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ESTIMATION OF SOIL LOSS AND SOIL EROSION MAPPING; THE CASE OF SHAR WATERSHED

BY

DESALEGN DEGEFU

ADVISOR DR. SEFU ADDIMASU

Bahir Dar, Ethiopia

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ESTIMATION OF SOIL LOSS AND SOIL EROSION MAPPING; THE CASE OF SHAR WATERSHED

DESALEGN DEGEFU

A Thesis submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, BDU in partial fulfillment of the requirements for the degree of

Master of Science in the Water Resource Engineering (Engineering Hydrology)

Advisor Name: Seifu Adimassu (Ph.D.)

Bahir Dar, Ethiopia

May 13, 2018

DECLARATION

I, DESALEGN DEGEFU WENDIE, hereby declared that this thesis entitled **"Estimation of soil loss and soil erosion mapping**; **The case of Shar watershed, Ethiopia"** submitted for the partial fulfillment of the requirements for the Masters of Science in Engineering Hydrology, is the original work done by me under the supervision of Seifu Admmasu (PhD.). This thesis has not been published or submitted elsewhere for the requirement of a degree program to the best of my knowledge and belief. Materials or ideas of other authors used in this thesis have been duly acknowledged and references are listed at the end of the main text.

Name of the student Desalegn Degefu Signature _____________

Date of submission: ________________

Place: Bahir Dar

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

Advisor Name: __________________________________

Advisor's Signature: ______________________________

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CIVIL AND WATER

RESOURCES ENGINEERING

Estimation of soil loss and soil erosion mapping; The case of Shar watershed, Ethiopia

By Desalegn Degefu Signature Date

The following graduate faculty members certify that this student has successfully presented the necessary written final thesis and oral presentation for partial fulfillment of the thesis requirements for the Degree of Master of Science in *Water resource Engineering (Engineering Hydrology)*

Approved By:

Advisor:

____

Name Signature Date

External Examiner:

____

Name Signature Date

Internal Examiner:

____

Name Signature Date

Chair Holder:

Name Signature Date

Faculty Dean:

Name Signature Date

BIOGRAPHICAL SKETCH

Desalegn Degefu Wendei was born in 1980 and grew up in Arjo, Ethiopia. After he attends high school education in Arjo comprehensive school, he joined to Ambo college of Agriculture in 2001 to study diploma in general Agriculture. After completed his diploma in 2002 he served Bullen Agricultural office for 7 years and he joined Haromaya University 2005 to study Bachelor of Science in Soil and Water Engineering and Management. After completed his BSc in 2009 he served Bullen Wereda Water, Mining and Energy office for 5 year. During the time of work he was served communities without, hesitate. Then he joined to Bahir Dar University in 2014 to learn Master of Science in department of water resource engineering with specialization of engineering hydrology. He prepared his master research to Estimation of soil loss and soil erosion mapping ; The case of shar watershed, Ethiopia

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ABSTRACT

Soil erosion is a severe environmental problem in many parts of the world. Efforts should be concentrated to decrease hazards of high erosion rates. This requires erosion hotspot areas assessment to identify critical areas where urgent conservation needed.

The revised universal soil loss equation (RUSLE) model with GIS and suspended sediment concentration measurement used to estimate the soil loss rate and to spatially identify high erosion areas in shar watershed with a size 8211 ha, Beles (main Belese) Sub Basin that is part of upper Blue Nile Basin of Ethiopia, to prioritize areas for conservation planning. Monthly precipitation, soil map, 30 m DEM (Digital Elevation model) and satellite image were used to determine the USLE (universal soil loss equation) values and combined on a cell-by-cell grid modeling procedure to predict soil loss.

The total sediment yield was 41082.2 ton/year; mean annual sediment yield was 5.00 ton/ha/year. From this model, the total soil loss estimated at 92749 ton/yr. The mean annual soil loss for the watershed was 11.28 ton/ha/yr. The east, central and southwest parts of the watershed constitutes 38 % of the total area and its soil erosion estimated greater than 10 ton/ha/year. The lowest soil erosion rate (<10 ton/ha/year) was observed from 62% of the area in the southwestern, western and northwestern parts of the watershed. From digitalized gully, area 89 % found between Stream power index 2.16 to 6.15 gully and total area of 472 Ha and from sample measurement of gully average width 3 m average depth of 1.3 m which is clustered at areas of high-population, high slope, river crosses specially by cattle's, and mining sites. RUSLE (Revised universal soil loss equation) could not locate gully hotspot area so it should be modified. The sediment delivery ratio of the watershed estimated at 44 %. The sediments transported from the watershed are already affecting reservoirs and irrigation canals in the downstream catchment of the sub basin. Using the estimated soil erosion rates, the watershed was divided into priority categories for conservation intervention. Micro watershed prone to severe soil erosion risks are Lower Tsunts (18.5 t/h/y), Right Tsunts (17.23 t/h/y), Meti and shar (14.66 t/h/y), Upper Gich mindi and Dawi (13.43 t/h/y), Upper Tsunts (10.80 t/h/y) and Endeg(10.34 t/h/y) these need immediate attention for soil conservation and watershed management planning.

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LIST OF ABBREVATIONS

DEM Digital Elevation Model

ETM+ Enhanced Themati Mapper Plus

EUROSEM European Soil Erosion Model

FAO Food and Agricultural Organization

MMF Morgan Morgan and Finney

GIS Geographic Information System

GPS Global Positioning System

MUSLE Modified Universal Soil Loss Equation

RUSLE Revised Universal Soil Loss Equation

SDR Sediment delivery ratio

USLE Universal Soil Loss Equation

UTM Universal Transverse Mercator

WEPP Water Erosion Prediction Program

SPI Stream power index

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1. INTRODUCTION

1.1. Background

Soil erosion is considered as one of major land degradation process, which is also the main source of environmental deterioration. It creates negative impacts on agricultural production, infrastructure, and water quality (Vrieling, 2006). Soil erosion is also the natural phenomenon, which is caused by natural force; it can be more accelerated when the process is influenced by human activities. It is considered that the accelerated soil erosion is a serious global problem and widely recognized (de Graaf, 1996). With the accelerated erosion, it can affect land productivity and flooding, sedimentation of reservoirs, siltation of agriculture field and decrease of water quality downstream.(Hudson, 1986)
Ethiopia is one of the developing country that seriously affected by land degradation caused by soil erosion, particularly the highland parts. The loss of considerably significant amount of soil attributed to various factors, of which the dominant causes of land degradation are population pressure, overgrazing and cultivation, deforestation, unsustainable agricultural production, erosive rainfall and rugged terrain features (Ethiopian Highland reclamation studies, 1984). Average soil losses due to erosion estimated as 12 tons per hectare per year or an estimate of 1493 million tons of soil per year. In contrast, the soil formation rate for Ethiopia is less than 2 tons per hectare per year, which is very low compared to soil erosion rates (Mahmud *et al.*, 2005).

To reduce soil erosion, land management interventions have been in place since 1980's (Binyam and Desalegn 2014). Mapping of soil erosion area is a prerequisite to prioritize intervention areas within the landscape. Soil erosion assessment and mapping of erosion prone area serve multidimensional purposes in watershed management actions. A critical component to the sustainability of any watershed management program is the ability to utilize limited resources and time most effectively to address priority areas, particularly in large watersheds. In fact, a range of sophisticated assessment tools currently exists to assist decision makers to identify key areas for the implementation of watershed management programs (Moltz, 2011). For instance, the hydrologic models that provide detailed assessments of hydrologic processes, calculate sediment loads applied at the field, and sub watershed scale. Process-based models provide for aiding water resources management at small-scale level. On the other hand, the accuracy of process-based hydrologic models of non-point pollution decreases with the increasing size of the system being modeled (Novotny, 1994). Large watersheds, like Shar watershed, show landscape variability that cannot accurately categorized at a minimal expense with process-based hydrologic models. Thus, an alternative would be the empirical based model tested and widely used USLE. This is acceptable for large watershed; limited data can be used to provide an initial identification of hot spot.

GIS is a tool for examining erosion hazard over large geographical areas, commonly used by decision makers and regulatory organizations. The basic data are often readily available and the results are usually easily understood and geographically representative (Maidment and Saunders, 1996). Although it may require large datasets in some cases, GIS has been shown to be very useful and capable for application to wide geographical areas because of its powerful analytic capabilities (Dayaw *et al.*, 1997).Therefore, USLE was preferred because of its simplicity in use, easiness of integration with GIS and their performance at watershed or a catchment level.

Most studies in soil erosion assessment are mainly focusing on estimating the rate and quantity of soil loss with different estimation result for similar landscape in Ethiopia (Gerawerk, 2014). Specific to Beles sub basin, which consists study area (shar watershed) and a part of Blue Nile basin estimation of rate of soil loss using USLE at Sub-Basin level for baseline information. This however could not go further than Baseline data but not assess soil erosion risk at watershed level for soil conservation program. Therefore, estimating rate and quantity of soil loss using USLE model with measuring sediment concentration, identifying gully location, area and density, and determining the location of priority areas is a critical factor and timely implementation for decision makers. This is critically important for the reduction of soil loss by developing and performs effective and economical erosion prevention programs. Thus the aim of this study was, to assess spatial erosion susceptibility in shar watershed using RUSLE model in a GIS environment, measuring the sediment concentration at the outlet of shar watershed, and identifying gully location and density.

This will help identifying and prioritizing areas susceptible to erosion for soil conservation planning and compering rate of soil loss obtained by model and measurement.

1.2. Problem Statement

Ethiopia seriously affected by soil erosion. Study area affected by soil erosion. Most studies in soil erosion assessment are mainly focusing on estimating the rate and quantity of soil loss with different estimation result for similar landscape in Ethiopia. The study area is located in Bullen wereda, Metekel zone, Benishangule gumuz regional state, North West part of Ethiopia. This area has been one of the most intensive agricultural areas in Highland of Ethiopia. The conversion of forest to agricultural land has been taking place. This area depends on biomass as source of energy and produce charcoal for trade illegally. In 1980s the water table was found at an average depth of 2 m but at this time it moves down and found at an average 6.5 m, number of spring ware reduced from more than 10 to 3. Dawi river was flow bank fully year round but currently it flows for about seven months (Jun to December), shar river reduced severely. The natural beauty of the area converted to degraded and woeful condition.

With the increasing of the population, the cultivation in the steep area, improper mining development, Gravel Road Maintenance without not considering soil erosion and improper dry season road construction has been taking place. The removal of natural forest and vegetation cover in steep slope and followed by improper land use practices have led to the various land degradation problems in the area. Each year during the rainy season, a lot of topsoil eroded and the agricultural and other lands are affected. Beles sub_basin report indicates the averge vegitation cover of the wereda dicreases 10 % per year for the last 11 years.

Bullen wereda agricultural office report indicates about 2000 ha of land was out of function due to erosion. In addition, water mining and energy development office report shows one deep well which is the source of water supply of Bullen town with all its facilities damaged by landslide (riverbank slide). On the other hand, the eroded soil and sediments, which are transported by the surface runoff, affect the downstream land.

Therefore, this research tries to estimate the current sediment yield and map soil erosion areas of shar watershed, which is part of the least studied Belese Basin.

1.3. Objective of the study

General objective: The general objective of this study is to estimate sediment yield, identify, and prioritize areas susceptible to erosion using observations and USLE.

Specific objectives: The Specific objectives were

i. To monitor stream flow and sediment concentration at the outlet of shar watershed
ii. To map hotspot soil erosion areas using USLE
iii. To map hotspot gully potential areas using stream power index

1.4. Scope of the study

This study is a watershed level study and thus focuses on the identification of soil loss risk area and identification of the most soil erosion susceptible micro-watersheds. Thus, sediment yield was estimated from measurement and RUSLE model were used for the estimation of soil loss rate. As the model cannot estimate soil loss caused by gully erosion, potential gully areas were identified by SPI (stream power index) threshold concept to identify soil erosion hazard areas.

1.5. Significance of the study

Shar watershed is highly affected by soil erosion that is difficult to implement rehabilitation and soil and water conservation works in the entire watershed. Thus, purpose of the study is to estimate sediment yield by measurement at the outlet, relation of runoff and sediment yield, estimate rate of soil erosion by USLE and the susceptibility of the micro-watersheds and identify factors that contribute most soil-erosion rate. In addition, it contributes in reducing erosion problem on time and in a cost effective manner. The result of this study will be used as an input data for development of integrated watershed management and other studies.

2. LITERATURE REVIEW
2.1. Land degradation

Land degradation is a serious problem in highlands of Ethiopia. Regardless of the expanding desertification and the frequent drought, the land and water resource is highly threatened by deforestation, improper cultivation and over grazing among others. However, soil degradation and deforestation are major forms of environmental degradations, which directly or indirectly reduce land productivity.

The key reasons of land degradation are overgrazing, over cultivation, extensive clearing of vegetation for agriculture and fuel wood; deforestation; extensive cultivation of marginal lands; the use of inappropriate agricultural technology; poor management of arable land ; topography and soil characteristics and others.

In general environmental degradation, mainly soil depletion, and deterioration of vegetation cover, are among the major factors that results into decline in land productivity such as; farm lands, pasture, rangeland, forest and woodlands. Studies by (Food and Agricultural Organization, 2000b) states that soil erosion is the most widely recognized cause of falling productivity; and the effect may include food insecurity, economic stress, and loss of biodiversity.

The Ethiopian highland reclamation studies revealed that the Ethiopian highlands that cover 44% of the country's total land area, seriously threatened by land degradation. On average Ethiopia losses 12 tons of soil per hectare per year, and 1493 million tons of soil per year due to erosion. On the other hand, the soil formation rate for Ethiopia is less than 2 ton per hectare per year, which is very low compared to soil erosion rates. Annually, Ethiopia loses about 1-1.5 million tons of grain due to soil erosion (Hunri, 1988; Mahmud *etal.*,2005) The problem of arriving at a mutually agreed definition arises from continuously changing perceptions on what constitutes land degradation, its causes, processes, and manifestations. This has led to the development of non-comprehensive land degradation assessment methods that focus on particular aspects of land degradation, either soils or vegetation. In the present study, rate and area of soil loss that is a form of land degradation considered.

2.2. Soil erosion

Soil erosion is the removal of soil by forces of nature more rapidly than various soil forming processes can replace it (Roo A. , 1993). The cause of Soil erosion is the interaction between rainfall as an erosive agent and soil as a medium that is detached, and transported (Nanna, 1996). These processes generally determined by locational factors including soil, climate, topography, vegetation, and soil conservation measures.

In many part of the world soil erosion, is considered as the most serious environmental problem because it threatens the environment and agriculture (Hagos, 1998). Erosion degrades soil by removing topsoil, decreasing plant nutrients, rooting depth and water reserve. Growth of population, overgrazing and agricultural activities on steep slopes with marginal soils in combination with heavy and erratic rainfall, make large areas extremely sensitive to erosion (Petter, 1992). The degradation of soil by erosion is of particular concern because soil formation is extremely slow (Hagos, 1998). Among the consequences of soil erosion is the reduced ability of cultivating possibilities on eroded hill slides and sedimentation of water reservoirs, which reduces irrigation possibilities and leads to decreased agricultural production. The potential erosion risks are higher under intensive arable land use than under forestry or pastureland.

2.3. Rainfall

Soil loss is related to rainfall through the effect of detachment by raindrops striking the soil surface and by runoff (Mkhonta, 2000). The ability of rainfall to cause erosion depends on characteristics such as rainfall energy and rainfall intensity particularly half-hour rainfall. These characteristics determine the ability of raindrops to detach soil particles and the possible occurrence of surface runoff, a primary means for transportation and deposition of detached soil particles (Nanna, 1996). The amount of rainfall governs the overall water balance and the relative proportion that becomes runoff (Hagos, 1998). Erosion is related to rainfall events, the characteristics affecting splash detachment. Detachment is due to the size of the raindrop and its velocity. Big raindrops have high erosive power to detach the soil particles (Nanna, 1996). The amount of rainfall governs the overall water balance and the relative proportion that becomes runoff (Hagos, 1998). Erosion is related to rainfall events, the short-lived intense storm where the infiltration capacity of the soil is exceeded, and the prolonged storm of low intensity, which saturates the soil before runoff begins. In addition to the rainfall amount, drop size distribution, kinetic energy, and depth of overland flow are important characteristics affecting splash detachment. Detachment is due to the size of the raindrop and its velocity. Big raindrops have high erosive power to detach the soil particles

2.4. Soils

The resistance of soil to both detachment and transport is a soil erodibility factor (Morgan R. , 1995). Soils with high erodibility index are more sensitive to erosion than soils with low erodibility index. Soil erodibility (K-factor), varies with soil characteristics, e.g., texture, bulk density, shear strength, organic matter content, aggregate stability, infiltration capacity, chemical properties and transport ability of loosened soil particles (Mkhonta, 2000). The aggregate stability of a soil determines how easily soil particles can be detached. Transportability determines how easily these loosened soil particles can be washed away.

Particle size is an important element in soil erodibility. Larger particles are more resistant to transport due to greater force entailed to move them. However, in soils with particles less than 0.06 mm, the erodibility is limited by the cohesiveness of the particles. This is a reversed relationship compared to that of particle size. The particles that are less resistant to erosion are therefore silt and fine sand (Petter, 1992). Soil texture also influences the infiltration capacity. This is defined as the maximum sustained rate at which soil can absorb water, and depends on pore size, pore stability and the form of the soil profile. Clay soils have a low infiltration capacity and produce more overland flow than soils consisting of coarser material, with higher infiltration capacity (Petter, 1992).

