm hr^{-1} to 90 mm hr^{-1}. (*Appendix A table2*) show the median infiltration rate from all 24 measurements were 22 mm hr^{-1} for treated and 19 mm hr^{-1} for untreated. This value showed that the SWC activities enhance infiltration rate in the treated watershed than the untreated one. To compare rainfall intensity with infiltration rate, median infiltration rate, and exceedance probability is meaningful parameters (Tilahun, 2012). As *Figure 4-1*) shows that the median infiltration is exceeded 6% in 2015 and 7% in 2016. Only 6% and 7% of the time infiltration rates were exceeded by rainfall intensity. This means, 94% and 93% of the time, infiltration rate exceed rainfall intensity. Therefore, rainfall intensity is not as such important. It is only important 6% of the time. This figure showed the infiltration excess runoff generations were 6% and 7%, but the other 94% and 93% were saturation excess in 2015 and 2016 data recording periods respectively.

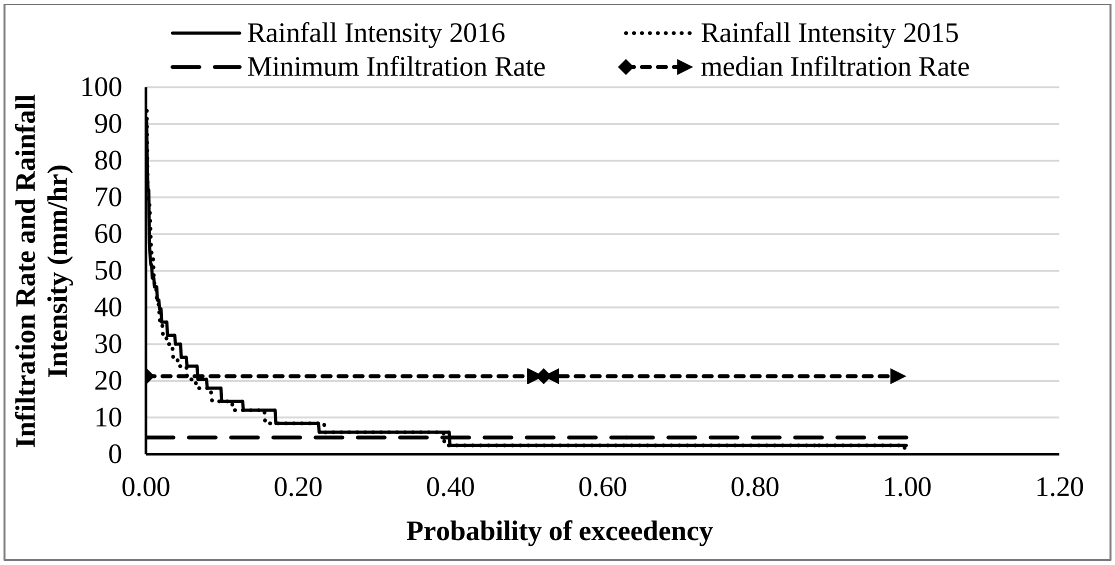

Figure 4-1: The exceedance probability of the average intensity and median infiltration rate for the *Alekt Wenz* watersheds in 2015 and 2016.

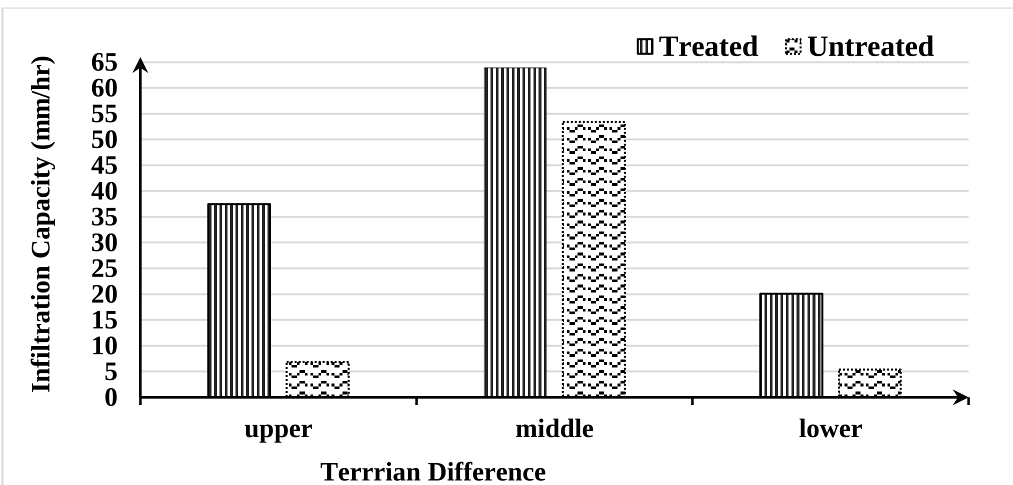

Figure 4-2: Infiltration capacity versus slope difference for the treated and the untreated watershed.

Figure (4-2) illustrate that the maximum infiltration occurs in the middle parts of both watersheds, this is due to the upper part was the steep slope and the lower part due to all the soil void space occupied by water/saturated.

Therefore, the watershed with gentle and unsaturated has higher infiltration rate than steep unsaturated and lower saturated.

4.2. Perched groundwater level

Groundwater level dynamic was measured from the installed piezometers from treated and untreated watersheds. Water table level was rise during August, and decline during September. The average water level below the surface was 0.43 meter (m), 0.83 m and 1.14 m for lower, middle and upper slope of treated watershed respectively. During early August, the soil becomes saturated; results from water level rise up and reach near the surface. For untreated watershed, the average water level below the surface was 0.54 m, 0.70 m, and 0.77 m for lower, middle, and upper slope respectively. Piezometer's water level in the untreated watershed more fluctuate depend on the rainfall amount than treated watershed, this is due to the rainfall in the treated watershed has a chance to infiltrated and delay the fluctuation *(Figure 4-3 and Figure 4-4).*

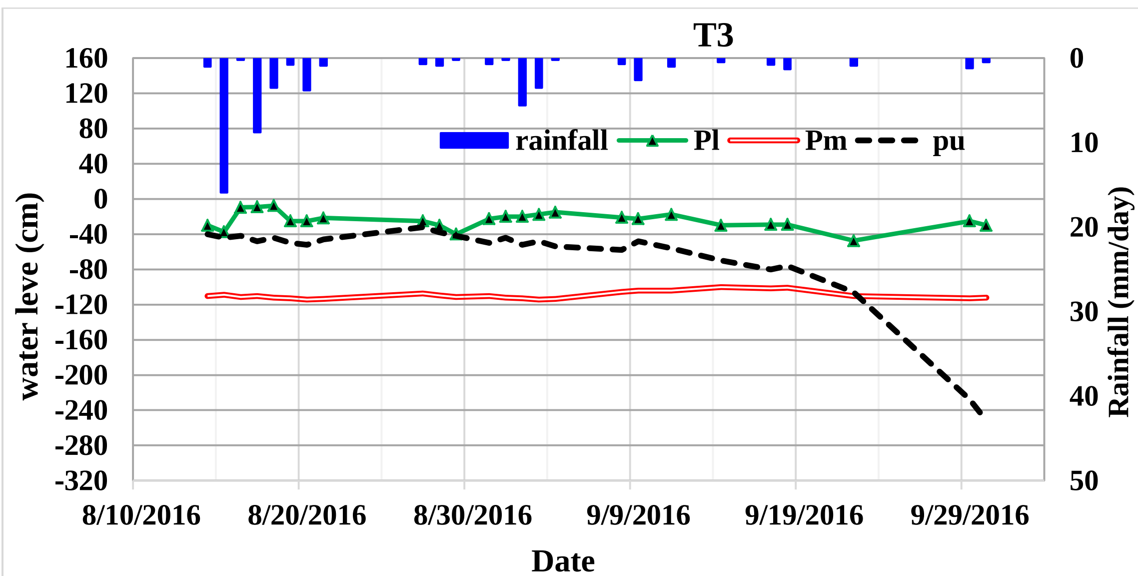

Figure 4-3: Water level measured from T3 (transect three) of treated watershed, (where Pl= piezometer at the lower slope, Pm= at the middle slope and Pu= at the upper slope).

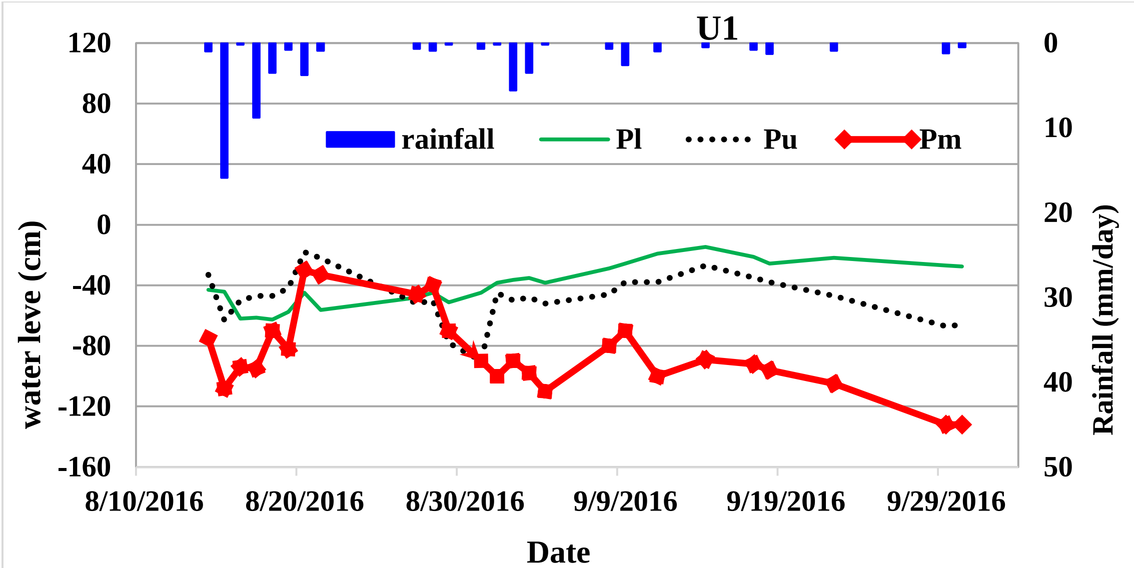

Figure 4-4: Water level measurement from U1 (transect one) of the untreated watershed (where Pl= piezometer at the lower slope, Pm= at the middle slope and Pu= at the upper slope.

The rapid declination of groundwater level in the upper part treated watershed *(Figure 4-3)* was due to water rapidly drain out due to the steep slope and lower infiltration rate. *Figure (4-5)* below illustrated that obtained from Inverse Distance Weighting (IDW) and the green color indicates that the perched groundwater table was near the surface, the yellow color was indicated that the perched groundwater table become deeper, this happens during the day of limited rainfall or reduction of rainfall amount. In addition, the red, pink and white color shown that the perched groundwater table located far from the surface of the earth.