2.5. Vegetation

Vegetation covers is a fundamental factor in decreasing soil loss (Petter, 1992). In general, as the protective canopy of land cover increases, the erosion hazard decreases (Mkhonta, 2000). It protects the soil against the action of falling raindrops, increases the degree of infiltration of water into the soil, maintains the roughness of the soil surface, reduces the speed of the surface runoff, and binds the soil mechanically. It diminishes micro climatic fluctuations in the uppermost layers of the soil, and improves the physical, chemical, and biological properties of the soil (Petter, 1992). As long as vegetation cover is continuous, erosion and runoff are small despite erosivity of the rainfall, slope steepness, and soil instability. The effects of vegetation cover on erosional processes especially on surface erosion are varied depending on the type of vegetation cover, density, undergrowth cover, and litter. These determine the interception loss, absorption of kinetic energy and increasing water infiltration. Land with good cover allows soil retardance to overland flow. Vegetation acts as a protective layer or buffer between the atmosphere and the soil. The above ground cover absorbs energy of falling raindrops, running water and wind, so that less is directed at the soil. The below ground components comprising the root system contribute to the mechanical strength of the soil (Hagos, 1998).

2.6. Management

Farming of very steep slopes and marginal can accelerates soil erosion if there are no proper conservation techniques applied. Proper management practices such as Mechanical and biological conservation techniques significantly reduce soil erosion. On the other hand improper land use, such as reclamation of forest area, cultivation of steep slopes without conservation, can severely promote soil erosion.

2.7. Topography

Slope steepness and slope length have a strong relationship to erosional process and useful in quantitative estimation of erosion. Slope gradient and slope length are the common parameters used in erosion modeling (Petter, 1992). Slope gradient has an exponential relationship with erosion. Steep slopes are more susceptible to soil erosion because the erosive forces splash, scour, and transport all have a greater effect on steep slopes (Hudson, 1995). On the other hand, longer slopes are more susceptible to soil loss due to greater buildup of surface runoff, velocity, and depth.

2.8. Scale of erosion assessment

Soil erosion has been assessed at different levels using a variety of methods (Mainam, 1999). These can be grouped into three levels following the objectives of assessment. They include: micro plot level, plot level and watershed level. At micro plot level (0.5 to 2 m^2), evaluations are conducted under controlled conditions to study erosion processes such as splash or interill erosion and the effects of soil properties on them. Studies at plot level conducted mainly under natural conditions. The scale varies from a few square meters to a few hectares. Soil erosion scale at field scale allows the evaluation of the effects of farming practices, land use systems, or topographic factors. The study of soil erosion at watershed level involves areas covering hundreds and thousands of square kilometers and deals with streams and river basins. It is used to assess the erosion rates of large areas such as river basins and at regional level

2.9. Soil erosion model

Model is a simplification of processes and their interactions with the aim of extracting, evaluating, and simulating the relevant processes Renschler (1996). The objective of soil erosion models is either predictability or explanatory (Petter, 1992). Erosion models are currently the most feasible approach in generating data on erosion hazard (Meijerink and Lieshout, 1996). Models explain on erosion through mathematical equations in a simplified form. However, the reality represented can differ from model predictions (Nanna, 1996). This can be due to the way of representation of particular models as well as the spatial and temporal scales model.

Several models have been developed and many are in the process. The main categories of erosion models are empirical, physical, stochastic, hybrid and rule based. Most erosion models are of empirical type. Stochastic models are models in which any of the variables included in the model are regarded as random variables having distributions in probability.

If all variables are regarded as free from random variation, the model is regarded as deterministic (Roo, 1993).

Models can be lumped or distributed. Lumped models take no account of the spatial distribution in the input variables (S), or of the spatial variation in parameters characterizing the physical processes acting upon input. Procedures may use to calculate effective values for the entire area.

Distributed models incorporate data concerning the spatial distribution of variables together with computational algorithms to evaluate the influence of the distribution on simulated behavior (Roo et al., 1994). Furthermore, models can be conceptual or empirical. A model is conceptual if the physical processes acting upon the input variable to produce the output variable are considered in terms of the physical laws. Empirical models are by strict definition based on observation and experiment, not on theory. The term physically based models is used to replace conceptual distributed models, because if models are physically based, meaning firmly based in our understanding of the physics of the processes, they are necessarily distributed because the equations on which they are defined generally involve one or more space coordinates.

2.10. Empirical models

Empirical models describe erosion using statistically significant relationships between assumed variables where a reasonable database exists (Kadupitiya, 2002a). Empirical models are based on defining important factors through field observation, measurement, experimentation and statistical techniques relating erosion factors to soil loss (Petter, 1992). In empirical models, the inherent processes involved are not used and the models can only be operated in the designed direction where inputs go into one side of the equation and the out-put on the other side. Empirical models are quick in predicting erosion. Empirical models are frequently used in preference to complex physically based models as they can be implemented in situations with limited data and parameter inputs, particularly as a first step in identifying sources and rate of soil loss (Merritt *et al.*, 2003). The most widely used empirical model in soil erosion studies is the USLE. Others include RUSLE, MUSLE, SLEMSA, DUSLE, etc which are based on modifications made on USLE. Some of selected empirical models are discussed.

The USLE is the most widely used model in predicting soil erosion. It is used in education and research as a starting point in developing understanding of erosion hazard prediction because of its simplicity and clarity (Hagos, 1998). Many scientists have proposed changes on factors, rainfall erosivity, soil erodibility, slope length, slope class, land cover and land management that directly proportional to the rate of annual soil erosion (Sohan and Lal, 2001).

RUSLE is a revised version of USLE, intended to provide more accurate estimates of erosion (Renard et al., 1994). It contains the same factors as USLE, but all equations used to obtain factor values have been revised. It updates the content and incorporates new material that has been available informally or from scattered research reports and professional journals. The major revisions occur in the C, P, and LS factors. The C or cover management factor is now the product of 4 sub factors: prior land use, canopy cover, soil surface cover and surface roughness.

The modified universal soil loss equation (MUSLE) is one of the improved versions of the USLE. The rainfall energy factor was replaced with runoff. The runoff factor includes both total storm runoff volume and peak runoff rate. Compared with USLE, this model is applicable to individual storms, and eliminates the need for sediment delivery ratios, because the runoff factor represents energy used in detaching and transporting sediment. The main limitation is that it does not provide information on time distribution of sediment yield during a runoff event. It is strictly a sediment yield equation and should not be used where detachment controls sediment yield (Roo, 1993).

The MMF model is an empirical model for predicting annual soil loss from field sized area on hill slopes (Morgan et al., 1984). It was aimed at bridging the gap between models such as USLE and CREAMS. The model has a stronger physical base than USLE and is simple and more flexible than CREAMS. The model separates the soil erosion process into two phases i.e. the water phase and the sediment phase. In the water phase annual rainfall is used to determine the energy of the rainfall for splash detachment and the volume of runoff, assuming that runoff occurs whenever the daily rainfall exceeds a critical value representing moisture storage capacity of the soil crop complex and that the daily rainfall amounts approximate an exponential frequency distribution. In the sediment phase, splash detachment is modeled using a power relationship with rainfall energy modified to allow for the rainfall interception effect of the crop. The model has been revised with new changes incorporated owing to the rise in data availability and difficulties in estimating certain parameters as in the original version. In the revised version, changes have been made to the way soil particle detachment by raindrop impact is simulated, which now takes account of plant canopy height and leaf drainage, and a component has been added for soil particle detachment by flow (Morgan, 2001).

2.11. Physical based model

Physically based models are based on fundamental erosion processes that define physical process. They are intended to represent the essential mechanisms governing erosion. The advantage of the physically-based models is that they can represent a synthesis of the individual component which is related to erosion, including the complex interactions between various factors and their spatial and temporal variations (Lal, 1994)

There has been several physically based models developed for soil erosion prediction, many of them are represented to the small area or plot scale, but there are few models developed for large scale for soil loss assessment. The representative models that included in the physically based method are: CREAM, ANSWER, WEPP, PESERA, EUROSEM and AGNPS etc. The main limitation of this model is high data demand.

2.12. Geographic information system and soil erosion modeling

Soil erosion is a spatial phenomenon, thus geo information techniques play an important role in erosion modeling. Remotely sensed data and existing maps provide a lot of data for model input (Petter, 1992). Data generated from RS can be linked with their spatial location for GIS applications (Mkhonta, 2000). GIS systems can deal with information about features that is geo-referenced. Generally geo-information techniques offer the following advantages in erosion modeling: - (1) Fast and cost effective estimates, (2) Possibilities to investigate larger areas, (3) Greater possibilities of continuous monitoring of these areas, (4) Possibilities to refine the soil erosion model depending on the required output scale i.e. rough global to more precise local scale.

The use of digital elevation models and GIS offers possibilities to estimate relevant topographical parameters. The size of a drainage basin, the mean slope, or the amount of water passing a certain point on the land surface (runoff), can be computed from a DEM (Petter, 1992). In this study, GIS and RUSLE was utilized to identify hotspot area and soil loss rate.

2.13. Direct measurement of soil loss

Field measurement of soil erosion is carried out at outlet of the watershed which both runoff and soil loss are monitored. By dividing the data obtained, it is possible to estimate the average (sediment yield) soil loss and average annual factors used for different empirical models such as USLE (Wischmeier and Smith, 1965). Direct measurements of soil losses are costly, labor intensive, and time consuming but data's accuracy is better than estimation by models and used to compare the soil loss estimated by RUSLE

2.14. Sediment delivery ratio and sediment yield

Sediment delivery ratio (SDR) is defined as the fraction of gross erosion that is transported for a given time interval. It is a measure of sediment transport efficiency, which accounts for the amount of sediment that is actually transported from the eroding sources to a measurement point or catchment outlet compared to the total amount of soil that is detached over the same area above that point. In relatively large catchments, most sediment gets deposited within the catchment and only a fraction of the soil that is eroded from the hill slope reaches the catchment outlet. Erosion rates estimated by USLE are often higher than those measured at catchment outlets. Sediment delivery ratio (SDR) is used to correct for this reduction effect (Andreas, 2006). An accurate prediction of SDR is important in controlling sediments for sustainable natural resources development and environmental protection.

3. METHODOLOGY AND MATERIALS

3.1. Description of the Study Area

The Shar watershed is located in the Benishangul Gumuz regional state in Metekel Zone near, which is one of the small watershed of Beles sub basin. The area lies between 1220000 N to 1120000 N and 140000 E to 180000 E. The total watershed area of shar watershed is 81 km^2

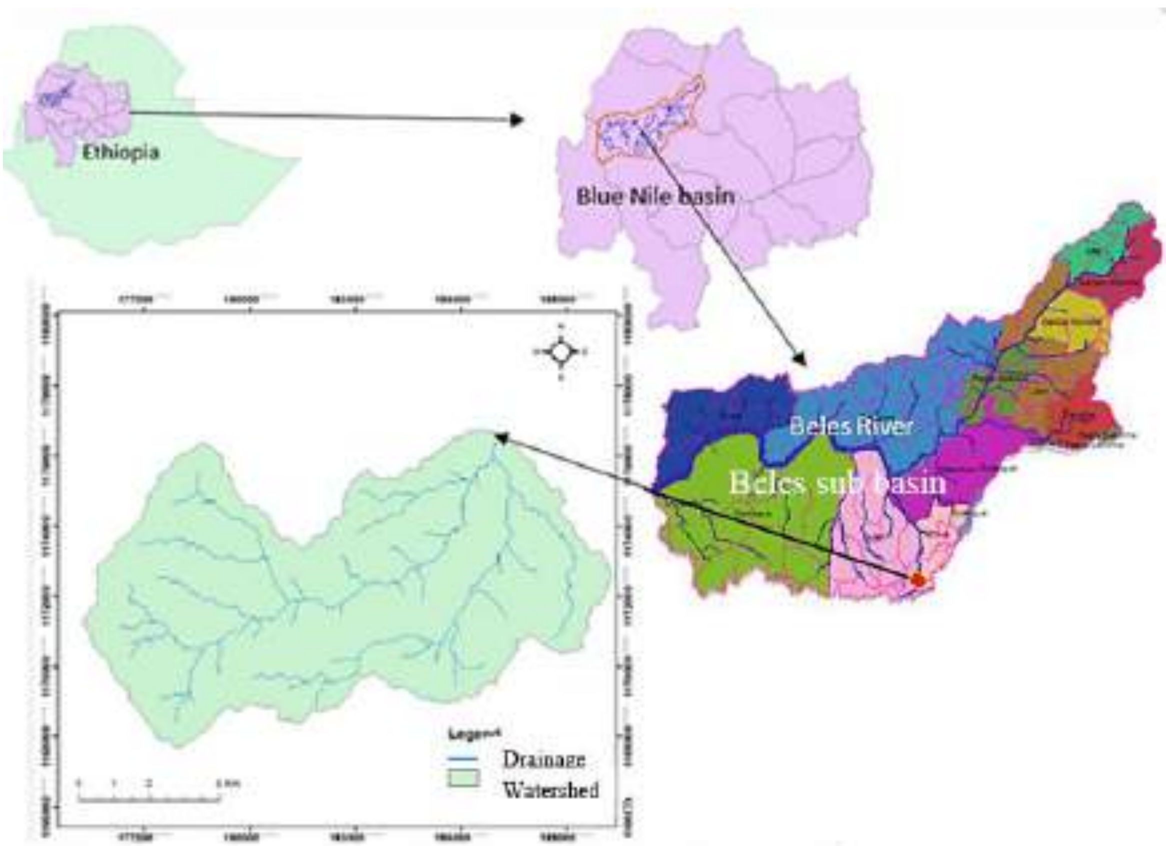

Figure 3:1 Map of the study area

3.2. Climate

The study area (Bullen wereda) is characterized by semi-arid climate. The area gets rainfall in the months May to October; and attains maximum in August. The maximum daily temperature of the area is 30.7 and the minimum is 11.6 occurring during the months of

April and December respectively. The study area receives mean annual precipitation (1980 to 2009) of 1462 mm (Figure 2 and Appendix 1).

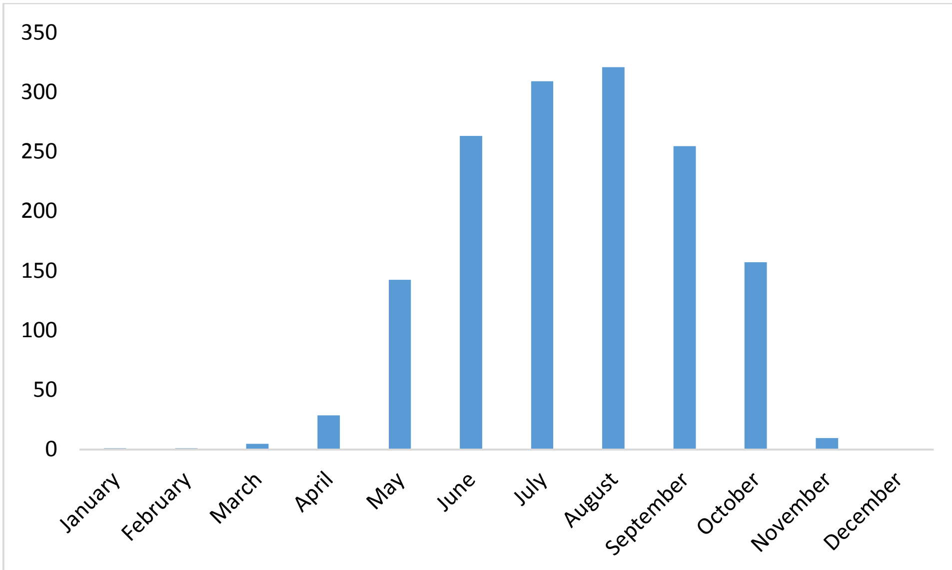

Figure 3:2 Mean monthly rainfall distribution in Bullen station

3.3. Soil type and Land use

For this study a soil data as per (FAO, 1988) soil group were collected from Bullen wereda water mining energy resource development office. Soils of the study area are Nitosols (92.1%) and Luvisols (3.4%) and Rock surface (3.6%) (296 ha) Their distribution and description are summarized in Table 1 and Fig 3. In Shar watershed the land use are farm land which is 12.4%, Grass land and Bushes (18.7%), Forest (33.4%), degraded land (35.5%).

Table 3:1 Major Soil Types, Soil Units, and their Characteristics in the Study Area

No	Soil type	Area (ha)	Description
1	Luvisols	(279) 3.4%	Dark reddish brown color, deep sandy-clay-loam soils, and well-draining
2	Nitosols	(5419) 92.1%	Low-activity clay, P fixation, many Fe oxides, strongly structured, reddish in color

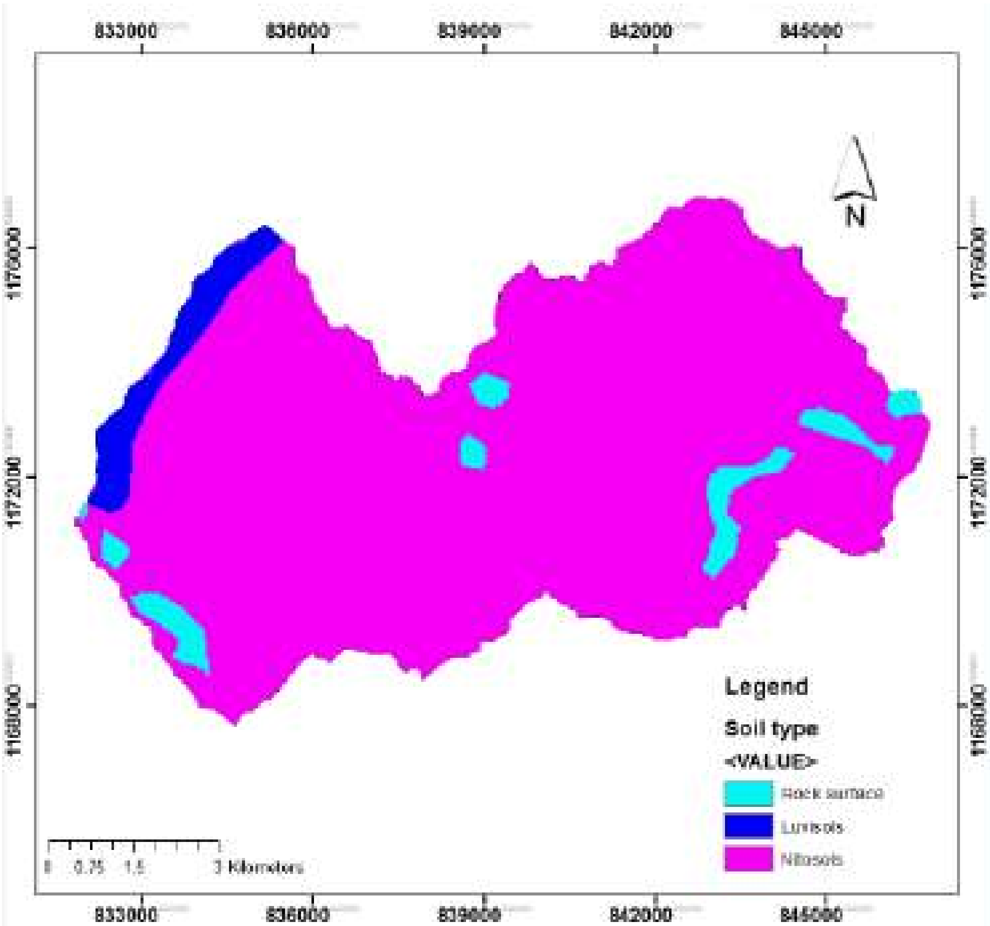

Figure 3:3 Soil type of study area

3.4. Topography

The average slope of shar watershed estimated as 5.18°. Large portion of the area fall in gently flat to undulating terrain (73.9%) and flat to almost flat terrain (15.7%) slope class. The elevations of the study area vary from 1396 m to 1900 m above mean sea level and majority of the watershed area are from 1396 m –1801 m above mean sea level.

Table 3:4 Slope of the study area

Slope	Class Name	Area (Ha)	Area (%)
0_2^0	Flat to almost flat terrain	1287.56	15.68
$2^0\_10^0$	Gently flat to undulating terrain	6073.98	73.97
$10^0\_15^0$	Rolling terrain	641.83	7.81
$15^0\_29^0$	Hilly Terrain	207.76	2.53
Total		8211.15	100

3.5. Gully

Report from Bullen wereda land use and Enviromental protectioa office indicates the watershed was significantly affected by gully, caused by inappropriate land use, road construction and maintenance, mining development and vegetation removal, which contributes to gully erosion especially at the steep and populated areas. As observed during field visit, during road maintenance the flow was diverted to open field and to stream without considering erosion this leads to gully formation. Inappropriate land use especially cultivation also contributes to gully formation. After construction stone and local gold mining, the excavated soil was not covered or maintained to protect erosion this also contributed to gully formation. Measurements were conducted during field visit the depth of gully is ranges from 0.4 m to 9 m average width 3 m average depth 1.3 m and area ranges from some 20 m^2 to 4500 m^2 and average length are 5 km was observed.

Figure 3.4 Gully erosion of study area

Figure 3.5 Quarry site (Construction stone)

Figure 3:6 Deep well source of water supply of Bullen Town (demolished due to riverbank erosion)

3.6. Source of Data and materials

3.6.1. Sources of Data

This research results were achieved with the utilization of different materials, spatial and attribute and measured data both primary and secondary and information collected in the study area. The primary data has two sub categories, these include, data from measurement sediment concentration, flow depth, velocity and discharge and second category includes data generated from remote sensing such as; satellite imageries, ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer , and Global Positioning System (GPS) surveying information collected from field using observation, and wereda office. Most of the spatial data was generated from DEM and satellite imageries in combination with ground control points collected using GPS. On the other hand, secondary data, such as; meteorological data, soil data, Land use Land cover map, were collected from different offices. These offices were Ethiopian Meteorological Agency, Bullen wereda water mining and Energy Resource Development office, Agricultural office and Land and Environmental office.

3.6.2. Materials and Soft wares used

Different materials used during this study include, One litter container (315 in number) for sampling one litter water to determine sediment concentration and 50 m measuring tape and 3 m steel measuring tape for river cross section measurement and other measurements. Graduated iron bar for measuring water elevation (Gauge). Cement, sand, gravel for anchoring gauges and 4 kg hammer, Ink, levels and 50 m long polyethylene rope for different uses. GPS and Digital Camera were used for ground trothing field data collection. Software used includes, ArcGIS 10.1 for GIS based DEM processing image classification and overlay analysis. Arc SWAT for micro watershed delineation. MS office packages for chart making, tabulation, and word processing.

No	Materials	Purpose
1	One litter container (Bottle)	For sampling water
2	Gauge (Graduated iron bar)	Installed across river to take water elevation
3	Cement, Sand and Gravel	To fixing Gauge

4	Level	To level Gauge marks to the next Gauge
5	Measuring Tap	For different measurements
6	Hammer	To Separate hard rock for Gauge installation
7	GPS	To locate watershed outlet, land use and Gully
8	Digital camera	To take river cross-section, Gully and different activities photo
9	Arc GIS	For DEM processing, image classification, stream power index and soil rate calculation
10	Arc SWAT	For micro watershed delineation
11	MS-Office package	For chart, tabulation and word processing

3.7. Data Analysis method

Methodology involved measurement of river flow and sediment concentration and calculating sediment yield for the watershed, calculating runoff and runoff coefficient and the use of adapted USLE model in a GIS environment with factors obtained from different sources. Each factor is considered as a thematic layer.

These layers were spatially overlaid and combined by cell by cell-grid modeling procedures in ArcGIS 10.1 to predict the mean annual soil loss in a spatial domain and produce a resultant layer of a composite map of erosion hazard intensity in ton/ha/ year. This intensity map was then classified into different priority classes upon maximum acceptable limits of estimated soil loss. From these data, simple algorithms were used to classify the area into different erosion hazard zones.

The various layers of data were brought to common coordinates before being processed together.

In this research work, two major type were executed. River Stage, velocity, Cross-sectional area and discharge measurements and sampling the sediment at the outlet of watershed (study area) then Runoff and Runoff coefficient calculations were executed. Second includes; satellite image processing and land use land cover classification, and finally erosion hazard modeling using Universal Soil Loss Equation adapted for Ethiopia, applicable to the study area, in a GIS environment and Sediment delivery Ratio were executed

3.8. Stream flow data

Gauges were installed at the outlet of shar watershed to measure stream flow and base flow from the watershed. The stream flow (storm runoff as well as base flow) was measured from specified cross sections of the river. During storm the runoff data, the depth of the storm and surface velocity using floating material, was collected three times per day in every 6-hour interval in 2016 rainy season. Surface velocity was measured by dropping the floater at 15 m to upside of the outlet and recorded the travel time to reach at the outlet. The velocity was calculated by dividing the distance above the outlet (15 m) by the time taken to reach at the outlet. The calculated velocity (surface velocity) was multiplied by two-third to get actual velocity. The discharge was also calculated by multiplying the mean velocity with cross sectional area of the at measured depth. The best-fit rating curve was developed from the depth and discharge. A power function is best fit to develop relationship between depth and discharge. The calculated discharge from the power function was divided by contributing area of the watershed to get runoff depth.

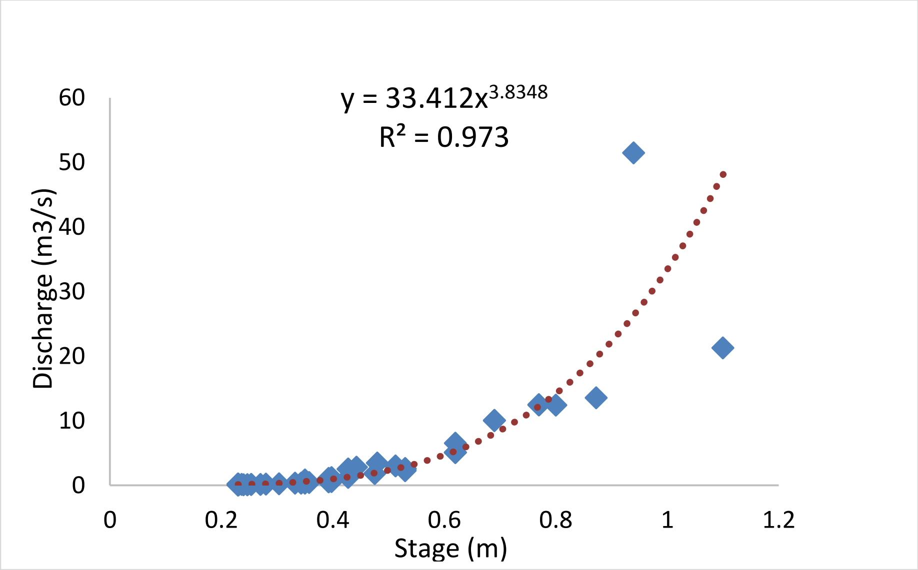

Figure 3:7 Stage Discharge relationship

3.9. Sediment concentration data

The gauge was installed at the outlet of shar watershed, which is used as a place recording water level, sampling one-liter water to determine sediment concentration, and to measure floating velocity. Water samples were collected from the river during morning, during evening and during storm events. In addition, for each observation, the river depth was recorded from installed gauge, the cross sectional area of the river was calculated by multiplying each width to corresponding depth. The velocity was measured by using floating material (dividing traveled distance by time of travel) finally; Discharge was obtained by multiplying Cross-sectional Area with Velocity. Three time per day and more (depending on the presence of precipitation), observations were recorded.

The samples were collected from top surface to bottom of the river under installed gauge. After transporting the samples to Bahir Dar university soil Lab. The samples were filtered using standard filter papers. The weight of the filter paper was measured prior to filtering. After the sediment was filtered out of the sample, the sediment and filter paper were placed on a dish and placed in an oven to remove water from the sediment. The filter paper with sediment was removed from the oven and weighed. The mass of sediment could then be determined by subtracting the initial filter paper weight from the weight of the dried sediment and filter paper. Once the weight of the sediment was determined, the suspended sediment concentration was calculated. The sediment yield was calculated by multiplying suspended sediment concentration with calibrated discharge.

Figure 3:8 Gauge installed at the outlet

The river flow and sediment concentration was monitored starting from July 07/07/2016. To estimate runoff for June, May and July 01/2016 to 06/2016 the relation was developed. from rainfall and runoff to estimate runoff and between runoff and sediment yield to estimate sediment yield. A Second-degree polynomial function is best fit to develop relationship between daily rainfall to daily runoff and power function is best fit to develop relationship between daily runoff and daily sediment yield.

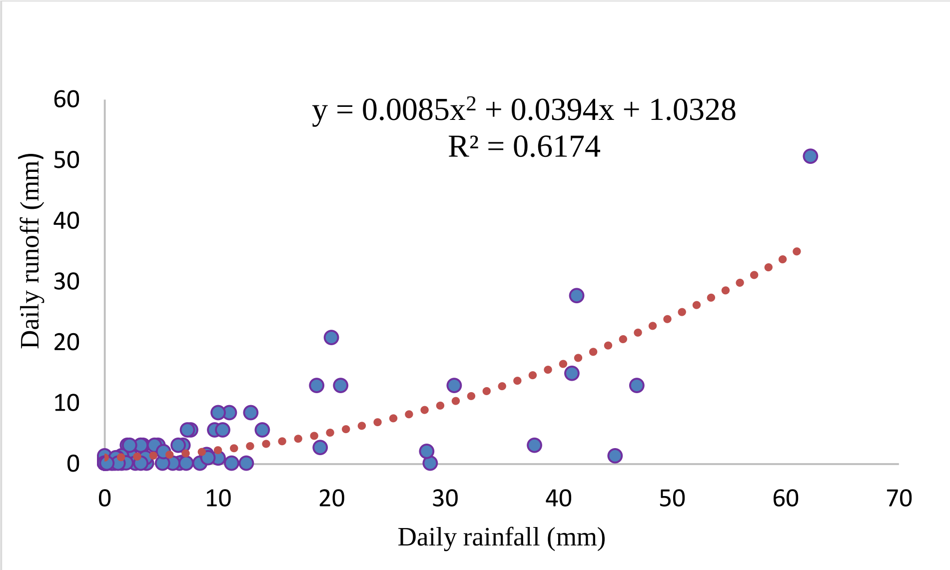

Figure 3:9 Relation between Rainfall (mm) and Runoff (mm)

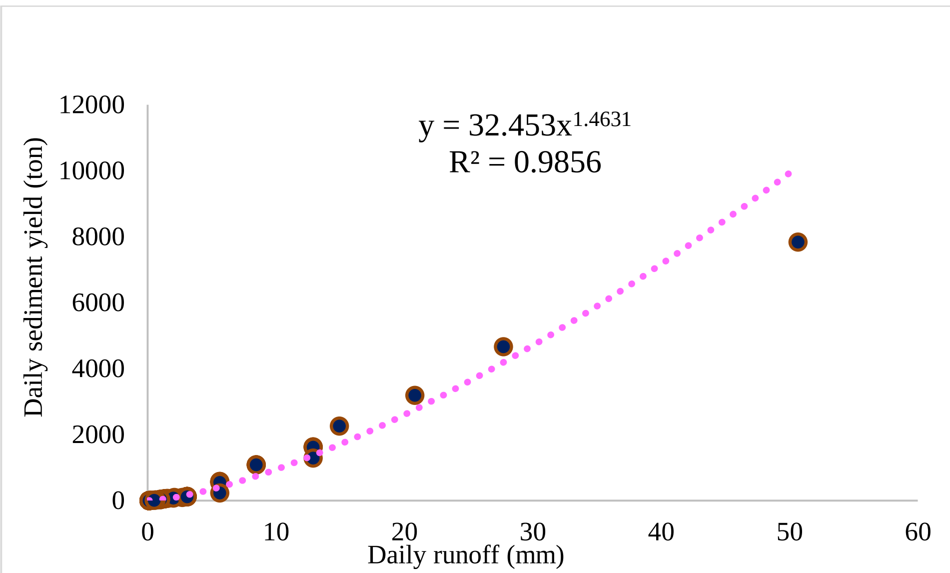

Figure 3:10 Relation between Runoff (mm) and sediment yield (ton)

From these relation for July 01 /2016 to 06 /2016 and for June and May the runoff and Sediment yield was estimated.

3.10. Spatial patterns of gullies and location

To locate potential gully formation areas, stream power index (SPI) has been used. SPI is very useful for determining potential Critical Source Area locations (Minnesota Leg/ Ref, 2014). SPI is calculated as the product of the natural log of both slope and flow accumulation. High SPI values areas on the landscape where high slopes and flow accumulations exist and thus areas where flows can concentrate with erosive potential.