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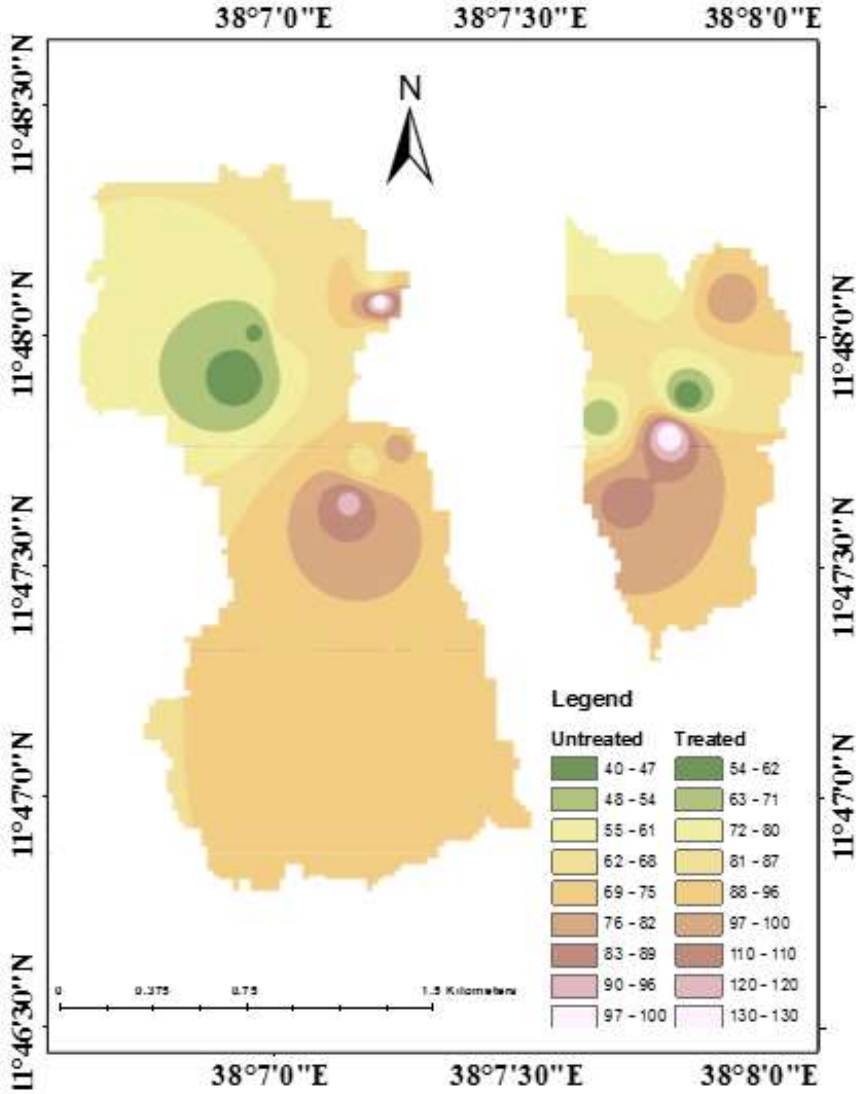

Figure 4-5: Perched groundwater level interpolation map of *Alekt Wenz* watersheds.

4.3. Streamflow responses

Runoff coefficient (RC) which is computed by the quotient of runoff to rainfall was the most suitable tools for comparison of direct runoff (DRO) between treated and untreated watersheds. The average RC from treated watersheds were 0.02 for 2015 and 0.04 for 2016 and from untreated watershed 0.1 in both of 2015 and 2016. Therefore, the untreated watershed was generating highest runoff rate than treated watershed in both data recording period.

The quantified DRO for untreated watershed were 17.3mm in 2015 and 15.3mm in 2016, while the smallest DRO was recorded from treated watershed i.e. 8.5mm in 2015 and 9.6mm in 2016. Due to the effectiveness of SWC practices, the baseflow were higher in treated watershed with a value of 180.7 mm yr^{-1} in 2015 and 212 mm yr^{-1} in 2016. But, from the untreated watershed, the baseflow was lower in both data recording periods, which had 69.8 mm yr^{-1} in 2015 and 195.4 mm yr^{-1} in 2016. *Table (4-1)* shown that DRO reduced by 50.8% in 2015 and 42.2% in 2016, and 17% increment of baseflow detected in treated watershed.

Table 4-1: The annual DRO and baseflow response from treated and untreated watersheds.

	Treated		Untreated	
	2015	2016	2015	2016
Direct Runoff (mm)	8.5	9.8	17.3	15.3
Base flow (mm)	180.7	212.0	69.8	195.4

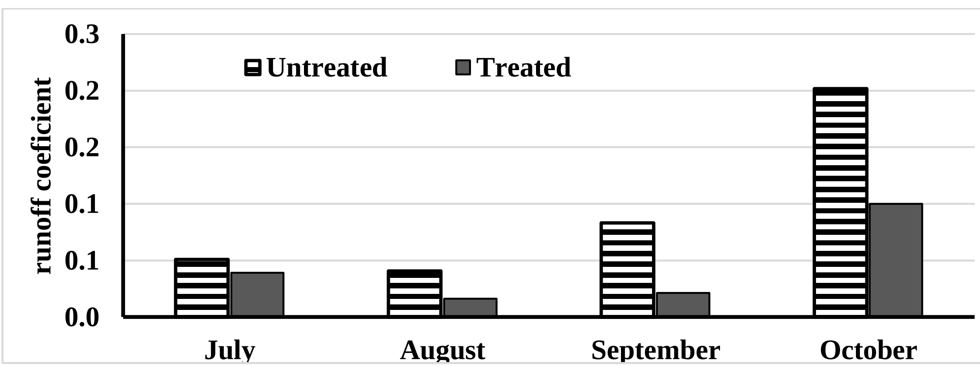

Figure 4-6: Monthly distribution of runoff coefficient for 2015 of treated and untreated watersheds.

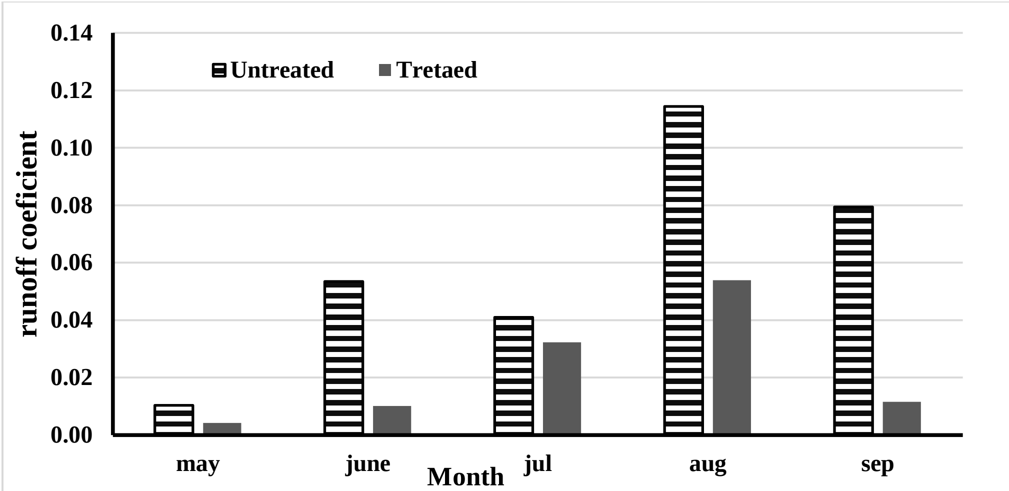

Figure 4-7: Monthly distribution of runoff coefficient for 2016 of *Alekt Wenz* watersheds.

During the late rainy season/August/, the runoff was generated by low rainfall with saturated watershed and low infiltration capacity as shown in (*Figure 4-6 and Figure 4-7*).

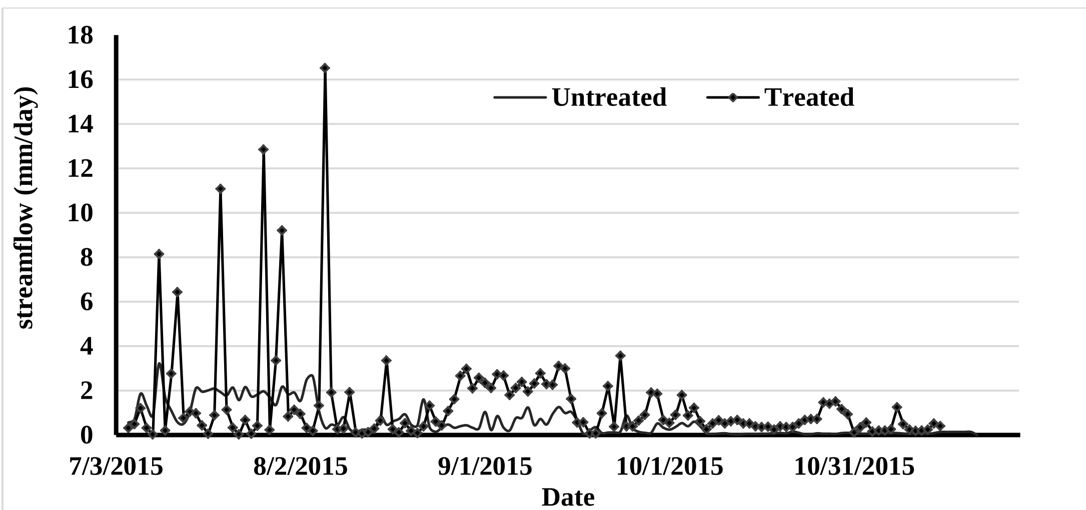

Figure 4-8: Time series diagram showing discharge fluctuations obtained from the rating curves for a treated and untreated watershed in 2015.

Figure (4-8) shows the conservation practices have a capacity to reduce the runoff generation by intercepting and dissipating the velocity of surface runoff and increase the base flow.

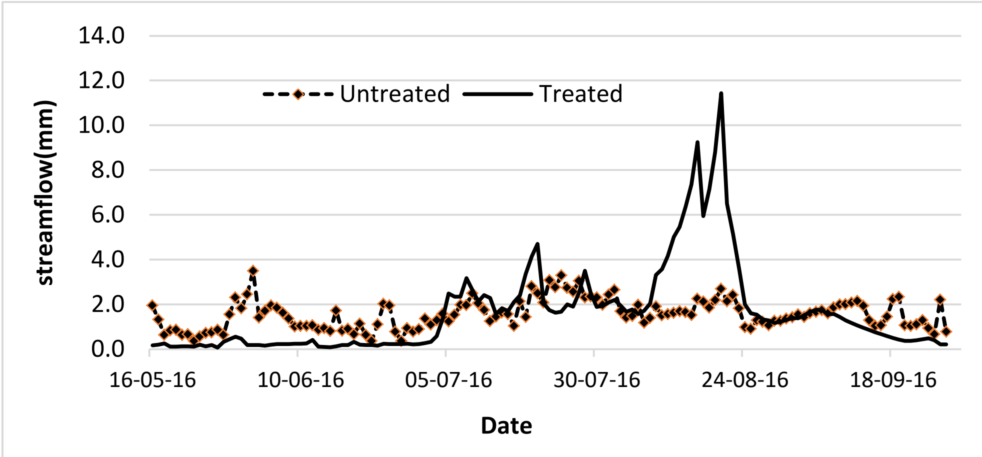

Figure 4-9: Time series diagram showing discharge fluctuations obtained from the rating curves for a treated and untreated watershed in 2016.