SPI=LN (([FlowAccum_Raster] + 0.001)* ((Slope_Raster]/100) + 0.001))………(1)

To compare with the actual gully site sample of gullies digitized from Google earth and its location were collected by GPS to validate the mapping by SPI. To compare potential and actual gully erosion areas, gully areas identified by SPI were overlaid on map from google earth. High SPI values are the characteristics of Hilly and upper parts of the area and it shows areas of high erosion. Thus, reclassification was done to indicate low to high gully potential

3.11. Sediment delivery ratio and Sediment yield

Sediment delivery ratio is defined as the fraction of gross erosion that is transported for a given time interval. It is a measure of sediment transport efficiency, which accounts for sediment that actually transported from the eroding sources to a measurement point or catchment outlet compared to the total amount of soil that is detached over the same area above that point. In relatively large catchments, most sediment deposited within the catchment and only a fraction of the soil that is eroded from the hill slope reaches the catchment outlet. An accurate prediction of SDR is important in controlling sediments for sustainable natural resources development and environmental protection. Total amount of soil eroded in the watershed was estimated using the RUSLE model. The sediment yield (SY) measured at the outlet of the watershed. Hence, sediment delivery ratio (SDR) was calculated by divided the annual sediment observed (measured) at the outlet with annual erosion from obtained by RUSLE model

$$SDR = \frac{SY}{E} \quad (2)$$

Where, SY = annual sediment measured at the outlet and E = the annual soil loss from the corresponding catchment

3.12. Land use/Land cover Classification

The land use/land cover map of the study area was prepared from landsat images. land cover classification procedure mainly involved unsupervised and supervised classifications. Unsupervised classification has been done prior to the field survey using visual interpretation method for differentiating various land-use/land-covers in the study area. After field survey, GPS data with equal sample size from different cover classes were collected. Different land use land cover classes were determined, based on information extracted from field survey and unsupervised classification. Four land use and land cover classes were recognized using visual image interpretation and field survey. These include forest, shrub, Farm land, bare land, built ups and grass. (Figure 3:11)

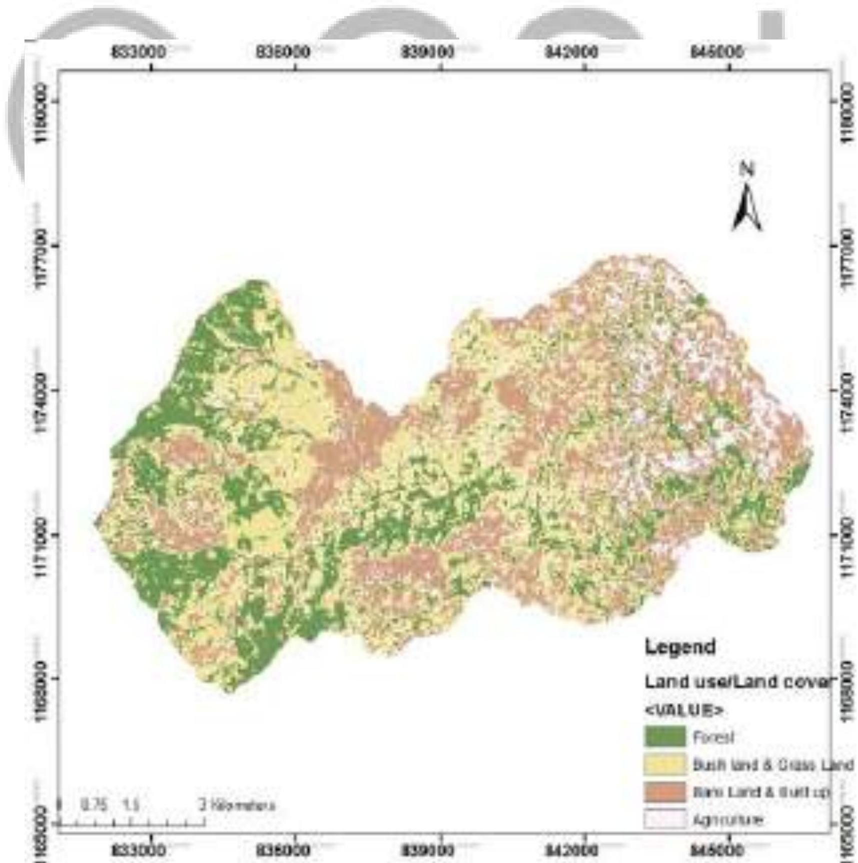

Figure 3:11 Land Use/ Land Cover of the Study Area

3.13. Estimation of rate of soil loss

The Revised Universal Soil Loss Equation (RUSLE) is an empirical based model, which has the ability to predict the long-term average annual rate of soil erosion on a field caused by rainfall pattern, soil type, topography, management practices (Renard et al., 1997). In GIS environment, it can predict erosion potential on a cell-by-cell basis, which is successful in attempting to identify the spatial pattern of soil loss present within a large watershed area (Shi et al., 2003) (Equation 3)

$$A = R.K.LS.C.P \quad (3)$$

Where A is the amount of soil erosion (t /ha/yr) which is eroded within unit area during the corresponding period of rainfall;

R is a rainfall erosivity factor

K is a soil erodibility factor

LS is a surface characteristic factor (slope-length and steepness factor,

L is the slope length while S is the slope gradient)

C is a cover management factor

P is support practice factor

Each USLE factor combined on a cell-by-cell grid modeling procedure in ArcGIS 10.1 to predict soil loss. The factors were processed with 30m by 30m cell size. All layers were projected with Adindan Zone 37N using the Adindan datum; these correspond to standards used by the Ethiopia Mapping Agency. The following methodology was used to generate the factor grids. Figure 3:12 Show the general framework followed.

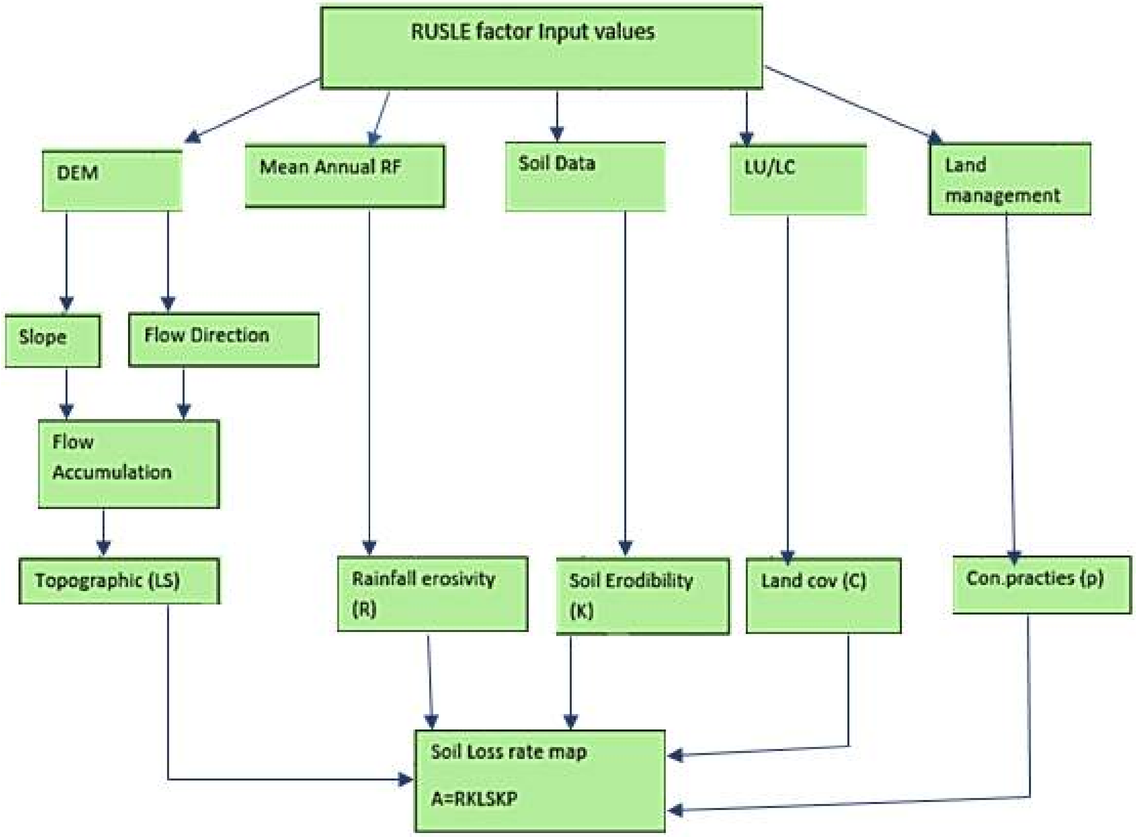

Figure 3:12 Framework to estimate Soil Erosion Rate and Map Using USLE Model in A GIS

3.14. Estimation rainfall erosivity (R_factor)

Rainfall erosivity is a climatic factor, which is estimated from the rainfall data. It is a measure of the kinetic energy (E, MJ m^2) based on the 30 minutes maximum intensity of rainfall (I_{30}, mm /h) (Wischmeier and Smith, 1978). Computing EI_{30} required continuous rainfall intensity data. However, rainfall intensity data are not available for the study area. Therefore, alternative methods used include empirical equations to estimate erosivity values from the available annual total rainfalls (Roose, 1977; Morgan, 1974).

Kaltenrieder (2007) developed equation to estimate R factor from annual total rainfall amount (Equation 4):

$$R = 0.36\,X + 47.6 \tag{4}$$

Where, X is mean annual rainfall in mm.

Hurni (1985) developed an empirical equation while adapting the USLE model to the Ethiopian highlands (Equation 5)

$$R = -8.12 + 0.562P \qquad (r^2=0.8) \qquad (5)$$

Where, R is the rainfall erosivity factor (in MJ mm/ ha/h/yr.), and P is the mean annual rainfall (mm).

The Equation developed by (Kaltenrieder, 2007) estimates lower R-factor than that by Equation (Hurni 1985). Thus, Hurni (1985) model was used in this study.

Monthly precipitation data of 11 years (2006 - 2016) of Five meteorological stations found within and around the study area were utilized to estimate point R_factor values from mean annual rainfalls (Table 3:3)

The rainfall erosivity (R_factor) thus computed was used to prepare Isoerodent maps by using Ordinary Kriging interpolation technique, in spatial analyst tool of ArcGIS 10 software (Figure 13). The cell size for interpolation was 30 m.

Table 3:3 Mean Rain fail of Bullen, Debrezit,Mambuk Mandura, and Pawi

Month	Bullen	Debrezt	Mambuk	Mandura	Pawe
January	1.59	0	4.9	0.27	2.02
February	2.07	8.4	11	1.42	3.53
March	11.16	10.08	18.9	11.81	4.51
April	35.89	34.36	35.5	27.86	54.81
May	159.37	207.06	99	142.39	142.33
June	224.52	305.2	194.5	290.27	264.25
July	262.22	316.52	289.5	308.4	374.71
August	341.21	335.08	282.9	410.71	441.11
September	295.3	257.03	195.6	215.28	334.9
October	115.45	135.3	81.4	134.43	121.59
November	12.29	12.53	22	17.25	15.71
December	1.67	1.56	5.7	1.81	4.88
Annual	1462.76	1623	1241	1561.9	1764.35

Table 3:4 The R_value of the study area

Class	1	2	3	4	5
R_value	826.7_828.3	828.3_829.4	829.4_830.3	830.3_830.9	830.4_830.9

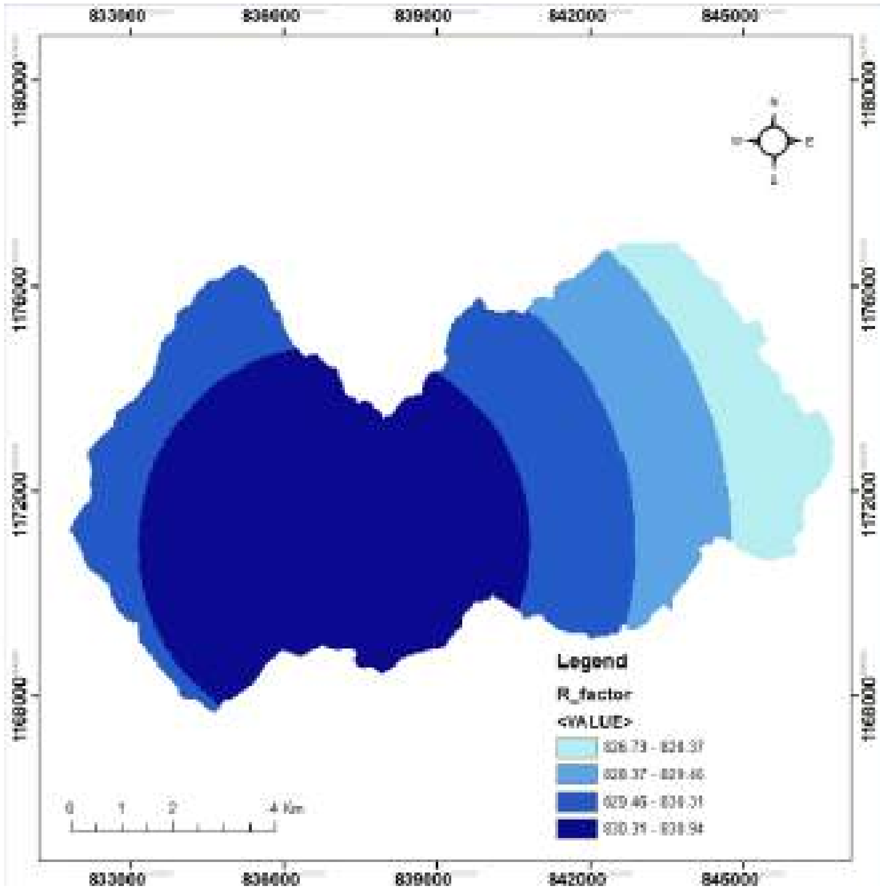

Figure 3:13 R_factor Value

3.15. Estimation of soil erodeblity (K_factor)

In the present study, Hurni (1985) adapted K_factor estimations for different soil types of Ethiopia were used. The soil data for this study were obtained from the soil map of Bullen wereda soil map which is developed by Ministry of water and Energy. This map was used for analyzing the soil erodability factor (K_factor). However, after changing the vector format in to raster grid, the grid data set was reclassified based on K_value of each soil class in ArcGIS 10.1 Spatial Analyst Tool. The K_factor values for study area are presented in Table 3:5

Table 3:5 Soil Erodibility (K_Factor)

Soil type	Hurni (1985) K_Factor value
Luvisols	0.11
Nitosols	0.13

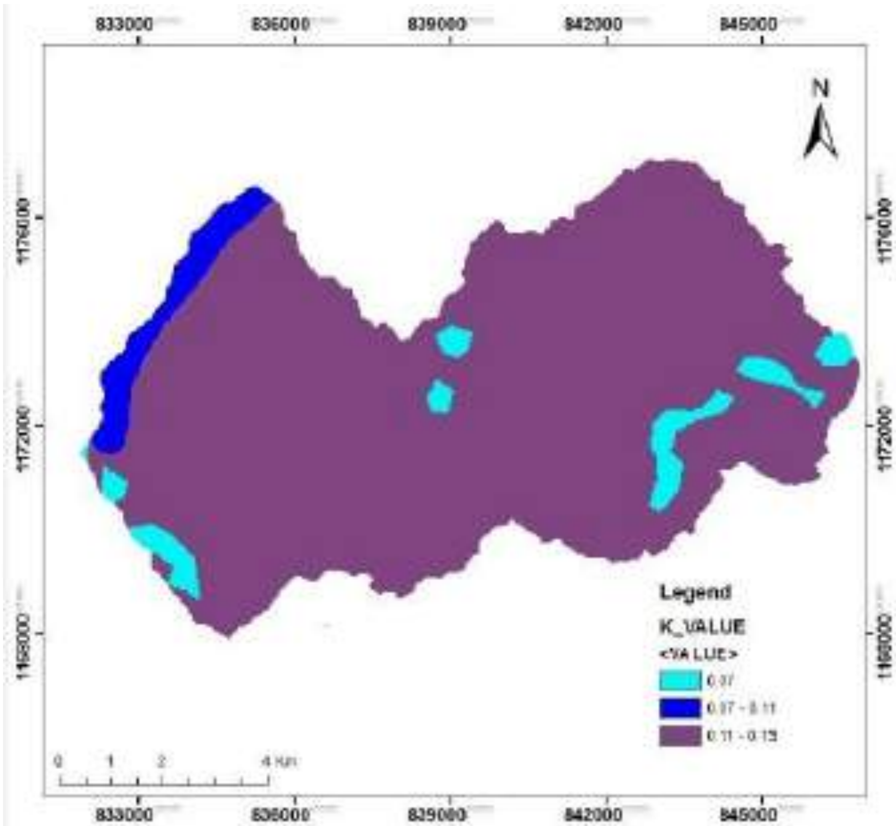

Figure 3:14 K_factor

3.16. Estimation of Topographic (L and S) factors

The LS-factor has been derived from slope and flow accumulation. Slope were generated from 30m*30m resolution DEM using ArcGIS 10. To generate flow accumulation which is the unit contributing area first, any sinks within the DEM were filled. In this process, individual sink elevations were flattened. Then by using filled DEM the flow directions of each DEM cell was calculated. From flow directions Flow accumulation was determined in ArcGIS 10. Then the LS factor grid was estimated with the following equation using raster calculator proposed by (Wischmeier and Smith 1978).

$$LS = (\text{Flow accumulation} * (\text{Cell value})/22.1)^{m} (0.065 + 0.045\,S + 0.0065\,S^2) \ldots\ldots (6)$$

Where LS is slope steepness length factor, the cell value is the resolution of DEM which is 30 and S is slope in percent generated from DEM. The value of m ranges from 0.2 to 0.5 depending on the slope (Wischmeier and Smith 1978). The value of m is estimated from Table 3:6

Table 3:6 Value of m (Wischmeier and Smith 1978)

Slope (%)	m-value
> 5	0.5
3-5	0.4
1-3	0.3
<1	0.2

Table 3:7 Calculated LS_value

Class	1	2	3	4	5
LS_value	0.0_3.22	3.22_10.90	10.90_33.56	33.56_85.84	85.84_164.59