Figure (4-8) and figure (4-9) shown that the streamflow depth was higher in treated watershed during both data recording period, this is due to the improvement of infiltration rate and base flow increment through the implemented conservation practices.

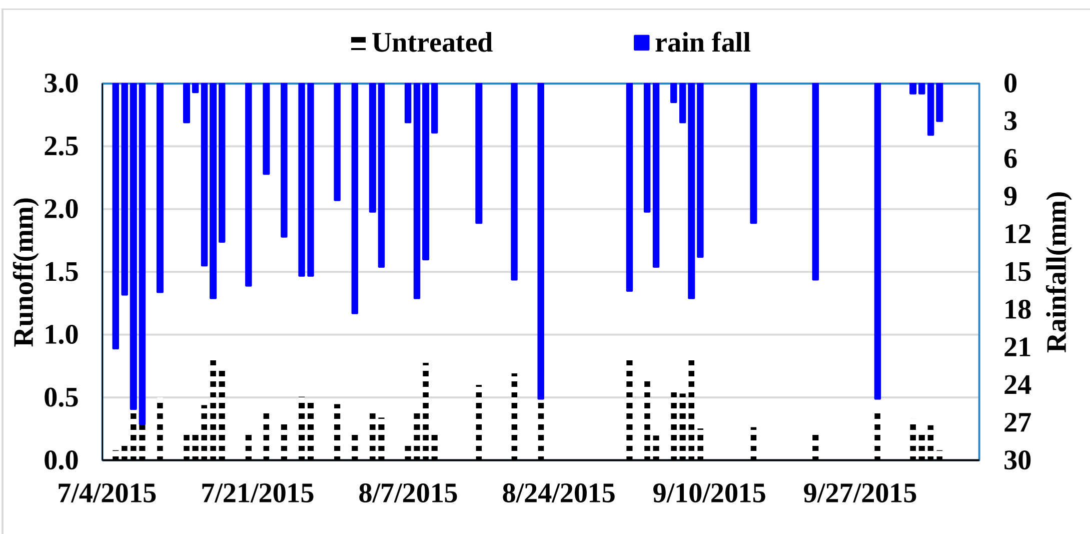

Figure 4-10: rainfall-runoff relationship of the untreated watershed for 2015 of the rainy season.

The above *Figure 4-10)* shows the rainfall-runoff relationship

To show significances of the effectiveness of the implemented SWC practices, the study was compared the two adjacent watersheds under different treatments. The study was employed t-test for two independent samples/two-tailed tests with 5% significance level. This statistical test conducted on the hydrological responses like direct runoff, sediment yield, nutrient losses, which are obtained from both watersheds. The study accepts and rejects the null hypothesis if the F-calculated from the data is larger than the F-critical, which is in the rejection region and can reject the null hypothesis with (1-α) level of confidence.

In addition, a p-value here is the probability of getting an F calculated even greater than what the study observed. If by chance, the F-calculated equal to F-critical, then the p-value would exactly equal to alpha value (α=0.05). With larger F-calculated values, we move further into the rejection region and the p-value becomes less than α value.

Therefore, the decision rule is as follows: If the p-value obtained from the t-test is less than α, then reject null hypothesis or accept alternative hypothesis, and vice versa. The direct runoff which is measured from the two nested watersheds tested by setting the null hypothesis has no different and alternative hypothesis has significant different between the watersheds under different degree and state of treatments. The study had 93 number of observation for treated and untreated watersheds.

H_0: The difference between the mean is equal to 0 (H_0: $\mu1 - \mu2 = 0$)

Ha: The difference between the mean is different from 0 ($\mu1 - \mu2 \neq 0$)

t (Observed value)	***-4.856***
|t| (Critical value)	***1.973***
DF	184
p-value (Two-tailed)	< 0.0001
alpha	0.05

***Test interpretation**:* As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis, and accept the alternative hypothesis, (the research hypothesis). The risk to reject the null hypothesis while it is true is lower than 0.01%. The implemented SWC practices reduce the direct runoff generation, so with 95% confidentially the untreated storm runoff significantly differ from treated watershed. The volume of runoff generated from untreated watershed greater than treated watershed.

4.4. Suspended sediment yield

In the study watershed, various SWC practices were implementing in treated watershed and closure downstream from cattle and human intervention, but the middle and upper slope are susceptible to erosion. This scientific study was quantified suspended sediment yield from treated watersheds and untreated watershed in annual flow basis in 2015 and 2016. This difference of sediment yield between the watersheds was due to the influence of conservation practices, while the difference of sediment yield between the years was due to the higher rainfall in 2016 than in 2015. The reduction of sediment concentration in the treated watershed was due to a decrease in runoff volume and trapped by stone/soil bunds, and gabions. Sediment yield was higher during the beginning of rainfall period because of formation of rills from plowing of the agricultural area. *Table (4-2)* realizes that losses from untreated watershed higher delivery than treated watershed. From a total of sediment yield delivery from *Alekt Wenz* watershed, a treated watershed share 40.6% in 2015 and 19% in 2016, this is a lower contribution as compared to the untreated watershed.

Table 4-2: Annual sediment yield from Alekt Wenz watershed from 2015- 2016.

sediment yield (ton $ha^{-1}yr^{-1}$)	Treated	Untreated
2015	2.4	6
2016	2.1	8.5

The value of sediment losses from treated part of *Alekt Wenz* watershed was very lower than Debre Mawi watershed which had losses of 13 tonha^{-1}yr^{-1} (Dagnew et al., 2015). This value was higher as we compared to the untreated part of *Alekt Wenz* watershed. The reason for this difference, there is higher runoff volume with a different number of gullies, and most are with active gull heads in Debre Mawi watershed (Dagnew et al., 2015) than *Alekt Wenz* watershed. Besides to this, there is no gully treatment measure in Debre Mawi watershed (Mekuria et al., 2015).

However, sediment yield from the untreated watershed of *Alekt Wenz* was higher than Andit Tid with the value of 5.4 t ha^{-1} yr^{-1}and Maybar (8.8t ha^{-1} yr^{-1}) (Guzman, 2011).

The treated part of Alekt Wenz watershed was lost lower sediment than Andit Tid and Maybar. Also, Anjeni watersheds lost higher sediment with the value of 22.5t ha^{-1} yr^{-1}than *Alekt Wenz* watershed (Guzman, 2011). This indicated that the SWC practices in *Alekt Wenz* watershed were more effective than other watersheds. A t-test conducted on sediment yield measured from the two watersheds for 2015 and 2016 data recording periods, which is shown (*Appendix A table7 and Appendix A table9*).

H_0: The difference between the mean is equal to 0.

Ha: The difference between the mean is different from 0.

The result of t-test by assuming two samples have equal variance,

t (Observed value)	-7.890
|t| (Critical value)	1.973
DF	182
p-value (Two-tailed)	*<0.0001*
alpha	0.05

Test interpretation: As the computed p-value is lower than the significance level alpha = 0.05, one should reject the null hypothesis, and accept the alternative hypothesis. The risk to reject the null hypothesis while it is true is lower than *0.01%*.The study accepts the alternative hypothesis (the research hypothesis), and the implemented SWC practices reduce the sediment losses from treated watershed.

So, with 95% confidence, the untreated sediment losses significantly differ from treated watershed and a number of sediment losses from the untreated watershed were greater than treated watershed

4.5. Nutrient losses

Dissolved nutrient is a part of soil nutrient losses through direct runoff and the base flow basis from the watershed. The study examined dissolved and sediment-embedded nutrient losses from the study watershed under different treatments. This study detected that lower soil nutrient loss from treated watershed than the untreated watershed in both data recording periods. Losses of dissolved nitrogen were higher than losses of dissolved phosphorus, which is lost as sediment-embedded due to the higher affinity of suspended sediment to absorbs phosphorus nutrients (Bertol et al., 2003).

Table 4-3: Nutrient losses and corresponding replacement cost for *Alekt Wenz* watershed in 2015.

Watershed Status	Nutrient type	Nutrient losses (kg ha^{-1})	Replacement Cost ($) $ha^{-1}yr^{-1}$
Treated	Psd	0.02	0.1
	Nsd	8.2	13.2
Untreated	Psd	0.2	1.2
	Nsd	25.4	41.1

Where: P_{sd} *(Dissolved and sediment–associated Phosphorus),* N_{sd} *(Dissolved and sediment–associated Nitrogen).*

As shown in the *table (4-3)* the implemented SWC practices have the capacity to diminish nutrient losses from treated watershed by 99% of P and 67.7% of N as compared to untreated watershed during 2015.

Table 4-4: Nutrient losses and corresponding replacement cost for *Alekt Wenz* watershed in 2016.

Watershed Status	Nutrient type	Nutrient losses (kg ha-1)	Replacement Cost ($)ha-1yr-1
Treated	Psd	0.16	0.8
	Nsd	11.92	19.3
Untreated	Psd	0.80	4.1
	Nsd	61.01	98.6

(*Where: DP =Dissolved Phosphorus, DN =Dissolved Nitrogen).*

During 2016, 75% of P and 64.8% of N, dissolved nutrient losses were conserved by SWC activities from treated watershed when we compared with the untreated watershed. The farmers who are living in the untreated watershed incurred higher ($42.3)

US dollar than treated one ($13.3) to replace the lost N-P nutrient in 2015. Also, the untreated watershed acquired $102.8, which is higher than the treated one ($20.1) to replace nutrient of N and P. The t-test for two independent samples /Two-tailed test/ implemented on dissolved nutrient losses from *Alekt Wenz* watershed (*Appendix A table8 and Appendix A table10).*

Test on dissolved phosphorus: The dissolved phosphorus losses that measured from the two watersheds tested by setting the null hypothesis has no different and alternative hypothesis has significant different between the watersheds under different degree and state of treatments.

H_0: The difference between the mean is equal to 0.

Ha: The difference between the mean is different from 0.

The test result is shown below and the study compared by p-value and critical versus calculated value.

t (Observed value)	-3.706
|t| (Critical value)	1.973
DF	184
p-value (Two-tailed)	0.0003
alpha	0.05

Test interpretation: As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis, and accept the alternative hypothesis. The risk to reject the null hypothesis while it is true is lower than 0.03%. This tells as the implemented SWC practices reduce the dissolved phosphorus losses. Therefore, with 95% confidence dissolved phosphorus from untreated watershed significantly differs from treated watershed and the amount of dissolved phosphorus from untreated watershed greater than treated watershed.

A t-test for dissolved nitrogen: The dissolved nitrogen losses were tested by setting the null hypothesis has no different and alternative hypothesis has significant different between the watersheds under different degree and state of treatments.

H_0: The difference between the mean is equal to 0.
Ha: The difference between the mean is different from 0.

t (Observed value)	-4.322
|t| (Critical value)	1.973
DF	184
p-value (Two-tailed)	< 0.0001
alpha	0.05

Test interpretation: As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis, and accept the alternative hypothesis. This figure tells as the implemented SWC practices reduce the dissolved nitrogen losses, so with 95% confidence the untreated dissolved nitrogen significantly differ from treated watershed, and the amount dissolved nitrogen from untreated watershed greater than treated watershed.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

There are different factors that affect the runoff generation, soil and nutrient losses such as drainage density, area, slope, longest flow path, shape, and use/land cover, and SWC practices. In this study, the effects of those factors are insignificant on hydrological responses. The present study focused on the hydrological responses treat only by considering SWC practices on treated and untreated sub-watersheds. The two watersheds are adjacent to each other and comparable in terms of slope, area, longest flow path, shape, and drainage density. The result indicates that the watershed under different SWC practices has a 5% significance level different on hydrological responses. From the treated watershed, runoff, sediment and nutrient losses were reduced, and infiltration rate was enhanced due to the effects of SWC measures as compared to the untreated watershed. Sediment concentrations reduced as runoff reduced. This is happen due to the conservation activities dissipates energy and speed of erosive runoff, and trapped sediment losses through gabions, stone/soil bunds in the treated part of *Alekt Wenz* watershed. Significantly, direct runoff controlled and reduced by implementing different SWC practices and increase base flow. Dissolved phosphorus and dissolved nitrogen losses were reduced due to the effects of SWC practices.

This study detected that watershed without conservation activities and used to agricultural purpose produce higher peak rate and volume of runoff, sediment, and nutrient losses as compared to treated watershed. The implemented SWC measure such as field bund, gabion, arc weir, and closure have a considerable effect in reduced soil and nutrient losses. In addition, the study employed t-test to show the significance different on the two watersheds and concluded that with 95% confident the SWC practices enhance infiltration capacity, and reduced the surface runoff generation and increase base flow.

The suspended sediment losses also increase when the velocity and volume of runoff increase which is higher in the beginning of rainfall and reduced as rainfall cease and availability of sediment in the watershed reduced. The dynamic fluctuation of perched ground water table shows that the water level below the surface was shallow in treated watershed. Generally, the conservation practices enhance infiltration rate and contribute water to the ground water, and base flow of the treated watershed has improved.

5.2. Recommendations

Various SWC practices implemented in different watersheds to control erosion reduce soil and nutrient losses to increase agricultural productivity. However, the effectiveness to reduce losses is not satisfactory as compared to the capital that used for implementation. This is because the implementation did not consider the hydrological response of the watersheds where intervention practiced. Therefore, implementation according to hydrological characteristics and effectiveness evaluation of SWC practice to hydrological responses is crucially mandatory rather than estimating the losses. To realize the effectiveness of various soil and water conservation measure continuous hydrological data recording and evaluating are very important. It is important to investigate the long-term effect reduction of soil and nutrient losses. In addition, it is important in evaluating the linking between watershed characteristics and hydrological responses. This study provides different SWC practices for untreated watershed like gully treatment, gabion, soil bund, integrated with elephant grass, closure of the downstream area.

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APPENDIX

Appendix A: rainfall and intensity

Appendix A table1: Daily rainfall and intensity of Alekt Wenz watersheds from 2015-2016

2015			2016		
Date	depth of Rainfall (mm)	Intensity (mm/hr)	Date	depth of Rainfall (mm)	Intensity (mm/hr)
6/29/2015	3.2	38.4	5/16/2016	5	60
6/30/2015	0.2	2.4	5/25/2016	3	36
7/1/2015	13.4	160.8	5/26/2016	0.8	9.6
7/2/2015	9.5	114	5/27/2016	6.5	78
7/3/2015	0.2	2.4	5/28/2016	26.5	318
7/4/2015	18.8	225.6	5/29/2016	14.7	176.4
7/5/2015	21.1	253.2	5/30/2016	7.6	91.2
7/6/2015	19.6	235.2	5/31/2016	14.2	170.4
7/7/2015	23.1	277.2	6/1/2016	0.2	2.4
7/8/2015	4.9	58.8	6/3/2016	0.2	2.4
7/9/2015	22.4	268.8	6/7/2016	0.4	4.8
7/10/2015	16.6	199.2	6/8/2016	0.2	2.4
7/11/2015	1.2	14.4	6/12/2016	0.2	2.4
7/12/2015	3.2	38.4	6/15/2016	2.5	30
7/13/2015	3.1	37.2	6/16/2016	5.8	69.6
7/14/2015	4.5	54	6/17/2016	13.2	158.4
7/15/2015	14.5	174	6/18/2016	20.3	243.6
7/16/2015	17.1	205.2	6/19/2016	5.7	68.4
7/17/2015	12.6	151.2	6/20/2016	10	120
7/18/2015	0.2	2.4	6/21/2016	0.2	2.4
7/19/2015	1	12	6/22/2016	1.2	14.4
7/20/2015	16.1	193.2	6/23/2016	0.6	7.2
7/21/2015	0.2	2.4	6/24/2016	8.4	100.8
7/22/2015	7.2	86.4	7/1/2016	12	144
7/23/2015	0.6	7.2	7/2/2016	19.6	235.2
7/24/2015	12.2	146.4	7/3/2016	0.8	9.6
7/25/2015	2.4	28.8	7/4/2016	42.5	510
7/26/2015	15.3	183.6	7/5/2016	38.6	463.2
7/27/2015	15.3	183.6	7/6/2016	5.4	64.8
7/28/2015	9.2	110.4	7/7/2016	9	108
7/29/2015	3.6	43.2	7/8/2016	26.5	318
7/30/2015	9.3	111.6	7/9/2016	19.3	231.6

7/31/2015	2.3	27.6	7/10/2016	11.2	134.4
8/1/2015	16.5	198	7/11/2016	20.5	246
8/2/2015	1.5	18	7/12/2016	5	60
8/3/2015	10.2	122.4	7/13/2016	11.5	138
8/4/2015	14.6	175.2	7/14/2016	15.5	186
8/5/2015	0.2	2.4	7/15/2016	9.3	111.6
8/6/2015	1.5	18	7/17/2016	12.5	150
8/7/2015	3.1	37.2	7/19/2016	15.7	188.4
8/8/2015	17.1	205.2	7/20/2016	7.8	93.6
8/9/2015	13.8	165.6	7/21/2016	14.3	171.6
8/10/2015	3.7	44.4	7/22/2016	2.4	28.8
8/11/2015	0.2	2.4	7/23/2016	21.2	254.4
8/12/2015	0.4	4.8	7/24/2016	50.2	602.4
8/13/2015	5.3	63.6	7/25/2016	39.6	475.2
8/14/2015	2	24	7/26/2016	29	348
8/15/2015	11.1	133.2	7/27/2016	46.4	556.8
8/16/2015	0.4	4.8	7/28/2016	21.2	254.4
8/17/2015	5.3	63.6	7/30/2016	26.7	320.4
8/18/2015	0.2	2.4	7/31/2016	5.4	64.8
8/19/2015	15.6	187.2	8/1/2016	14.6	175.2
8/20/2015	0.4	4.8	8/2/2016	26.7	320.4
8/21/2015	0.2	2.4	8/3/2016	17.8	213.6
8/22/2015	25.1	301.2	8/4/2016	44.5	534
8/23/2015	0.8	9.6	8/5/2016	32	384
9/1/2015	16.5	198	8/6/2016	24	288
9/2/2015	1.5	18	8/9/2016	11	132
9/3/2015	10.2	122.4	8/14/2016	1	12
9/4/2015	14.6	175.2	8/15/2016	15.9	190.8
9/5/2015	0.2	2.4	8/16/2016	0.2	2.4
9/6/2015	5.65	67.8	8/17/2016	29.7	356.4
9/7/2015	6.5	78	8/18/2016	3.5	42
9/8/2015	17.1	205.2	8/19/2016	3.6	43.2
9/9/2015	13.8	165.6	8/20/2016	8.6	103.2
9/10/2015	3.7	44.4	8/21/2016	0.9	10.8
9/11/2015	0.6	7.2	8/27/2016	0.7	8.4
9/12/2015	0.2	2.4	8/28/2016	0.9	10.8
9/13/2015	5.3	63.6	8/29/2016	0.2	2.4
9/14/2015	2	24	8/31/2016	0.7	8.4
9/15/2015	11.1	133.2	9/1/2016	0.2	2.4
9/16/2015	0.4	4.8	9/2/2016	5.6	67.2
9/18/2015	0.2	2.4	9/3/2016	3.5	42
9/19/2015	0.2	2.4	9/4/2016	0.2	2.4
9/22/2015	15.6	187.2	9/8/2016	0.7	8.4
9/24/2015	0.2	2.4	9/9/2016	2.6	31.2

9/25/2015	0.2	2.4	9/11/2016	1	12
9/28/2015	0.2	2.4	9/14/2016	0.5	6
9/29/2015	25.1	301.2	9/17/2016	0.8	9.6
9/30/2015	0.8	9.6	9/18/2016	1.3	15.6
10/1/2015	0.4	4.8	9/22/2016	0.9	10.8
10/2/2015	0.2	2.4	9/29/2016	1.2	14.4
10/3/2015	11.6	139.2	9/30/2016	0.5	6
10/4/2015	22.9	274.8			
10/5/2015	11.3	135.6			
10/6/2015	1.3	15.6			
10/7/2015	0.2	2.4			

Appendix A table2: Infiltration capacity conducted on 24 points of Alekt Wenz watersheds.

Land use and terrain difference	Infiltration Capacity (mm/hr)	Infiltration Capacity (mm/day)
GUU	4.8	115.2
GU_M	4.8	115.2
GUL	6.0	144
GTU	12.0	288
GTM	6.0	144
GTL	3.6	86.4
BTU	6.0	144
BTM	120.0	2880
BTL	9.6	230.4
BUU	3.6	86.4
BUM	120.0	2880
BUL	6.0	144
WUU	7.2	172.8
WUM	84.0	2016
WUL	3.6	86.4
WTU	120.0	2880
WTM	9.6	230.4
WTL	60.0	1440
FTU	12.0	288
FTM	120.0	2880
FTL	7.2	172.8
FUU	12.0	288

FUM	4.8	115.2
FUL	6.0	144

Where: *GUU (Grazing untreated upper), GUM (Grazing untreated mid), GUL (Grazing untreated lower), BUU (Barley untreated upper), BUM (Barley untreated mid), BUL (Barley untreated lower), WUU (Wheat untreated upper), WUM (Wheat untreated mid), WUL (Wheat untreated lower), FUU (Forest untreated upper), FUM (Forest untreated mid), FUL (Forest untreated lower).*

Appendix A table3: Direct runoff (mm/day) measured from the two watersheds during the rainy seasons of 2015.

Date	Treated Direct runoff (mm/day)	Untreated Direct runoff (mm/day)
7/5/2015	0.24	0.08
7/6/2015	0.46	0.14
7/7/2015	1.13	1.31
7/8/2015	0.26	0.31
7/10/2015	0.32	0.50
7/13/2015	0.16	0.22
7/14/2015	0.16	0.21
7/15/2015	0.52	0.44
7/16/2015	0.31	0.81
7/17/2015	0.31	0.72
7/20/2015	0.36	0.23
7/22/2015	0.26	0.41
7/24/2015	0.60	0.29
7/26/2015	0.39	0.51
7/27/2015	0.21	0.48
7/30/2015	0.15	0.45
8/1/2015	0.41	0.21
8/3/2015	0.19	0.40
8/4/2015	0.13	0.34
8/7/2015	0.16	0.13
8/8/2015	0.06	0.40
8/9/2015	0.05	0.78
8/10/2015	0.04	0.21

8/15/2015	0.15	0.60
8/19/2015	0.28	0.69
8/22/2015	0.22	0.81
9/1/2015	0.22	0.80
9/3/2015	0.24	0.64
9/4/2015	0.16	0.20
9/6/2015	0.10	0.54
9/7/2015	0.10	0.53
9/8/2015	0.10	0.81
9/9/2015	0.13	0.25
9/13/2015	0.13	0.26
9/15/2015	0.16	0.24
9/29/2015	0.18	0.38
10/3/2015	0.12	0.33
10/4/2015	0.16	0.24
10/5/2015	0.09	0.28
10/6/2015	0.08	0.08

Appendix A table4: Daily baseflow of Alekt Wenz watersheds during 2015 data recording period.