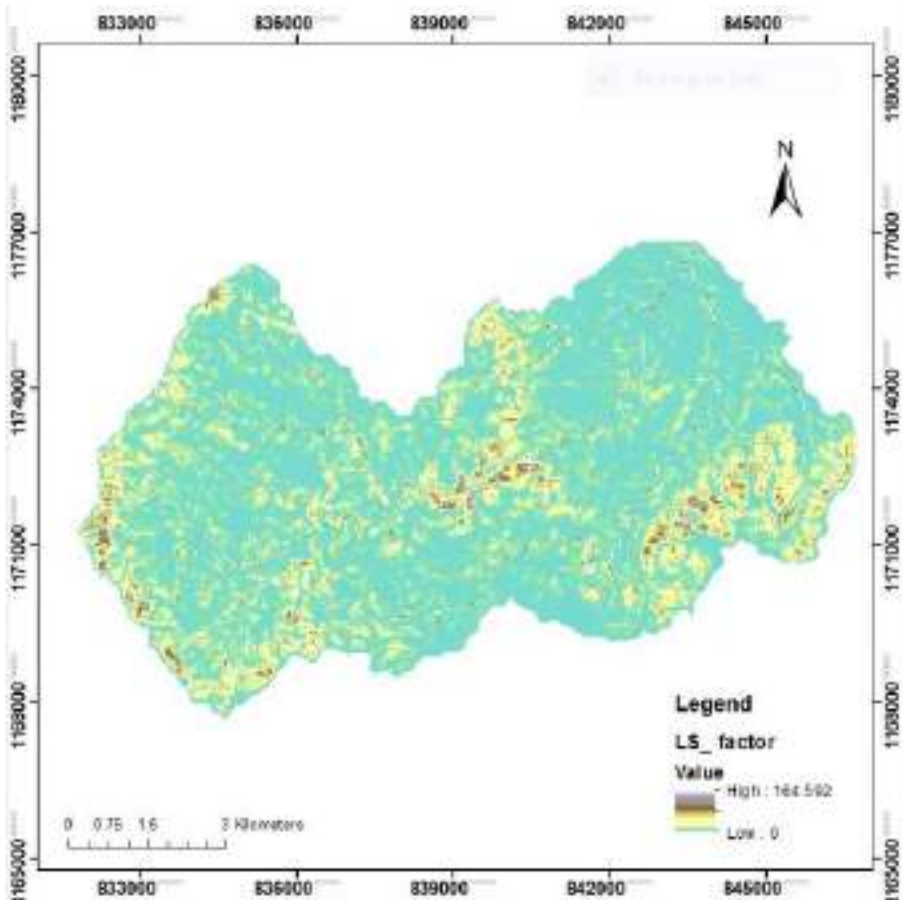

Figure 3:15 Topographic Factor (LS_Factor) Map of the Study Area

3.17. Estimation of Cover Management factor (C)

The cover management factor (C) represents the effects of vegetation, management and erosion control practices on soil loss rates from 1.0 in completely bare land (no cover) to 0.0 in water body or completely covered land surface. The cover (C) factor corresponding to each land use land cover was estimated from different literature listed in Table 3:8 and Figure 3:16 A corresponding C-value was assigned to each land use class.

Table 3:8 Cropping and land-cover (C) factor values

No	LULC Class	C factor	Sources
1	Cultivated land	0.17	Hurni (1988)
2	Disturbed Forest	0.02	Hurni (1985)
3	Grassland with Bush land	0.01	Eweg and van Lammeren (1996)
4	Bare land	0.05	Hurni (1988)

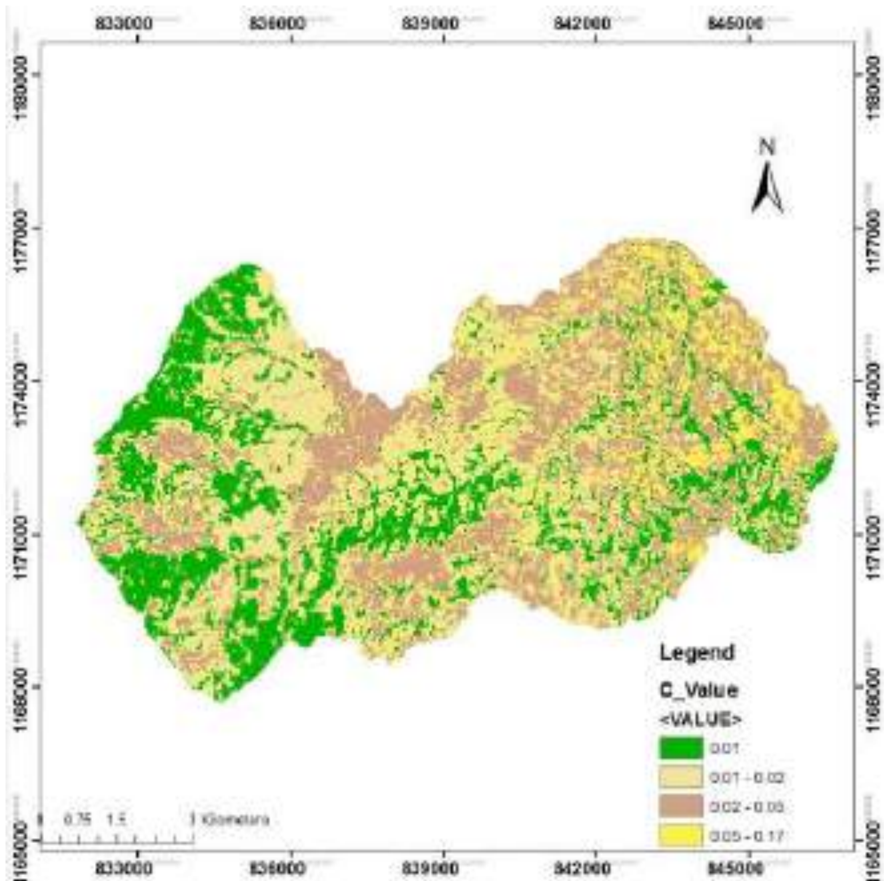

Figure 3:16 C_factor value of the study area

3.18. Estimation method of Supporting practice (P_Factor)

The conservation practices (P) in USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope tillage. The values depend on types of conservation measures implemented, and require mapping of conserved areas for it to be quantified. In the study area, there is only a small area that has been treated with terracing. The traditional conservation measure is a drainage ditch which is drain excess runoff from croplands during rainstorms. However, the entire study area is not treated with improved permanent soil and water conservation measures. Therefore, P factor values suggested by Wischmeier and Smith (1978), which considers two types of land uses (Agricultural and other) and land slopes were used in this study (Table 3:9 and Figure 3:17)

Table 3:9 The P factor values by land use types and slope categories suggested by (Wischmeier and Smith (1978)

Land-use type	Slope (%)	P factor
Agricultural land	0-5	0.1
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other land	All	1.00

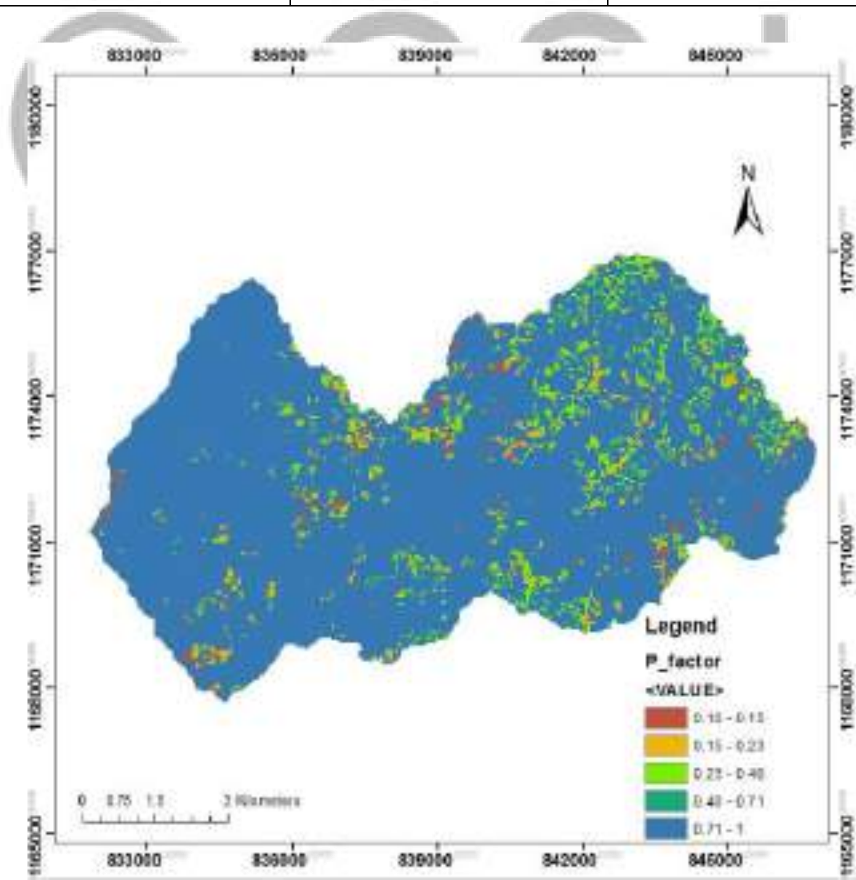

Figure 3:17 P_factor values of the study area.

The raster format of land use was combined with slope (percentage) and the P_factor values listed under Table 3:9 were assigned to each land use _slope combination grid. Finally the assigned P_factor values were lookup in Spatial Analyst Tool extension Reclass.

3.19. Identification of factors that contribute high soil erosion

To identify erosion factors and there class that contribute high soil erosion in special analysis tool zonal statics was utilized. Soil erosion hazard map was cross-tabulated with soil erosion factors to estimate the amount of soil loss from different erosion factors.

4. RESULTS AND DISCUSSION

4.1. Stream flow measurements generated from watershed

The total runoff depth generated from watershed was 278 mm per mean rainy season. The runoff generated from the rainfall is low at the beginning July and increased in August. Even though there is many other factors the main reason is that the watershed was saturated in August and the infiltration rate becomes low. Daily maximum were 50.6 mm/day and average runoff depths were 2.97 mm/day.

Table 4:1 Monthly rainfall and stream flow

Month	Monthly rainfall(mm)	Total Runoff (mm)
July	144.5	81.73
August	316.21	100.25
September	209.7	95.876

To compare runoff rainy month's monthly runoff coefficient was calculated by dividing monthly runoff to monthly precipitation. The runoff coefficients decreased from July (0.56) to August (0.31). The runoff coefficient of August is blow September this is due to different factors (Rainfall intensity, wind velocity, Temperature, Humidity and other factors) to analysis and obtain the reason. For these factors no data were obtained. The runoff coefficient follows the trained of rainfall which is due to geologic condition of the watershed. From water supply project of Bullen town majority of the area is covered by loos sediment (soil material). Therefore, the trend of runoff follows Rainfall. (Figure 4:1& Table 4:2).

Table 4:2 Monthly runoff coefficient

Months	July	August	September
Monthly Runoff (mm)	0.56	0.31	0.45

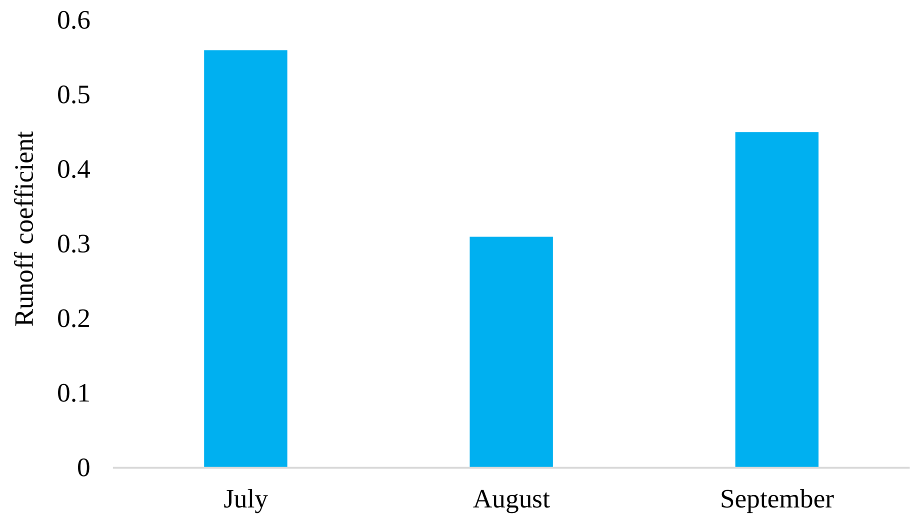

Figure 4:1 Runoff coefficient

From the time series plot the runoff depth is high at the end of July and end of August. It indicates that the runoff generated from the watershed was high after saturation and the runoff coefficient was high in the same month.

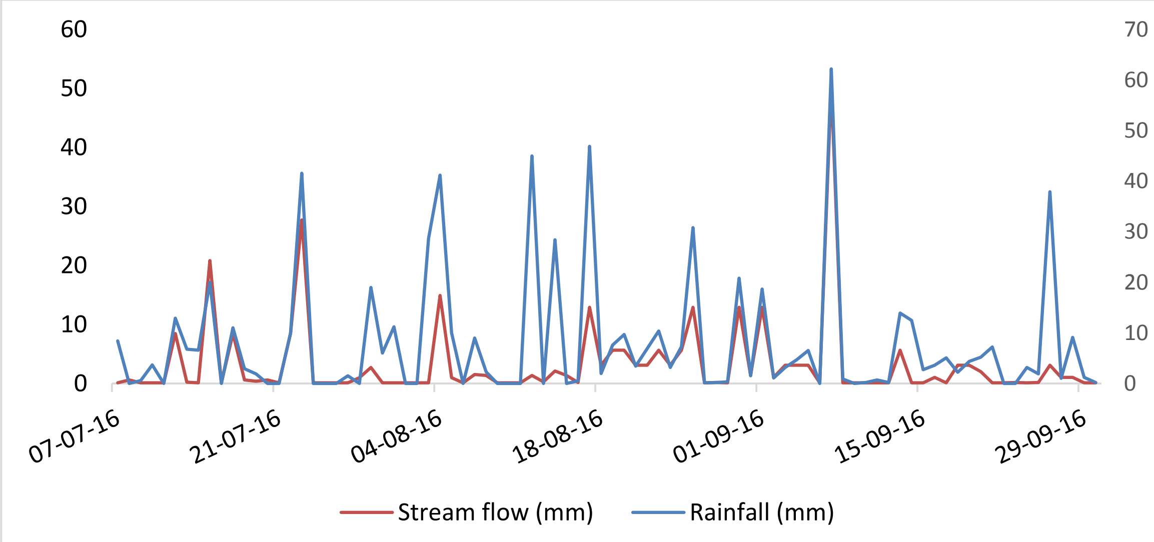

Figure 4:2 Stream flow depth vs. rainfall depth

4.2. Average sediment concentration with time

The concentration ranges from 70 mg/l at the end of September where there is low Rainfall, high vegetation cover, supply limited time or due to all sediment removed from the watershed, and 2050 mg/l in mid of July that is time of high Rainfall, less vegetation cover. High sediment concentration in July and low concentration in September were observed. The average sediment concentration was 470.64 mg/l. (Figure 4:3)

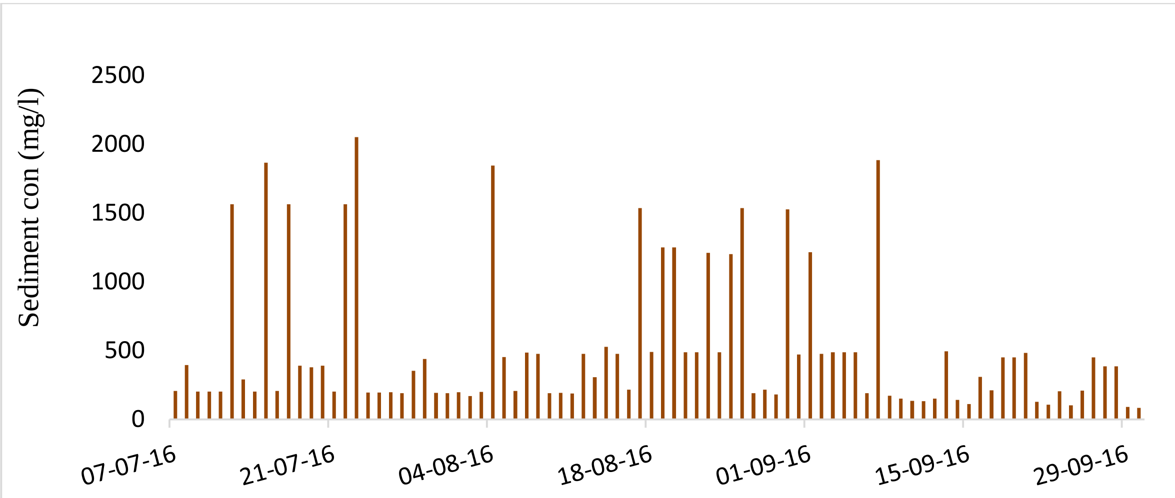

Figure 4:3 Time series plot of Average sediment concentration

4.3. Monthly Sediment yield and Runoff

USLE is estimating soil loss within cell. However, the soil loss within a cell can be deposited somewhere within the watershed. Only small portion of the soil loss will be sediment yield. Sediment yield was estimated by multiplied sediment concentration with calibrated discharge. This is for rainy months that have different Runoff. Sediment yield with runoff helps to understand their relation in rainy months. For this study area, Sediment yield in July was higher (11351.1 ton/month) this is due to this Rainfall and cultivation of some land and lower in September (10300.95 ton/month) when there was a supply limited time (Table 4:3 and Figure 4:4)

Table 4:3 Runoff vs. Sediment yield

Month	Runoff (mm)	Sediment yield (ton/month)
July	81.73	11351.1
August	100.25	10321.8
September	95.87	10301
Total		***31973.87***
Average		***3.89***

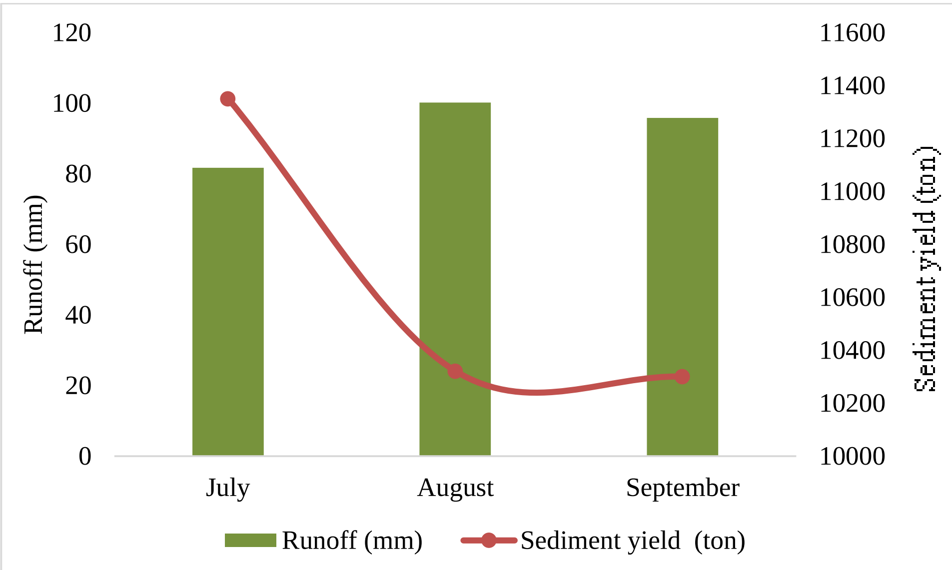

Figure 4:4 Monthly Runoff and Sediment yield

The stream monitoring was started from july 07/2016. From the relation of daily rainfall and runoff and runoff and sediment yield the sediment yield for May ,June and July 01-06/2016 was estimated. The runoff for May (87.79 mm), June (48.84 mm) and for July 01 to 06/2016 (9.25 mm). The sediment yield estimated for May (6155.44 ton), June (2541.48 ton) and for July 01 to 06/2016 (408.45 ton)

The total sediment lost including for May, June and July 07 to 06/2016 was 41082.2 ton per year or 5 ton per ha per year. The decreasing trend of sediment yield was observed. The high yield of sediment in low stream flow(runoff) in July and High Sediment yield in high flow in Junly were observed.

4.4. Estimated Annual soil loss by RUSLE and GIS

The annual soil loss rate determined by a cell-by-cell analysis, which is multiplying the respective USLE factor values in ArcGIS 10.1 spatial analyst, raster calculator using Equation (1). Fig. 4:5 shows the resulting soil loss map of the study area. In order to ease the presentation of the output data, the map showed six main categories (Fig 4:5. and Table 4:4). The estimated annual soil loss rate of Shar watershed was ranged from 0 tons/ha/yr in some plain parts of the studied area to over 80 tons/ha/yr in much of the steeper slope and banks of the river areas (Fig. 4:5). Higher soil losses rate (> 10 tons/ha/yr.) detected in areas where the following factors ware combined: soils with little vegetation cover and high LS_factor value. These areas dominantly found at the steeper slope banks of Shar River at the eastern and middle parts of the study area respectively. The high soil loss rate was also found in cultivated lands having rugged topography (high LS_factor) (14.5%; >10 tons /ha/yr.) and high erodibility. Relatively the lowest soil erosion rates were registered in forest cover areas (24%; below 10 tons/ha/yr.), and Bush and grass areas (34 % below 10 t/ha/yr). Areas of highest soil losses (>10 tons /ha/yr.) that the areas have a serious Problem that must be need attention for conservation measures. This is attributed to the fact that the type of cover occurred on the steep slope area with high value of LS_factor and a higher K value (0.13).

The total soil loss in the study area was estimated 92749 tons per year from 8211 ha (Table 4:4). The largest size among soil loss categories was that of 6.25 - 12.5 tons/ha/yr. which accounts for 61.6% of the study area (Fig.4:5 and Table 4:4). The average annual soil loss for the watershed was estimated at 11.28 tons /ha/yr. The estimated soil loss rate and the spatial patterns are generally realistic compared to what can be observed in the field as well as results from previous studies. For instance, the results of this study falls within the ranges of the estimated soil loss for Ethiopia, which was ranging from 0 to 300 tons/ha/yr. with an estimated mean of 12 tons/ha/yr. (Hurni,1985a). Similarly, Beles sub basin authority report indicates average soil erosion was 11 ton/ha/year and the average annual soil loss for the Beles sub-basin, Ethiopia was estimated at 9.9 tons/ha/yr. (Daniel 2015).

Table 4:4. Current soil erosion severity level in shar_watershade

Soil loss (t/ha/y)	Severity Level	Area (ha)	Percent of total Area
0_10	Low	5061.06	61.63
10_20	Moderate	1219.68	14.85
20_40	High	909.63	11.07
40_60	Very high	350.55	4.26
60_80	Severe	299.16	3.64
>80	Very severe	371.07	4.51
Total		8211.15	100

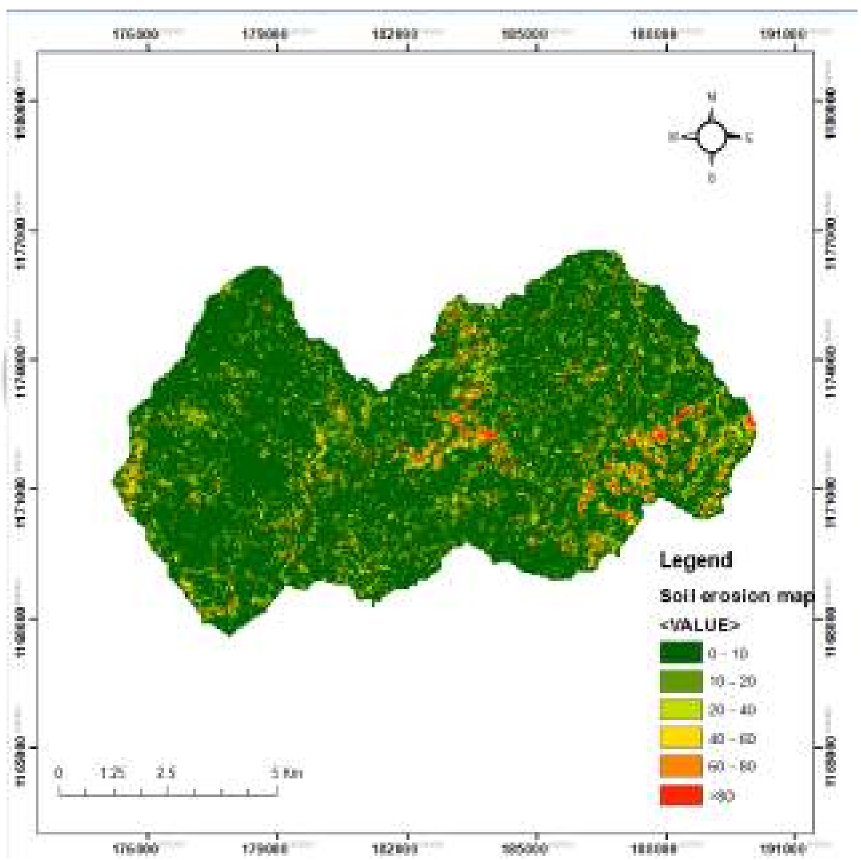

Figure 4:5 Mean Annual Soil Loss in shar watershed

The combined effect of all the above factors contributes to the soil erosion and it has high spatial variation among different factors. It was found that the agricultural area of the watershed were highly erodible, due to the loose soil type and the steep Area. Therefore, the findings of this study also highlights, that the vegetation is an important factor and soil erosion risk can be reduced to a satisfactory level by increasing vegetation cover in the area even though the areas belong to higher slope gradients. There is an Average annual 10 % reduction in vegetation cover Area this contributes 1.5 % of total soil loss or 1394 ton/year.

From the study, it is seen that the slope steepness plays a very important role in soil erosion. The slope steepness values are very high in the medium elevation Area of rugged terrain with little vegetation cover. Spatial distribution of the average soil loss indicates that the erosion feature such as rills, sheet and gullies erosions are located in the range of moderate to very high erosion area.

4.5. The relation between soil loss and some factors

To identify the existing relationship between the factors and rate of soil loss some of the parameters have been examined that is important to know factors that are most prone to soil erosion. Such information becomes valuable as these can be used to formulate a plan, focusing conservation measures in the concerned areas. Thus, not only the on-site effect but also the downstream effect of the sediment transport can be minimized.

4.6. Soil loss by slope gradient

Soil erosion hazard map was cross-tabulated with slope gradient map to estimate the amount of soil loss from different slope classes (Table 4:5 and Figure 4:6). Slope classes in degree and soil loss were cross tabulated to estimate area of soil loss. From the result, 57% of the soil degradation area occurred within the slope range of $0 – 5^0$ or Gentle slope classes and 37.31 % of total soil loss occurred within the slope range of $5 -10^0$ or moderate slope classes.

Table 4:5 Soil loss by slope group

Slope class	Slope Description	Area (ha)	Mean (t/ha/yr)	Total soil loss (t/yr)	Area %	Total soil loss %
0_5^0	Gentle	4635.18	13.39	62071.04	57.08	33.73
5_10^0	Moderate	2607.12	26.33	68667.73	32.1	37.31
10_18^0	Mod. Steep	801.36	54.56	43727.12	9.87	23.76
18_29^0	Steep	76.23	125.11	9537.753	0.93	5.18

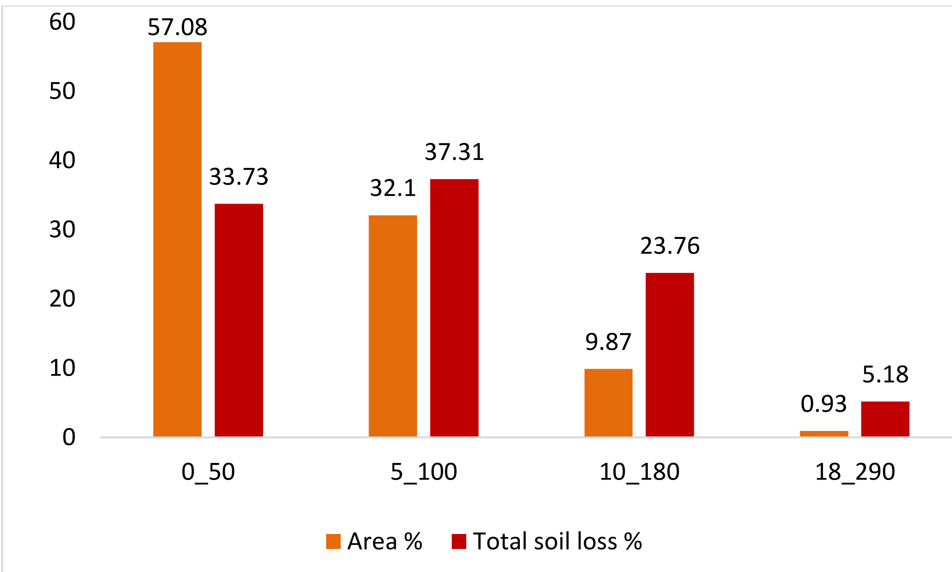

Figure 4:6 Relation between Slope Class to soil loss rate (t/h/yr.) and soil loss area (ha)

4.7. Soil loss by land use/land cover

The soil loss map was correlated with the land-use map to get the amount of soil loss from different land-use/land-cover classes and presented in (Table 4:6 and Figure 4:7) The table shows that the soil loss degradation area in bush and grassland is highest i.e. 34.47 % and 51 % of total soil loss was from Agricultural land

Table 4:6 Soil degradation by land uses

LU/LC	Area (ha)	Mean (t/ha/yr.)	Total soil loss (t/yr.)	Area %	Total soil loss %
Forest	1961.73	6.43	6381.472	23.89	6.88
Bush & grass	2830.86	10.94	15662.05	34.47	16.88
Bare land	2228.4	20.69	23298.35	27.13	25.11
Agriculture	1190.16	78.86	47407.23	14.49	51.11

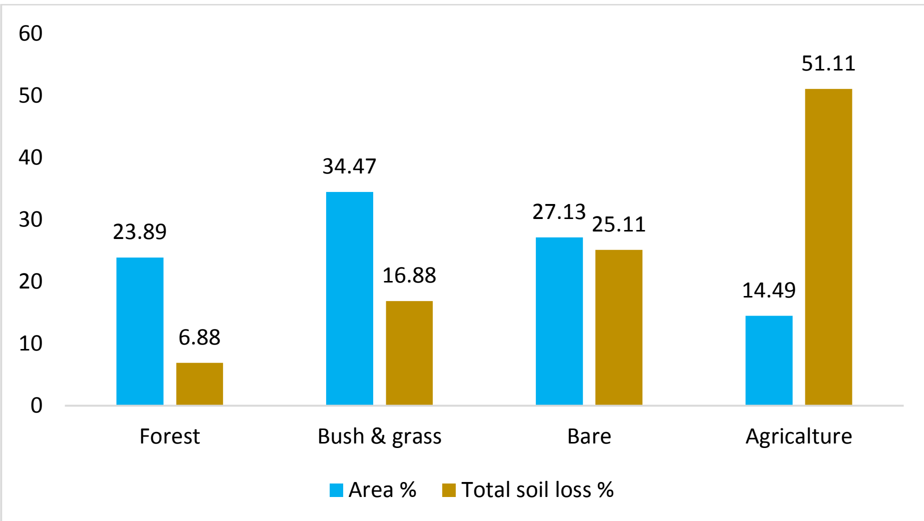

Figure 4:7 Relation of Land use type to area of soil loss (ha) and soil loss (t/h/yr)

4.8. Soil loss by soil type

The soil loss map was cross-tabulated to soil types and the output result presented in Table 4:7 and Figure 4:8. Accordingly, the most degraded soil in the study area is Nitosols. 92.3% of its total area was highly prone to high rate of soil loss that contributes 93.5 % of total soil loss

Table 4:7 Soil loss by soil type

Type	Area	Mean	Total loss (t/yr)	Area %	Total soil loss %
Rock surface	335.43	11.10486	3724.903	4.08	4.01
Luvisols	296.55	7.610332	2256.844	3.61	2.43
Nitosols	7579.17	11.44813	86767.32	92.3	93.55

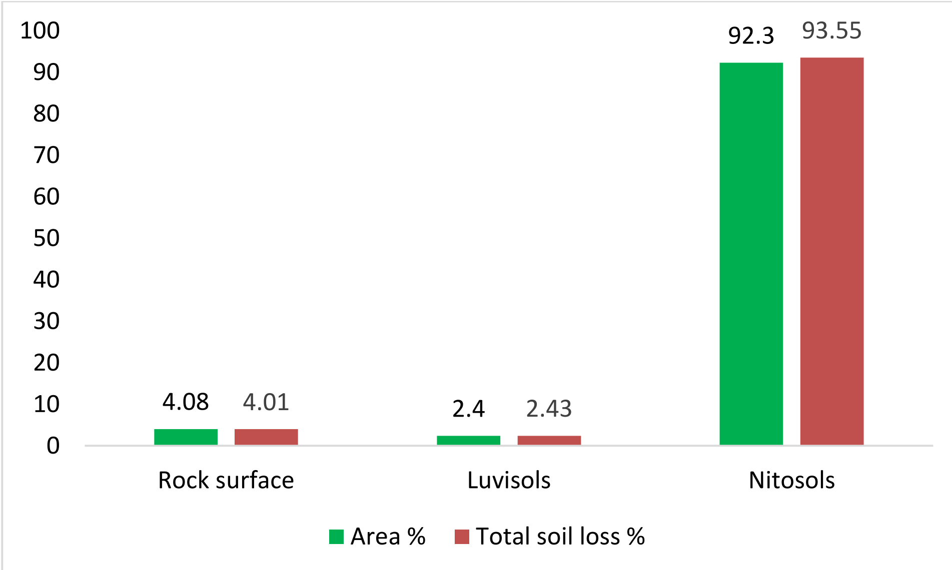

Figure 4:8 Soil loss by soil type

4.9. Soil loss by Rainfall (erosivity)

The rainfall energy directly related to rainfall intensity. However, not all rainfall events are erosive (Wischmeier and Smith, 1978). In order to know the relation between erosivity and rate of soil loss; an isoerodant map was prepared from interpolated rainfall erosivity map and has been cross-tabulated to the estimated soil loss map (Figure 4:9 and Table 4:8). Statistical output between erosivity and rate of soil loss resulted that 45.44% of the soil degradation Area contributes 43.82 % of total soil loss located within erosivity range of 830.3-830.9.