Treated		Untreated		Treated		Untreated		Treated		Untreated	
Date	Base-flow (mm /day)	Date	Base-flow (mm /day)	Date	Base-flow (mm /day)	Date	Base-flow (mm /day)	Date	Base-flow (mm /day)	Date	Base-flow (mm /day)
7/5/2015	0.1	7/5/2015	0.5	9/1/2015	0.1	9/1/2015	0.3	10/29/2015	0.6	10/29/2015	0.0
7/6/2015	0.0	7/6/2015	0.5	9/2/2015	0.1	9/2/2015	0.2	10/30/2015	0.4	10/30/2015	0.1
7/7/2015	0.1	7/7/2015	0.6	9/3/2015	1.0	9/3/2015	0.2	10/31/2015	0.3	10/31/2015	0.1
7/8/2015	0.0	7/8/2015	0.6	9/4/2015	2.2	9/4/2015	0.2	11/1/2015	0.5	11/1/2015	0.1
7/9/2015	0.0	7/9/2015	1.0	9/5/2015	0.4	9/5/2015	0.1	11/2/2015	0.5	11/2/2015	0.1
7/10/2015	12.6	7/10/2015	0.9	9/6/2015	3.6	9/6/2015	0.2	11/3/2015	0.1	11/3/2015	0.1
7/11/2015	0.2	7/11/2015	2.7	9/7/2015	0.4	9/7/2015	0.2	11/4/2015	0.1	11/4/2015	0.0
7/12/2015	3.3	7/12/2015	1.7	9/8/2015	0.4	9/8/2015	0.2	11/5/2015	0.1	11/5/2015	0.1
7/13/2015	9.1	7/13/2015	1.1	9/9/2015	0.6	9/9/2015	0.4	11/6/2015	0.1	11/6/2015	0.1
7/14/2015	0.8	7/14/2015	0.4	9/10/2015	0.9	9/10/2015	0.4	11/7/2015	0.1	11/7/2015	0.1
7/15/2015	0.7	7/15/2015	0.3	9/11/2015	1.9	9/11/2015	0.5	11/8/2015	0.0	11/8/2015	0.1
7/16/2015	0.9	7/16/2015	0.6	9/12/2015	1.7	9/12/2015	0.5	11/9/2015	0.1	11/9/2015	0.1

7/17/2015	0.1	7/17/2015	1.3	9/13/2015	0.7	9/13/2015	1.0	11/10/2015	0.1	11/10/2015	0.0
7/18/2015	0.1	7/18/2015	1.2	9/14/2015	0.5	9/14/2015	1.0	11/11/2015	0.1	11/11/2015	0.1
7/19/2015	1.3	7/19/2015	2.0	9/15/2015	0.9	9/15/2015	1.0	11/12/2015	0.1	11/12/2015	0.1
7/20/2015	16.5	7/20/2015	2.1	9/16/2015	1.7	9/16/2015	0.8	11/13/2015	0.1	11/13/2015	0.0
7/21/2015	1.7	7/21/2015	1.7	9/17/2015	0.7	9/17/2015	0.6	11/14/2015	0.2	11/14/2015	0.1
7/22/2015	0.2	7/22/2015	1.8	9/18/2015	1.1	9/18/2015	0.1				
7/23/2015	0.2	7/23/2015	1.7	9/19/2015	0.5	9/19/2015	0.2				
7/24/2015	1.9	7/24/2015	1.6	9/20/2015	0.2	9/20/2015	0.4				
7/25/2015	0.1	7/25/2015	1.9	9/21/2015	0.5	9/21/2015	0.1				
7/26/2015	0.1	7/26/2015	1.7	9/22/2015	0.7	9/22/2015	0.1				
7/27/2015	0.1	7/27/2015	1.3	9/23/2015	0.5	9/23/2015	0.1				
7/28/2015	0.3	7/28/2015	1.5	9/24/2015	0.6	9/24/2015	0.2				
7/29/2015	0.5	7/29/2015	1.7	9/25/2015	0.7	9/25/2015	0.9				
7/30/2015	3.3	7/30/2015	1.4	9/26/2015	0.5	9/26/2015	0.3				
7/31/2015	0.3	7/31/2015	1.7	9/27/2015	0.5	9/27/2015	0.1				
8/1/2015	0.1	8/1/2015	1.8	9/28/2015	0.4	9/28/2015	0.1				
8/2/2015	0.2	8/2/2015	1.7	9/29/2015	0.4	9/29/2015	0.1				
8/3/2015	0.2	8/3/2015	1.5	9/30/2015	0.4	9/30/2015	0.1				
8/4/2015	0.1	8/4/2015	2.1	10/1/2015	0.2	10/1/2015	0.3				
8/5/2015	0.2	8/5/2015	2.3	10/2/2015	0.4	10/2/2015	0.2				
8/6/2015	1.3	8/6/2015	1.1	10/3/2015	0.4	10/3/2015	0.4				
8/7/2015	0.6	8/7/2015	0.3	10/4/2015	0.4	10/4/2015	0.2				
8/8/2015	0.4	8/8/2015	0.3	10/5/2015	0.5	10/5/2015	0.2				
8/9/2015	1.1	8/9/2015	0.0	10/6/2015	0.7	10/6/2015	0.3				
8/10/2015	1.6	8/10/2015	0.0	10/7/2015	0.7	10/7/2015	0.3				
8/11/2015	2.7	8/11/2015	0.1	10/8/2015	0.7	10/8/2015	0.1				
8/12/2015	3.0	8/12/2015	0.1	10/9/2015	1.5	10/9/2015	0.0				
8/13/2015	2.1	8/13/2015	0.2	10/10/2015	1.4	10/10/2015	0.1				
8/14/2015	2.6	8/14/2015	0.2	10/11/2015	1.5	10/11/2015	0.1				
8/15/2015	2.1	8/15/2015	0.2	10/12/2015	1.2	10/12/2015	0.0				
8/16/2015	2.1	8/16/2015	0.2	10/13/2015	0.9	10/13/2015	0.0				
8/17/2015	2.5	8/17/2015	0.5	10/14/2015	0.1	10/14/2015	0.0				
8/18/2015	2.5	8/18/2015	0.6	10/15/2015	0.3	10/15/2015	0.1				
8/19/2015	1.8	8/19/2015	0.7	10/16/2015	0.5	10/16/2015	0.0				
8/20/2015	2.0	8/20/2015	0.2	10/17/2015	0.2	10/17/2015	0.1				
8/21/2015	2.3	8/21/2015	0.5	10/18/2015	0.2	10/18/2015	0.1				
8/22/2015	1.8	8/22/2015	0.4	10/19/2015	0.2	10/19/2015	0.1				
8/23/2015	2.3	8/23/2015	0.8	10/20/2015	0.3	10/20/2015	0.1				
8/24/2015	2.6	8/24/2015	0.3	10/21/2015	1.3	10/21/2015	0.1				

8/25/2015	2.3	8/25/2015	0.1	10/22/2015	0.5	10/22/2015	0.2				
8/26/2015	2.3	8/26/2015	0.3	10/23/2015	0.2	10/23/2015	0.1				
8/27/2015	3.0	8/27/2015	0.5	10/24/2015	0.2	10/24/2015	0.0				
8/28/2015	3.0	8/28/2015	0.3	10/25/2015	0.2	10/25/2015	0.0				
8/29/2015	1.5	8/29/2015	0.4	10/26/2015	0.2	10/26/2015	0.1				
8/30/2015	0.6	8/30/2015	0.4	10/27/2015	0.5	10/27/2015	0.1				
8/31/2015	0.6	8/31/2015	0.3	10/28/2015	0.4	10/28/2015	0.1				

Appendix A table5: Direct runoff (mm/day) measured from the two watersheds during the rainy seasons of 2016.

	treated	Untreated
Date	Direct runoff (mm)	Direct runoff (mm)
5/28/2016	0.12	0.11
5/29/2016	0.02	0.17
5/30/2016	0.01	0.09
5/31/2016	0.12	0.19
6/19/2016	0.14	0.35
6/20/2016	0.02	0.53
6/24/2016	0.04	0.52
7/1/2016	0.04	0.31
7/2/2016	0.11	0.53
7/3/2016	0.25	0.13
7/4/2016	0.17	0.24
7/5/2016	0.05	0.27
7/6/2016	0.13	0.16
7/7/2016	0.12	0.14
7/8/2016	0.43	0.17
7/9/2016	0.19	0.25
7/10/2016	0.33	0.61
7/11/2016	0.12	0.69
7/12/2016	0.46	0.44
7/13/2016	0.20	0.35
7/14/2016	0.18	0.22
7/15/2016	0.39	0.27
7/16/2016	0.32	0.51

7/17/2016	0.17	0.39
7/19/2016	0.17	0.11
7/20/2016	0.03	0.22
7/21/2016	0.53	0.16
7/22/2016	0.32	0.30
7/23/2016	0.26	0.24
7/24/2016	0.20	0.17
7/25/2016	0.47	0.17
7/26/2016	0.36	0.15
7/27/2016	0.40	0.39
7/28/2016	0.23	0.27
7/29/2016	0.30	0.27
7/30/2016	0.29	0.38
8/1/2016	0.13	0.48
8/2/2016	0.13	0.46
8/3/2016	0.30	0.53
8/4/2016	0.19	0.14
8/5/2016	0.58	0.32
8/6/2016	0.05	0.06
8/9/2016	0.09	1.74
8/16/2016	0.03	0.27
8/17/2016	0.10	0.22
8/18/2016	0.06	0.66
8/19/2016	0.08	0.08
8/20/2016	0.01	0.10
8/21/2016	0.02	0.06
8/22/2016	0.04	0.05
8/23/2016	0.03	0.38
8/30/2016	0.03	0.35
9/2/2016	0.03	0.18
9/3/2016	0.03	0.00
9/9/2016	0.03	0.00

Appendix A table6: Baseflow (mm/day) measured from the Alekt Wenz watersheds during 2016.