Table 4:8 Soil loss by R_factor

R_factor	Area	Mean	Total soil loss(t/y)	Area %	Total loss %
826.7 _828.3	910.98	26.35	24009	11.21	13.04
828.3_829.4	1231.47	21.88	26947.27	15.16	14.64
829.4_830.3	2287.35	22.9	52398.75	28.16	28.47
830.3_830.9	3690.18	21.85	80648.14	45.44	43.82

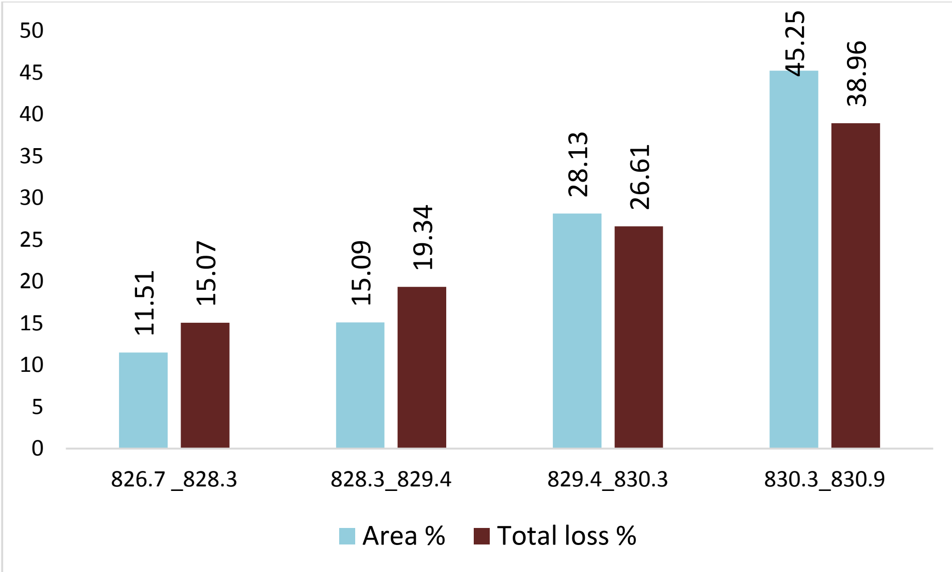

Figure 4:9 Soil loss by R_factor

4.10. Summary of Soil loss relation to different factors

Soil erosion hazard map was cross tabulated with slope gradient map, land use land cover, soil type and erosive factors to estimate the amount of soil loss from different soil erosion factors (Table 4:9 and Figure 4:10). From the result, 92.3 % of the soil degradation area and 92.5 % total soil loss occurred from soil type Nitosol, this is because Nitosols covers large area, it is less cohesive than Luvisol and resistivity to erosive factor is lower. 57.2 % of the soil degradation area from slope class 0^0_5^0 and 36.4 % total soil loss occurred from slope class 5^0_10^0 this is because slope class 0^0_5^0 covers large area. 34.7 % of the soil degradation area from Bush & grass and 25.11 % total soil loss form Bush land, this is due to Bush & grass covers larger area related to other land use. 45.2 % of the soil degradation area and 38.96 % total soil loss occurred from R_ factor 830.31-830.94, high erosive factor causes high erosion. For individual classes of factors estimated as the following figure and table, and the relation was shown in the table

Table 4:9 Soil loss from soil erosion factors

Slope class					LU/LC				Soil Type			R factor			
	0^0_5^0	5^0_10^0	10^0_18^0	18^0_29^0	Forest	Bush & grass	Bare land	Agriculture	Rock surface	Luvisols	Nitosols	826.7-828.37	828.37-829.46	829.46-830.31	830.31-830.94
Area %	57.28	31.99	9.79	0.92	23.89	34.47	27.13	14.49	4.08	3.61	92.3	11.5	15.09	28.13	45.25
Total soil loss %	33.61	36.4	25.83	4.15	6.88	16.88	25.11	51.11	4.01	2.43	93.55	15.07	19.34	26.61	38.96

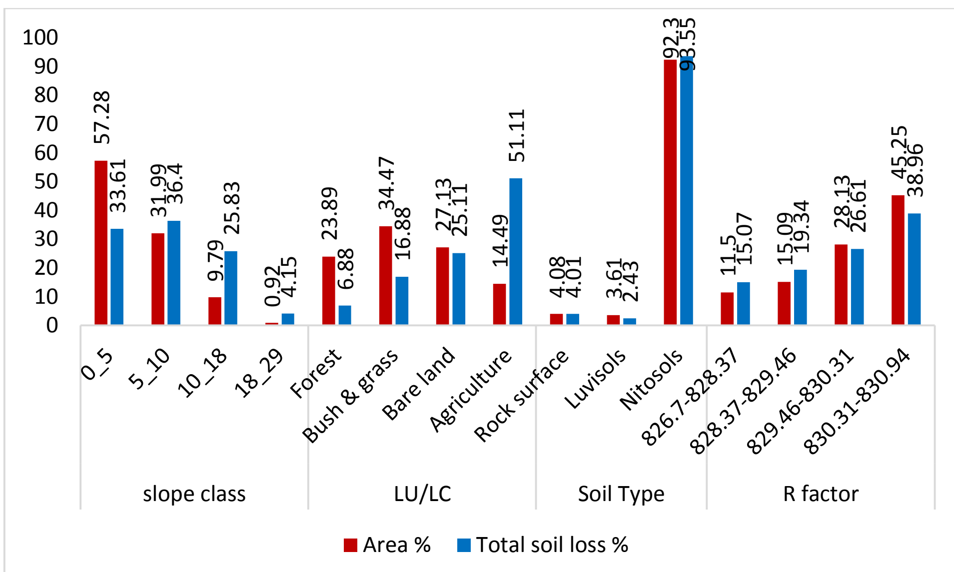

Figure 4:10 Relation between Area of factors (%) and soil loss rate (%)

4.11. Patterns of Gully and its location

Gully sites and density was identified from digitized polygon within the range of 2.16 to 6.16 Stream Power Index values and Stream Power Index of 0–2.16 are free of gully (Figure 4:11). The higher Stream Power Index (SPI) with in the range of 6.16–12.36 in the field were identified as areas that have linked with natural stream channels. Based on this result gully potential areas other than the natural stream channels are areas with stream power index from 2.16-6.15, which is shown in Figure 4:11 & 12. From the total area 472 Ha found in the SPI value from 2.16-6.15 which shows gully potential areas and actual gully. The other 7739 Ha are areas with no gully potential.

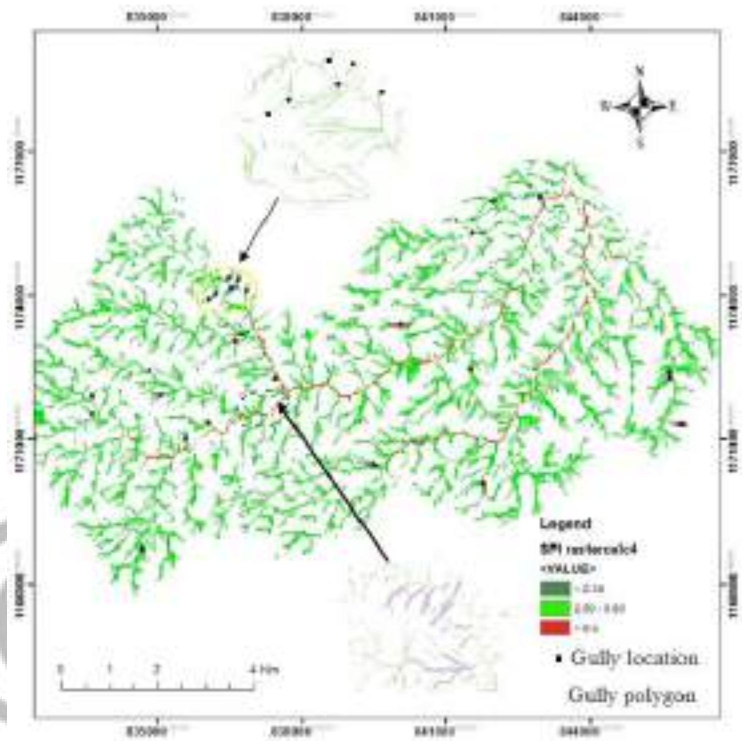

Figure 4:11 SPI, Gully location, digitalized gully and photo of gully.

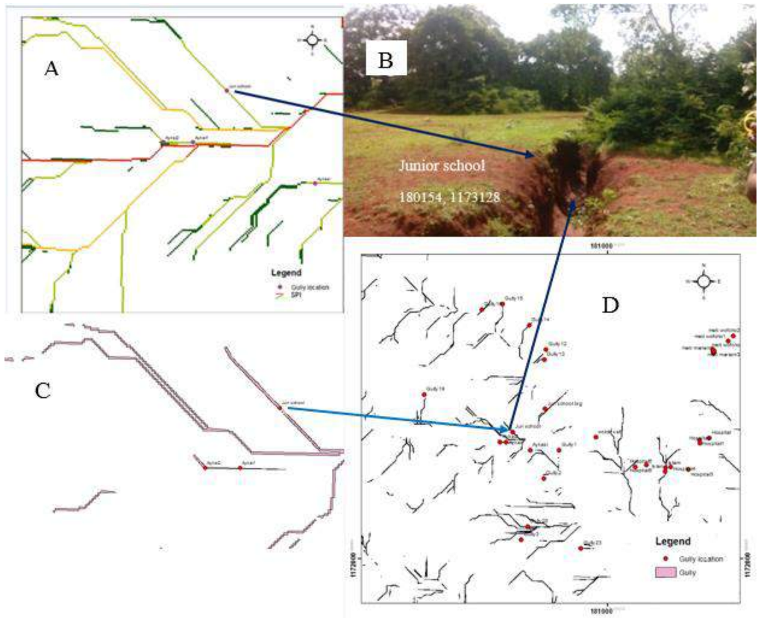

Figure 4:12 A indicates SPI, B shows photo of sample gully, C & D gully polygon from SPI.

Randomly Sampled of gullies was digitalized and its location was collected by GPS and cross tabulated with SPI index. Therefore,its accuracy was 89 % of gullies was Agree with SPI index from 2.16 to 6.15.

Table 4:10 polygons of gully and SPI value

SPI value	< 2.16	2.16 –6.15	>6.15
Polygons (No)	4	32	0
Total			***36***
Accuracy	(32/36)= 89 %		

4.12. Prioritization for soil and water conservation

Based on the estimated annual soil losses, the watershed is classified into six erosion severity classes (Figures 4.5 and Table 4.4). Accordingly, ≈ 62% of the watershed comes under the low soil erosion, severity class. On the other hand, significant portion of the watershed 38%, prone to moderate, high to very severe soil erosion hazard, far exceeding the soil loss tolerance level estimated for Ethiopia.

For strategic implementation of soil and water conservation measures identification of erosion hotspot areas and prioritization of micro watershed are necessary.

Therefore, as shown in the soil erosion hazard maps (Figures 4.12 and Tables 4.11) the middle and southwest parts of the watershed including upper Gich mindi, Gich mindi & shar, Lower Tsunts and Right Tsunts micro watershed are highly eroded, these are the first priority to implement soil and water conservation measures for a sustainable land use. The Middle, East and South East part of the watershed including Dawi, Endege and Upper Tsunts micro watershed are prone to moderate soil erosion and thus have the second priority to implement soil and water conservation measures. The South West weast,south and east part of the watershed including Duchin, Aykasi,Lay shar, Mora,upper shar and Lower gichina mingi are prone to low soil erosion, and thus have the third priority to implement soil and water conservation treatments.

Table 4:11 Annual Soil loss of micro watershed

	Soli loss t/ha/year					Severity
Micro_Wate	Area (ha)	Min	Max	Mean	STD	
Duchin	562.32	0	314.19	4.63	13.33	Low
Aykasi	493.2	0	410.66	5.78	16.86	Low
U.shar	636.57	0	879.89	10.25	28.07	Moderate
L.shar	610.65	0	412.23	7.55	19.21	Low
Dawi	230.94	0	709.59	11.63	30.05	Moderate
Aygok	515.97	0	764.53	7.73	20.21	Low
Gichi meti & shar	1444.59	0	1580.29	14.66	48.07	Moderate
Upper Tsunts	798.12	0	551.05	10.80	26.31	Moderate
Lower Tsunts	744.84	0	784.64	18.50	42.02	Moderate
Right Tsunts	494.82	0	575.32	17.23	36.42	Moderate
Endege	214.02	0	1083.55	10.34	44.46	Moderate
Lower Gich mengi	242.19	0	1206.54	8.10	38.79	Low
Upper Gich mengi	442.44	0	1832.22	13.43	46.21	Moderate
Mora	780.48		655.12	9.26	24.08	Low

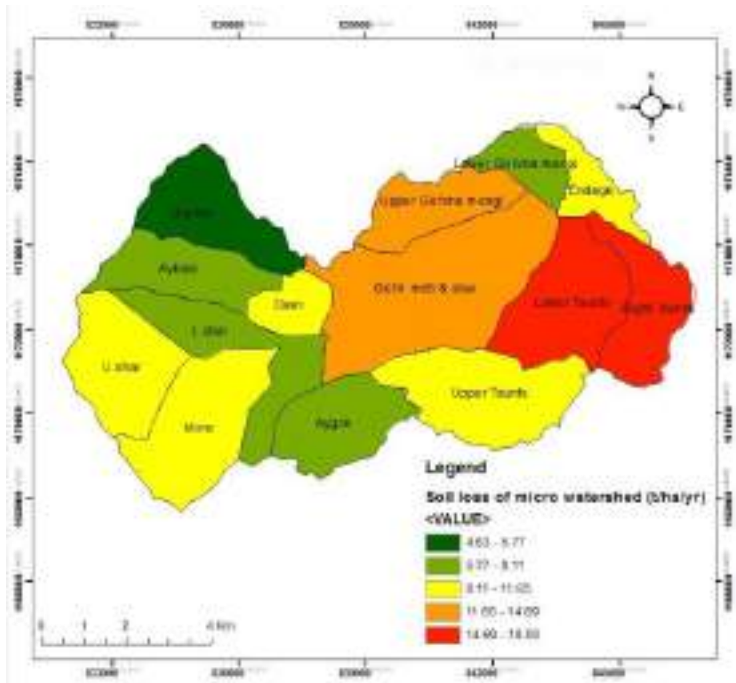

Figure 4:13a Mean Soil losses from micro watershed (t/h/yr.)

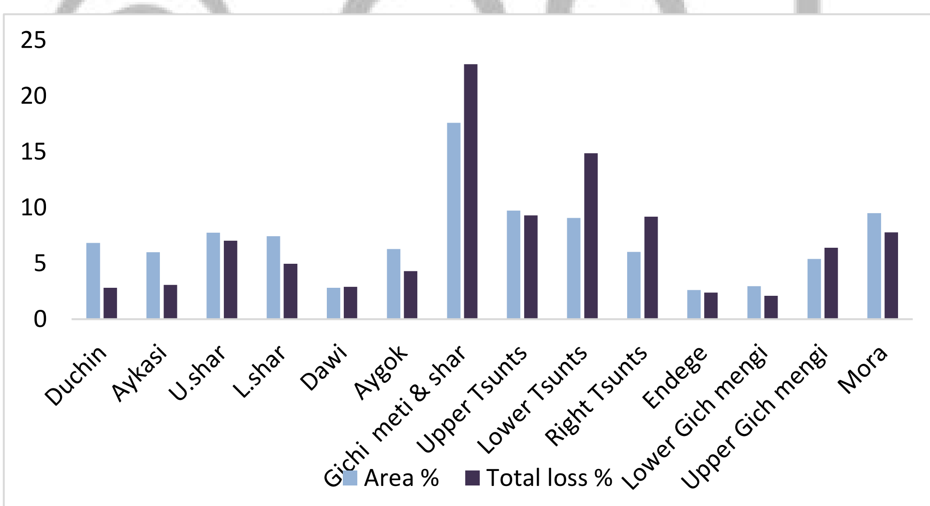

Figure 4:13b Total Soil losses (%) and Area of soil loss from micro watershed (%)

4.13. Sediment delivery ratio (SDR)

The sediment delivery ratio (SDR) was calculated for the watershed by relating the annual sediment yield (SY) measured at the outlet of watershed with the estimated amount of (41082.2 ton/yr.) Therefore, the sediment delivery ration (SDR) = (41082.2 ton/year) ÷

(92749 ton/year) = 0.44 or 44 %. This value is similar to the SDR estimated by Abdel Aziz (2009) 44 %, close to (Daniel 2015) 50% that he estimated from RUSLE and measuring sediment deposit in reservoir, and Awulachew *et al*. (2009a) 45 % for the Blue Nile Basin. Thus, sedimentation is a major threat for Sustainable land use and water quality in streams in the watershed and the downstream Catchments.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This paper described the method and results of research aimed to determining soil loss from the entire watershed using measurement of sediment concentration, RUSLE model and area and location of gully from SPI, measurement of sample of gully and Google earth image.

From sediment measurement, the total annual sediment yield was 41082.2 ton/year and the average annual sediment yield was 5.00 tons/ha/yr.