	Treated	Untreated		Treated	Untreated		Treated	Untreated
Date	Base-flow (mm /day)	Base-flow (mm /day)	Date	Base-flow (mm /day)	Base-flow (mm /day))	Date	Base-flow (mm /day)	Base-flow (mm /day)
5/16/2016	0.17	1.94	7/10/2016	1.80	1.44	9/3/2016	1.48	1.37
5/17/2016	0.19	1.32	7/11/2016	2.30	1.04	9/4/2016	1.66	1.61
5/18/2016	0.25	0.63	7/12/2016	1.82	0.80	9/5/2016	1.75	1.67
5/19/2016	0.11	0.84	7/13/2016	1.57	1.44	9/6/2016	1.75	1.73
5/20/2016	0.12	0.87	7/14/2016	1.65	1.29	9/7/2016	1.56	1.60
5/21/2016	0.13	0.63	7/15/2016	1.70	1.57	9/8/2016	1.56	1.86
5/22/2016	0.12	0.66	7/16/2016	1.78	0.82	9/9/2016	1.40	1.93
5/23/2016	0.11	0.36	7/17/2016	2.23	1.86	9/10/2016	1.28	2.00
5/24/2016	0.20	0.56	7/18/2016	3.36	1.44	9/11/2016	1.16	2.07
5/25/2016	0.13	0.72	7/19/2016	3.97	2.29	9/12/2016	1.05	2.14
5/26/2016	0.18	0.75	7/20/2016	4.67	2.09	9/13/2016	0.95	1.94
5/27/2016	0.07	0.87	7/21/2016	1.52	1.97	9/14/2016	0.85	1.29
5/28/2016	0.21	0.52	7/22/2016	1.41	2.86	9/15/2016	0.76	1.03
5/29/2016	0.41	1.37	7/23/2016	1.36	2.60	9/16/2016	0.67	1.07
5/30/2016	0.54	2.21	7/24/2016	1.47	2.99	9/17/2016	0.58	1.45
5/31/2016	0.35	1.63	7/25/2016	1.54	2.50	9/18/2016	0.50	2.24
6/1/2016	0.18	2.45	7/26/2016	1.54	2.39	9/19/2016	0.43	2.34
6/2/2016	0.18	3.50	7/27/2016	2.13	2.88	9/20/2016	0.36	1.07
6/3/2016	0.18	1.41	7/28/2016	3.27	2.16	9/21/2016	0.36	1.03
6/4/2016	0.16	1.71	7/29/2016	2.17	1.96	9/22/2016	0.40	1.10
6/5/2016	0.20	1.94	7/30/2016	1.60	2.04	9/23/2016	0.45	1.29
6/6/2016	0.22	1.86	7/31/2016	1.94	1.98	9/24/2016	0.49	0.93
6/7/2016	0.22	1.62	8/1/2016	1.95	2.16	9/25/2016	0.40	0.66
6/8/2016	0.23	1.37	8/2/2016	1.87	2.19	9/26/2016	0.22	2.21
6/9/2016	0.24	1.00	8/3/2016	1.64	1.21	9/27/2016	0.22	0.78
6/10/2016	0.24	1.03	8/4/2016	1.48	0.95	9/28/2016	0.00	0.69
6/11/2016	0.25	1.03	8/5/2016	1.58	1.01	9/29/2016	0.00	0.87
6/12/2016	0.41	1.07	8/6/2016	1.38	1.51	9/30/2016	0.00	0.78
6/13/2016	0.11	0.87	8/7/2016	1.71	1.18	10/1/2016	0.00	0.75
6/14/2016	0.10	0.93	8/8/2016	2.04	1.39	10/2/2016	0.00	0.87

6/15/2016	0.09	0.81	8/9/2016	3.13	1.44	10/3/2016	0.00	1.22
6/16/2016	0.12	1.72	8/10/2016	3.58	1.50	10/4/2016	0.00	1.29
6/17/2016	0.18	0.82	8/11/2016	4.16	1.56	10/5/2016	0.00	1.03
6/18/2016	0.18	0.91	8/12/2016	5.02	1.62	10/6/2016	0.00	1.14
6/19/2016	0.18	0.31	8/13/2016	5.45	1.69	10/7/2016	0.00	1.45
6/20/2016	0.18	0.60	8/14/2016	6.37	1.65			
6/21/2016	0.18	0.63	8/15/2016	7.36	1.51			
6/22/2016	0.18	0.36	8/16/2016	8.67	1.73			
6/23/2016	0.16	1.11	8/17/2016	5.90	1.79			
6/24/2016	0.20	1.50	8/18/2016	7.06	1.80			
6/25/2016	0.22	1.94	8/19/2016	8.76	1.98			
6/26/2016	0.22	0.78	8/20/2016	11.34	1.98			
6/27/2016	0.23	0.36	8/21/2016	6.44	2.05			
6/28/2016	0.24	0.94	8/22/2016	5.07	2.31			
6/29/2016	0.22	0.78	8/23/2016	3.58	1.75			
6/30/2016	0.22	0.89	8/24/2016	2.00	0.97			
7/1/2016	0.24	1.05	8/25/2016	1.59	0.90			
7/2/2016	0.22	0.55	8/26/2016	1.54	1.29			
7/3/2016	0.33	1.14	8/27/2016	1.33	1.23			
7/4/2016	1.20	1.33	8/28/2016	1.29	1.07			
7/5/2016	2.44	0.95	8/29/2016	1.17	1.26			
7/6/2016	2.22	1.37	8/30/2016	1.19	1.20			
7/7/2016	2.22	1.83	8/31/2016	1.32	1.37			
7/8/2016	2.74	1.78	9/1/2016	1.38	1.43			
7/9/2016	2.47	2.25	9/2/2016	1.35	1.48			

Appendix A table7: annual sediment yield of Alekt Wenz watersheds for 2015.

	Treated	Untreated
date	Sediment yield (ton $ha^{-1}yr^{-1}$)	Sediment yield (ton $ha^{-1}yr^{-1}$)
7/5/2015	0.01	0.01
7/6/2015	0.00	0.01
7/7/2015	0.03	0.18
7/8/2015	0.01	0.04
7/10/2015	0.02	0.05
7/13/2015	0.00	0.03

7/14/2015	0.03	0.02
7/15/2015	0.01	0.04
7/16/2015	0.00	0.11
7/17/2015	0.01	0.08
7/20/2015	0.01	0.02
7/22/2015	0.00	0.05
7/24/2015	0.00	0.03
7/26/2015	0.01	0.06
7/27/2015	0.00	0.05
7/30/2015	0.00	0.05
8/1/2015	0.00	0.02
8/3/2015	0.01	0.04
8/4/2015	0.00	0.04
8/7/2015	0.00	0.01
8/8/2015	0.00	0.04
8/9/2015	0.00	0.11
8/10/2015	0.00	0.02
8/15/2015	0.00	0.07
8/19/2015	0.00	0.08
8/22/2015	0.00	0.11
9/1/2015	0.00	0.10
9/3/2015	0.00	0.07
9/4/2015	0.00	0.02
9/6/2015	0.00	0.06
9/7/2015	0.00	0.06
9/8/2015	0.00	0.11
9/9/2015	0.00	0.03
9/13/2015	0.00	0.03
9/15/2015	0.00	0.02
9/29/2015	0.00	0.04
10/3/2015	0.00	0.03
10/4/2015	0.00	0.02
10/5/2015	0.00	0.03
10/6/2015	0.00	0.01

Appendix A table8: Dissolved nutrient losses from Alekt Wenz watersheds in 2015 of the rainy season.

	Treated		Untreated	
date	Dissolved phosphorus (kgha^{-1}yr^{-1})	Dissolved Nitrogen(kgha^{-1}yr^{-1})	Dissolved phosphorus (kgha^{-1}yr^{-1})	Dissolved Nitrogen (kgha^{-1}yr^{-1})
7/5/2015	0.003	0.004	0.00	0.00
7/6/2015	0.007	0.004	0.00	0.00
7/7/2015	0.009	0.003	0.01	0.01
7/8/2015	0.002	0.001	0.00	0.00
7/10/2015	0.006	0.001	0.00	0.00
7/13/2015	0.001	0.000	0.00	0.00
7/14/2015	0.001	0.000	0.00	0.00
7/15/2015	0.000	0.000	0.01	0.00
7/16/2015	0.001	0.000	0.01	0.01
7/17/2015	0.001	0.000	0.00	0.01
7/20/2015	0.000	0.000	0.00	0.00
7/22/2015	0.001	0.000	0.00	0.00
7/24/2015	0.000	0.000	0.00	0.00
7/26/2015	0.000	0.000	0.00	0.00
7/27/2015	0.000	0.000	0.01	0.00
7/30/2015	0.000	0.000	0.00	0.00
8/1/2015	0.000	0.000	0.00	0.00
8/3/2015	0.000	0.000	0.00	0.01
8/4/2015	0.000	0.000	0.00	0.00
8/7/2015	0.000	0.000	0.00	0.00
8/8/2015	0.001	0.000	0.00	0.00
8/9/2015	0.000	0.000	0.00	0.02
8/10/2015	0.000	0.000	0.00	0.01
8/15/2015	0.000	0.000	0.01	0.02
8/19/2015	0.000	0.000	0.00	0.01
8/22/2015	0.000	0.000	0.01	0.01
9/1/2015	0.000	0.000	0.00	0.01

9/3/2015	0.000	0.000	0.00	0.01
9/4/2015	0.000	0.000	0.00	0.00
9/6/2015	0.000	0.000	0.02	0.00
9/7/2015	0.000	0.000	0.01	0.01
9/8/2015	0.000	0.000	0.02	0.01
9/9/2015	0.000	0.000	0.00	0.00
9/13/2015	0.000	0.000	0.00	0.00
9/15/2015	0.000	0.000	0.00	0.00
9/29/2015	0.000	0.000	0.00	0.00
10/3/2015	0.000	0.000	0.00	0.00
10/4/2015	0.000	0.000	0.00	0.00
10/5/2015	0.000	0.000	0.00	0.00
10/6/2015	0.000	0.000	0.00	0.00

Appendix A table9: Annual sediment yield of Alekt Wenz watersheds for 2016.

	Treated	Untreated
date	Sediment yield(ton $ha^{-1}yr^{-1}$)	Sediment yield (ton $ha^{-1}yr^{-1}$)
5/28/2016	0.01	0.01
5/29/2016	0.00	0.02
5/30/2016	0.00	0.01
5/31/2016	0.01	0.02
6/19/2016	0.01	0.04
6/20/2016	0.00	0.07
6/24/2016	0.00	0.08
7/1/2016	0.00	0.04
7/2/2016	0.01	0.07
7/3/2016	0.01	0.01
7/4/2016	0.01	0.03
7/5/2016	0.00	0.03
7/6/2016	0.01	0.02
7/7/2016	0.01	0.02
7/8/2016	0.02	0.02
7/9/2016	0.01	0.03
7/10/2016	0.02	0.11
7/11/2016	0.01	0.11
7/12/2016	0.02	0.07

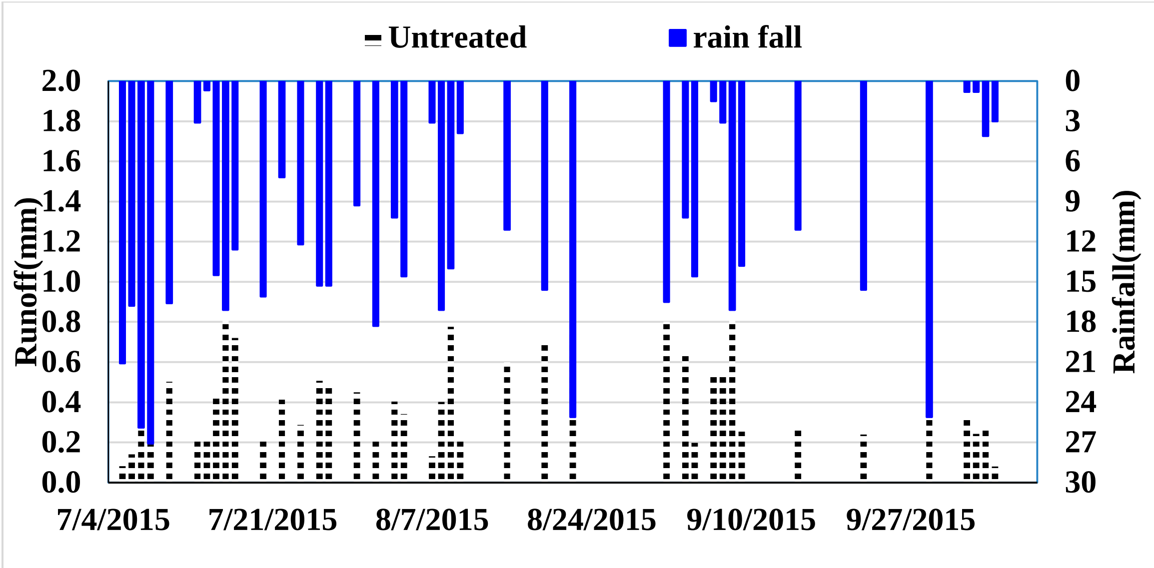
7/13/2016	0.01	0.05
7/14/2016	0.01	0.03
7/15/2016	0.02	0.04
7/16/2016	0.11	0.08
7/17/2016	0.01	0.06
7/19/2016	0.01	0.01
7/20/2016	0.00	0.03
7/21/2016	0.03	0.02
7/22/2016	0.01	0.05
7/23/2016	0.01	0.04
7/24/2016	0.01	0.02
7/25/2016	0.02	0.02
7/26/2016	0.02	0.02
7/27/2016	0.02	0.06
7/28/2016	0.01	0.03
7/29/2016	0.01	0.03
7/30/2016	0.01	0.06
8/1/2016	0.01	0.08
8/2/2016	0.01	0.07
8/3/2016	0.01	0.07
8/4/2016	0.01	0.01
8/5/2016	0.03	0.04
8/6/2016	0.00	0.00
8/9/2016	0.00	0.38
8/16/2016	0.00	0.03
8/17/2016	0.00	0.02
8/18/2016	0.00	0.11
8/19/2016	0.00	0.01
8/20/2016	0.00	0.01
8/21/2016	0.00	0.00
8/22/2016	0.00	0.00
8/23/2016	0.00	0.06
8/30/2016	0.00	0.05
9/2/2016	0.00	0.02
9/3/2016	0.00	0.00
9/9/2016	0.00	0.00

Appendix A table10: Dissolved nutrient losses from Alekt Wenz watersheds in 2016 of the rainy season.

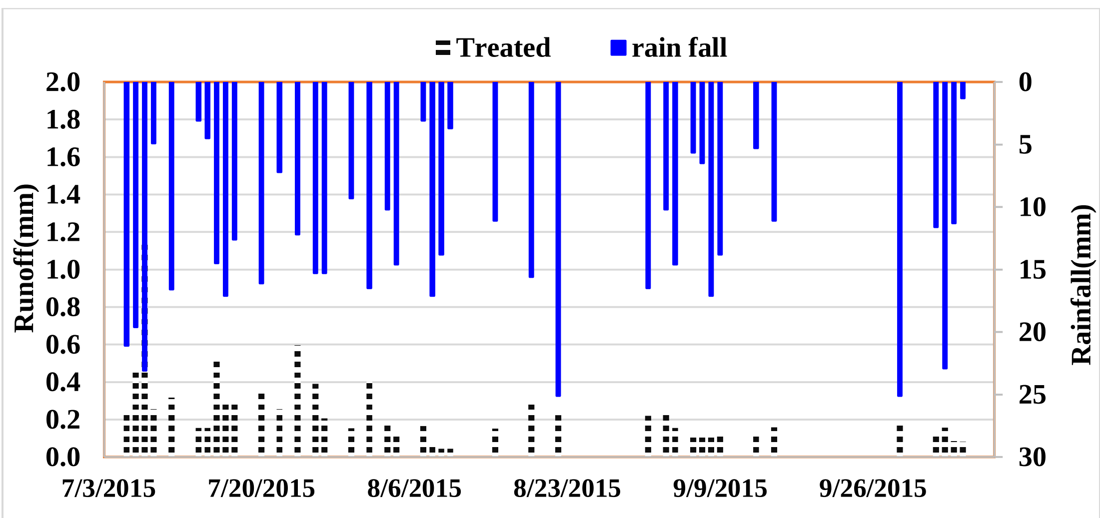
	Treated		Untreated	
Date	Dissolved phosphorus (kg $ha^{-1}yr^{-1}$)	Dissolved nitrogen (kg $ha^{-1}yr^{-1}$)	Dissolved phosphorus (kg $ha^{-1}yr^{-1}$)	Dissolved nitrogen (kg $ha^{-1}yr^{-1}$)
5/28/2016	0.001	0.001	0.000	0.003
5/29/2016	0.000	0.000	0.001	0.006
5/30/2016	0.000	0.000	0.001	0.001
5/31/2016	0.001	0.000	0.001	0.002
6/19/2016	0.001	0.001	0.002	0.003
6/20/2016	0.000	0.000	0.001	0.004
6/24/2016	0.000	0.000	0.003	0.003
7/1/2016	0.000	0.000	0.001	0.001
7/2/2016	0.000	0.001	0.002	0.005
7/3/2016	0.002	0.001	0.000	0.001
7/4/2016	0.001	0.001	0.000	0.004
7/5/2016	0.000	0.000	0.068	0.006
7/6/2016	0.000	0.001	0.001	0.002
7/7/2016	0.000	0.001	0.001	0.002
7/8/2016	0.001	0.014	0.002	0.004
7/9/2016	0.001	0.012	0.002	0.005
7/10/2016	0.001	0.002	0.004	0.018
7/11/2016	0.002	0.001	0.001	0.022
7/12/2016	0.002	0.003	0.002	0.039
7/13/2016	0.001	0.001	0.001	0.002
7/14/2016	0.000	0.003	0.002	0.005
7/15/2016	0.001	0.004	0.001	0.056
7/16/2016	0.001	0.001	0.006	0.011
7/17/2016	0.003	0.001	0.000	0.012
7/19/2016	0.004	0.000	0.002	0.003
7/20/2016	0.000	0.000	0.001	0.001
7/21/2016	0.001	0.003	0.000	0.000
7/22/2016	0.001	0.004	0.001	0.013
7/23/2016	0.006	0.004	0.001	0.001
7/24/2016	0.001	0.001	0.001	0.001
7/25/2016	0.000	0.027	0.001	0.050

7/26/2016	0.002	0.002	0.000	0.005
7/27/2016	0.001	0.002	0.002	0.003
7/28/2016	0.001	0.003	0.002	0.004
7/29/2016	0.002	0.006	0.002	0.004
7/30/2016	0.000	0.002	0.010	0.006
8/1/2016	0.000	0.000	0.001	0.005
8/2/2016	0.000	0.002	0.001	0.012
8/3/2016	0.001	0.010	0.004	0.002
8/4/2016	0.001	0.001	0.003	0.001
8/5/2016	0.003	0.003	0.001	0.001
8/6/2016	0.000	0.000	0.000	0.000
8/9/2016	0.000	0.000	0.012	0.010
8/16/2016	0.000	0.000	0.002	0.002
8/17/2016	0.000	0.001	0.002	0.001
8/18/2016	0.000	0.001	0.005	0.010
8/19/2016	0.000	0.000	0.000	0.001
8/20/2016	0.000	0.000	0.000	0.001
8/21/2016	0.000	0.001	0.000	0.000
8/22/2016	0.000	0.001	0.000	0.002
8/23/2016	0.000	0.001	0.001	0.002
8/30/2016	0.000	0.001	0.003	0.001
9/2/2016	0.000	0.001	0.001	0.006
9/3/2016	0.000	0.001	0.000	0.000
9/9/2016	0.000	0.001	0.000	0.000

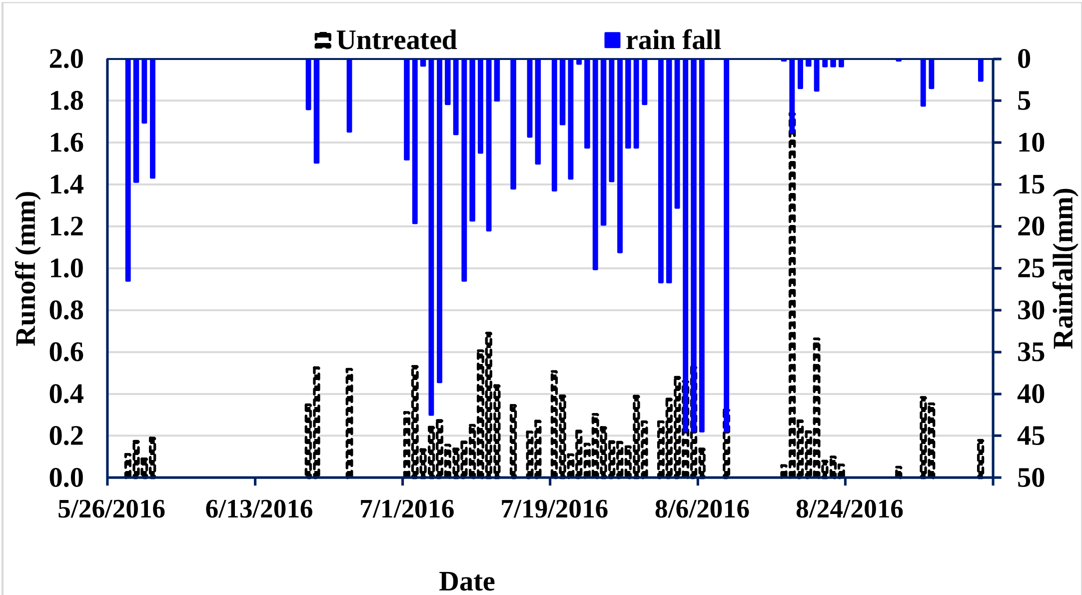
Appendix B: stream flow time series and perched groundwater level plot



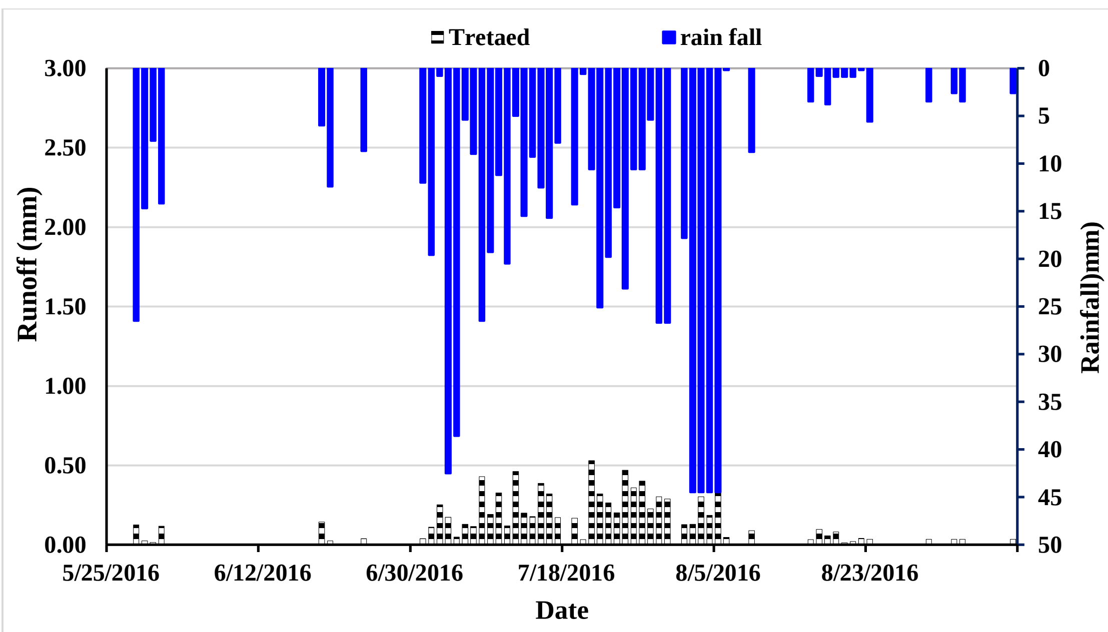
Appendix B Figure 1: rainfall-runoff relationship of the untreated watershed for 2015 of the rainy season.



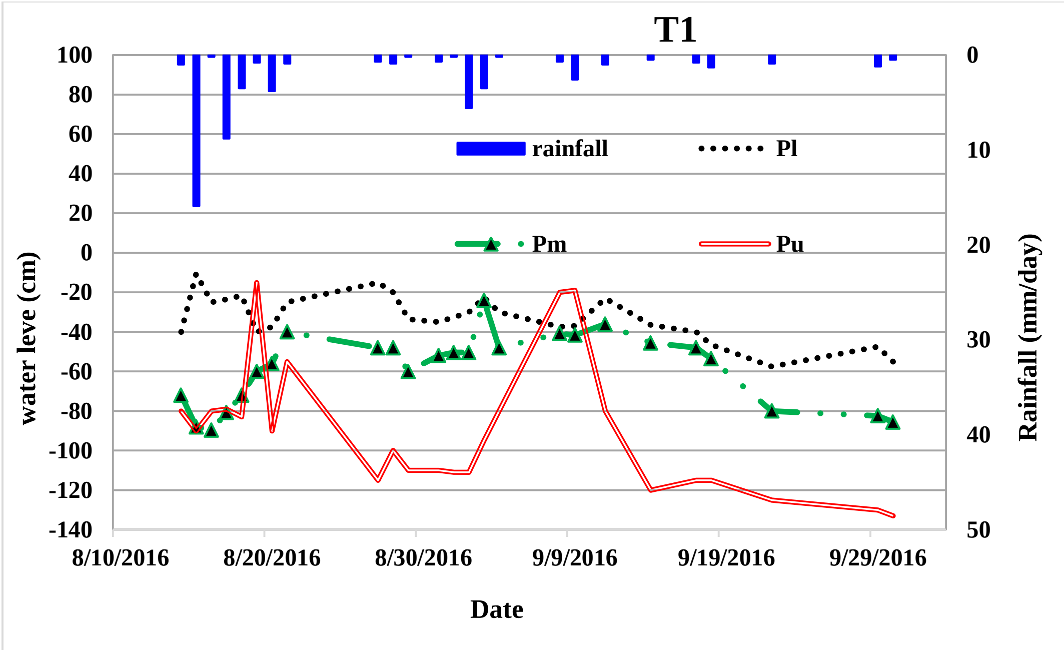
Appendix B Figure 2: rainfall-runoff relationship of the treated watershed for 2015 of the rainy season.

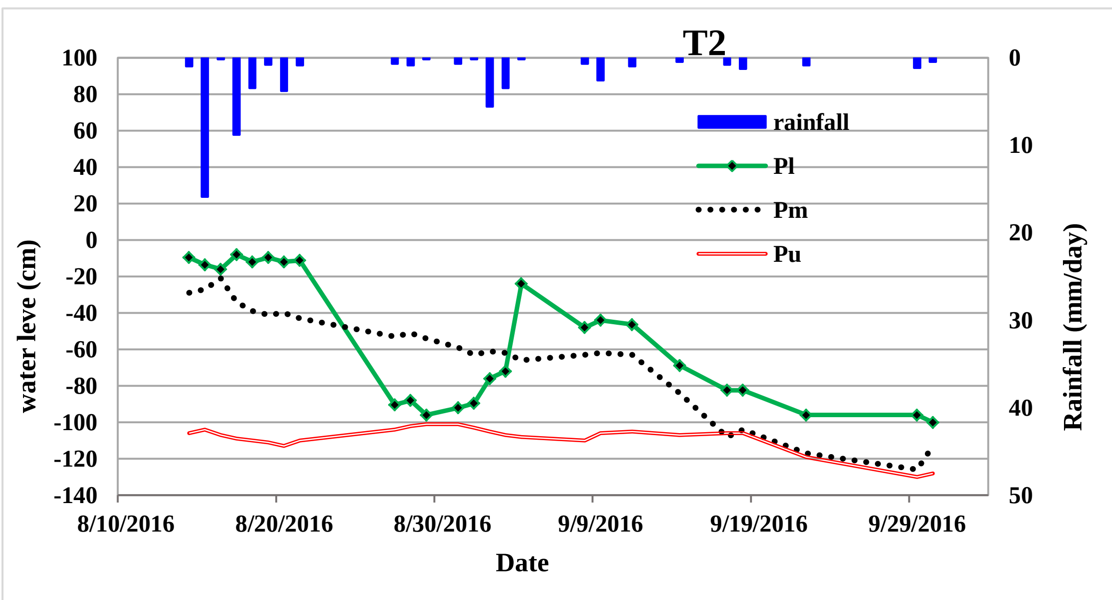


Appendix B Figure 3: rainfall-runoff relationship of the untreated watershed for 2016 of the rainy season.

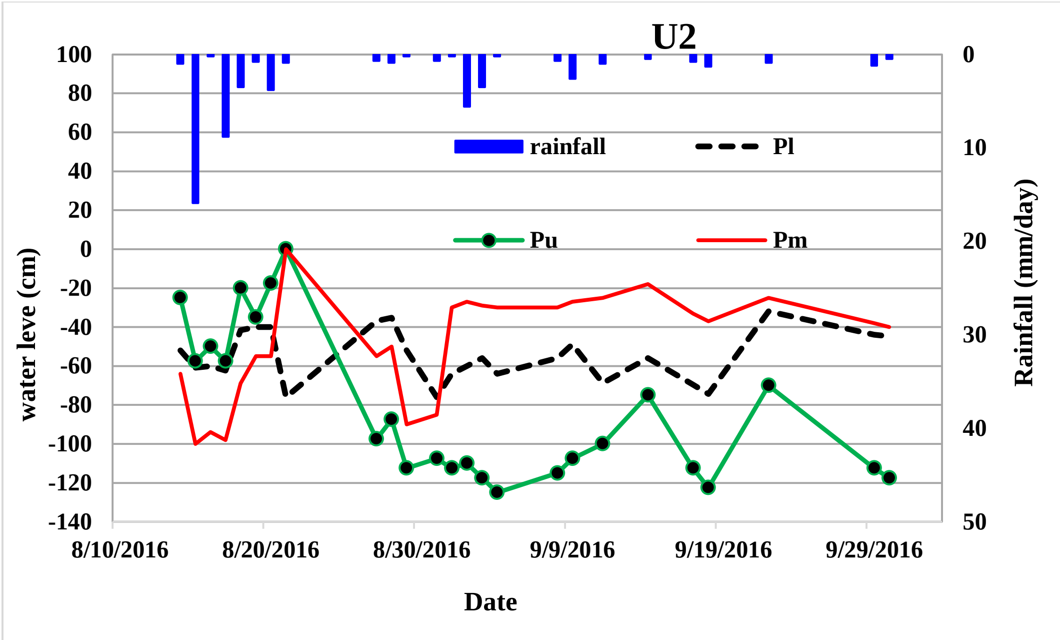


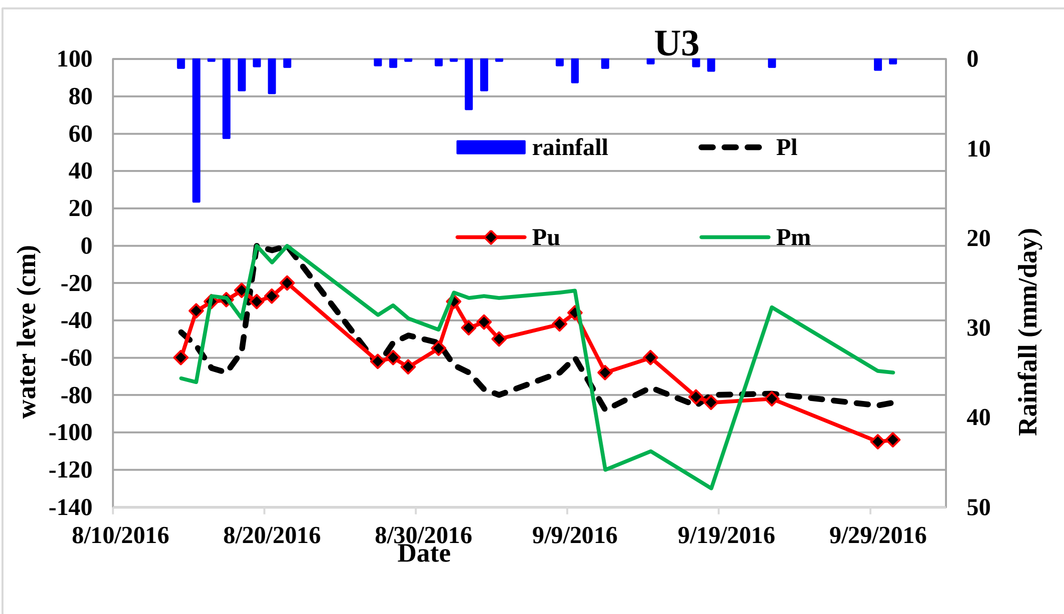
Appendix B Figure 4: rainfall-runoff relationship of the treated watershed for 2016 of the rainy season.





Appendix B Figure 5: Water level measured from (T1 = transect one, and T2 = transect two) from the treated watershed, (where Pl= piezometer at the lower slope, Pm= at the middle slope and Pu= at the upper slope).





Appendix B Figure 6: Water level measured from (U2 = transect two, and U3 = transect three) from the untreated watershed, (where Pl= piezometer at the lower slope, Pm= at the middle slope and Pu= at the upper slope).

A

B

C

D

Appendix B Figure 7: Pictures illustrated sediment filtration (A), staff gauge cross section defined (B), piezometer installation (C), and dissolved nutrient test (D).