The soil erosion rate from RUSLE model analysis was carried out from the soil erosion factors of 2016. The steep area (40 -80 t/h/y), riverbanks (80 – 1832 t/h/y) and mining site of the watershed was most vulnerable to soil erosion. The total soil loss was 92749 tons per year from 8211 ha and the average annual soil loss was 11.28 tons/ha/yr. There is an Average annual 10 % reduction in vegetation cover area that, Contributes (increase) 1.5 % of total soil loss or 1394 ton/year. The sediment delivery ratio of the watershed estimated at 44 %. Micro watershed level soil loss estimation indicated that Lower Tsunts, Right Tsunts, Meti and shar, Gich mindi, are the first largest soil erosion sensitive micro watershed. Thus, to utilize the limited resources in effective and efficient manner, soil and water conservation intervention (covering the steeper area with forest, protecting hotspot areas, mechanical and biological conservation practices) should start from that micro watershed which is at moderate risk of soil erosion. The total coverage area of gully was 472 ha clustered at the middle part where high population pressure, steep area, roadside, mining areas, river crosses and other areas as observed from SPI and measuring sample of gully and collecting ground truth using GPS. This study indicates that RUSLE model cannot locate gully but for this watershed SPI value 2.16 to 6.15 locates or overlies 89 % with ground truth collected by GPS. Therefore, RUSLE should be modified.

5.2. Recommendation

Recommendations resulting from this paper are to strength soil and water conservation practice, protect forest area, strength implementation of mining development regulation and gully control structures and biological controls in order to rehabilitate and Ground water site selection should consider erosion hotspot area.

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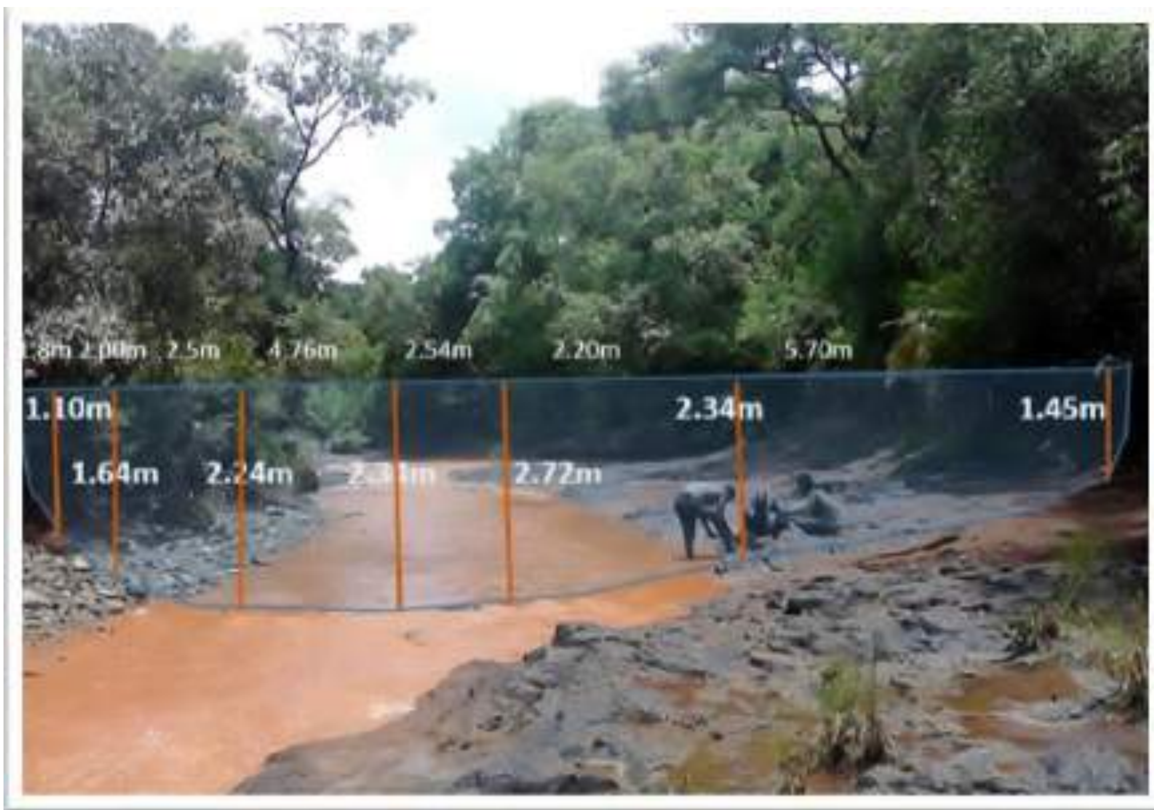
APPENDIX

Appendix 1a. Gauge installation and river cross section measurement



Appendix 1b. River cross section measurement profile

Date	width	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	Aver. Depth	Area (m2)
07-07-16	2.86						0.23					0.23	0.3289
08-07-16	4.42						0.343					0.34	0.7587667
09-07-16	2.86						0.23					0.23	0.3289
10-07-16	2.86						0.23					0.23	0.3289
11-07-16	2.86						0.23					0.23	0.3289
12-07-16	13.15				0.28	0.36	0.69	0.35				0.42	5.523
13-07-16	3.36						0.27					0.27	0.4536
14-07-16	2.86						0.23					0.23	0.3289
15-07-16	14.26			0.39	0.44	0.49	0.87	0.49	0.17			0.47	6.7794417
16-07-16	2.86						0.23					0.23	0.6578
17-07-16	13.15				0.28	0.36	0.69	0.35				0.42	5.523
18-07-16	4.36						0.35					0.35	0.763
19-07-16	3.74						0.30					0.30	0.5672333
20-07-16	5						0.35					0.35	1.75
21-07-16	2.86						0.23					0.23	0.3289
22-07-16	13.15				0.28	0.36	0.69	0.35				0.42	5.523
23-07-16	18.4			0.45	0.5	0.55	0.94	0.55	0.23			0.94	17.296
24-07-16	2.86						0.23					0.23	0.3289
25-07-16	2.86						0.23					0.23	0.6578
26-07-16	2.86						0.23					0.23	0.3289
27-07-16	2.86						0.23					0.23	0.3289
28-07-16	5.28						0.39					0.39	1.0362
29-07-16	10.48					0.13	0.51	0.13				0.32	3.3667
30-07-16	2.86						0.23					0.23	0.3289
31-07-16	2.86						0.23					0.23	0.3289
01-08-16	2.86						0.23					0.23	0.3289
02-08-16	2.86						0.23					0.23	0.3289
03-08-16	2.86						0.23					0.23	0.3289
04-08-16	13.5			0.32	0.38	0.42	0.8	0.42				0.8	5.4
05-08-16	5.28						0.39					0.39	2.0724
06-08-16	2.86						0.23					0.23	0.3289

07-08-16	7.98						0.44					0.44	3.53115
08-08-16	6.9						0.42					0.42	2.94975
09-08-16	2.86						0.23					0.23	0.3289
10-08-16	2.86						0.23					0.23	0.6578
11-08-16	2.86						0.23					0.23	0.6578
12-08-16	6.9						0.42					0.42	2.94975
13-08-16	3.49						0.28					0.28	0.4886
14-08-16	15					0.1	0.48	0.1				0.22	3.4
15-08-16	6.9						0.4275					0.42	1.474875
16-08-16	3.11						0.25					0.25	0.39
17-08-16	13.2			0.29	0.34	0.39	0.77	0.39				0.436	5.75
18-08-16	10.98				0.13	0.18	0.53	0.18				0.255	2.79
19-08-16	11.62			0.14	0.19	0.24	0.62	0.24				0.286	3.32
20-08-16	11.62			0.14	0.19	0.24	0.62	0.24				0.286	3.32
21-08-16	10.98				0.13	0.18	0.53	0.18				0.255	2.79
22-08-16	10.98				0.13	0.18	0.53	0.18				0.255	2.79
23-08-16	11.62			0.14	0.19	0.24	0.62	0.24				0.286	3.32
24-08-16	10.66				0.1	0.15	0.53	0.15				0.2325	2.47
25-08-16	11.62			0.14	0.19	0.24	0.62	0.24				0.286	3.32
26-08-16	13.2			0.29	0.34	0.39	0.77	0.39				0.436	5.75
27-08-16	2.86						0.23					0.23	0.65
28-08-16	3.11						0.25					0.2533333	0.39
29-08-16	2.86						0.23					0.23	0.32
30-08-16	13.2			0.29	0.34	0.39	0.77	0.39				0.436	5.75
31-08-16	6.9						0.42					0.4275	2.94
01-09-16	13.2			0.29	0.34	0.39	0.77	0.39				0.436	5.75
02-09-16	5.28						0.39					0.3975	2.09
03-09-16	10.98				0.13	0.18	0.53	0.18				0.255	2.79
04-09-16	10.98				0.13	0.18	0.53	0.18				0.255	2.79
05-09-16	10.98				0.13	0.18	0.53	0.18				0.255	2.79
06-09-16	2.86						0.23					0.23	0.32

07-09-16	16.68		0.17	0.62	0.67	0.72	1.1	0.72	0.4	0.17		0.57125	9.52
08-09-16	2.86						0.23					0.23	0.32
09-09-16	2.86						0.23					0.23	0.32
10-09-16	2.86						0.23					0.23	0.32
11-09-16	2.86						0.23					0.23	0.32
12-09-16	2.86						0.23					0.23	0.32
13-09-16	14.89			0.14	0.19	0.24	0.62	0.24				0.286	4.25
14-09-16	2.86						0.23					0.23	0.32
15-09-16	2.86						0.23					0.23	0.32
16-09-16	5.28						0.3975					0.39	1.04
17-09-16	2.88						0.23					0.23	0.34
18-09-16	10.98				0.13	0.18	0.53	0.18				0.255	2.79
19-09-16	10.98				0.13	0.18	0.53	0.18				0.255	2.79
20-09-16	9.6						0.47					0.475	2.28
21-09-16	2.86						0.23					0.23	0.32
22-09-16	2.86						0.23					0.23	0.32
23-09-16	2.99						0.24					0.24	0.35
24-09-16	2.86						0.23					0.23	0.32
25-09-16	2.99						0.24					0.24667	0.36
26-09-16	10.98				0.13	0.18	0.53	0.18				0.255	2.79
27-09-16	5.28						0.39					0.3975	2.09
28-09-16	5.28						0.39					0.3975	1.04
29-09-16	2.86						0.23					0.23	0.32
30-09-16	2.86						0.23					0.23	0.32
01-10-16	5						0.35					0.3575	0.89
02-10-16	2.86						0.23					0.23	0.32
03-10-16	2.86						0.23					0.23	0.32
04-10-16	2.86						0.23					0.23	0.32
05-10-16	2.99						0.24					0.24667	0.36
06-10-16	2.86						0.23					0.23	0.32
07-10-16	2.86						0.23					0.23	0.32
08-10-16	2.86						0.23					0.23	0.32
09-10-16	4.35						0.33					0.3325	0.723

(D1, D2 and others) indicates depth River cross section from left to right.

Appendix 2a. Sediment concentration, Sediment yield and runoff generation from watershed

Date	sediment con(mg/l)	Sed yield (t/d)	Stream flow (mm)
07-07-16	206	2.121472	0.125422
08-07-16	395	18.90501	0.582886
09-07-16	201	2.06998	0.125422
10-07-16	201	2.06998	0.125422
11-07-16	201	2.06998	0.125422
12-07-16	1563	1087.411	8.473028
13-07-16	289	5.504373	0.23196
14-07-16	200	2.059682	0.125422
15-07-16	1866	3192.825	20.83855
16-07-16	206	2.121472	0.125422
17-07-16	1563	1087.411	8.473028
18-07-16	390	20.0943	0.627498
19-07-16	377	11.22083	0.362483
20-07-16	390	20.0943	0.627498
21-07-16	201	2.06998	0.125422
22-07-16	1563	1087.411	8.473028
23-07-16	2050	4667.892	27.73134
24-07-16	194	1.997891	0.125422
25-07-16	194	1.997891	0.125422
26-07-16	196	2.018488	0.125422
27-07-16	190	1.956698	0.125422
28-07-16	353	28.22586	0.973815
29-07-16	439	97.63708	2.708658
30-07-16	191	1.966996	0.125422
31-07-16	190	1.956698	0.125422
01-08-16	196	2.018488	0.125422
02-08-16	169	1.740431	0.125422
03-08-16	198	2.039085	0.125422
04-08-16	1844	2262.281	14.94134
05-08-16	453	36.22186	0.973815
06-08-16	205	2.111174	0.125422
07-08-16	484	61.29285	1.542298
08-08-16	475	52.70158	1.351245
09-08-16	190	1.956698	0.125422

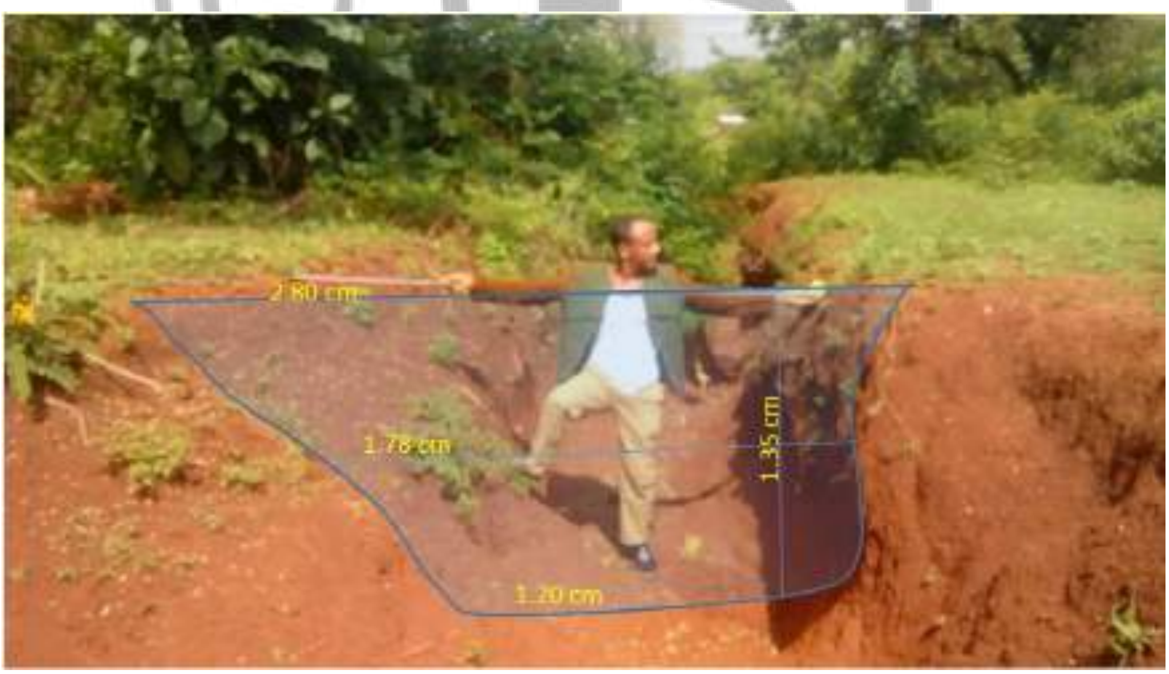
10-08-16	191	1.966996	0.125422
11-08-16	187	1.925802	0.125422
12-08-16	475	52.70158	1.351245
13-08-16	306	6.700377	0.266675
14-08-16	526	90.99674	2.106901
15-08-16	475	52.70158	1.351245
16-08-16	215	3.207259	0.181677
17-08-16	1536	1627.504	12.90431
18-08-16	490	123.9554	3.080869
19-08-16	1249	576.5571	5.621909
20-08-16	1249	576.5571	5.621909
21-08-16	486	122.9435	3.080869
22-08-16	486	122.9435	3.080869
23-08-16	1209	558.0925	5.621909
24-08-16	487	123.1965	3.080869
25-08-16	1200	553.9379	5.621909
26-08-16	1536	1627.504	12.90431
27-08-16	190	1.956698	0.125422
28-08-16	215	3.207259	0.181677
29-08-16	180	1.853714	0.125422
30-08-16	1526	1616.908	12.90431
31-08-16	470	52.14683	1.351245
01-09-16	1215	1287.381	12.90431
02-09-16	475	39.87015	1.022253
03-09-16	487	123.1965	3.080869
04-09-16	487	123.1965	3.080869
05-09-16	487	123.1965	3.080869
06-09-16	190	1.956698	0.125422
07-09-16	1884	7838.443	50.67022
08-09-16	170	1.750729	0.125422
09-09-16	150	1.544761	0.125422
10-09-16	134	1.379987	0.125422
11-09-16	131	1.349092	0.125422
12-09-16	151	1.55506	0.125422
13-09-16	495	228.4994	5.621909
14-09-16	141	1.452076	0.125422
15-09-16	110	1.132825	0.125422
16-09-16	309	25.93658	1.022253
17-09-16	210	2.413106	0.139946

18-09-16	450	113.8366	3.080869
19-09-16	450	113.8366	3.080869
20-09-16	483	80.26903	2.023973
21-09-16	126	1.297599	0.125422
22-09-16	106	1.091631	0.125422
23-09-16	204	2.473321	0.147657
24-09-16	101	1.040139	0.125422
25-09-16	207	2.787881	0.164024
26-09-16	450	113.8366	3.080869
27-09-16	384	32.23187	1.022253
28-09-16	384	32.23187	1.022253
29-09-16	90	0.926857	0.125422
30-09-16	82	0.84447	0.125422

Appendix 2b. Filtration, sample packing, and balancing of sediment concentration

Appendix 3a. Gully

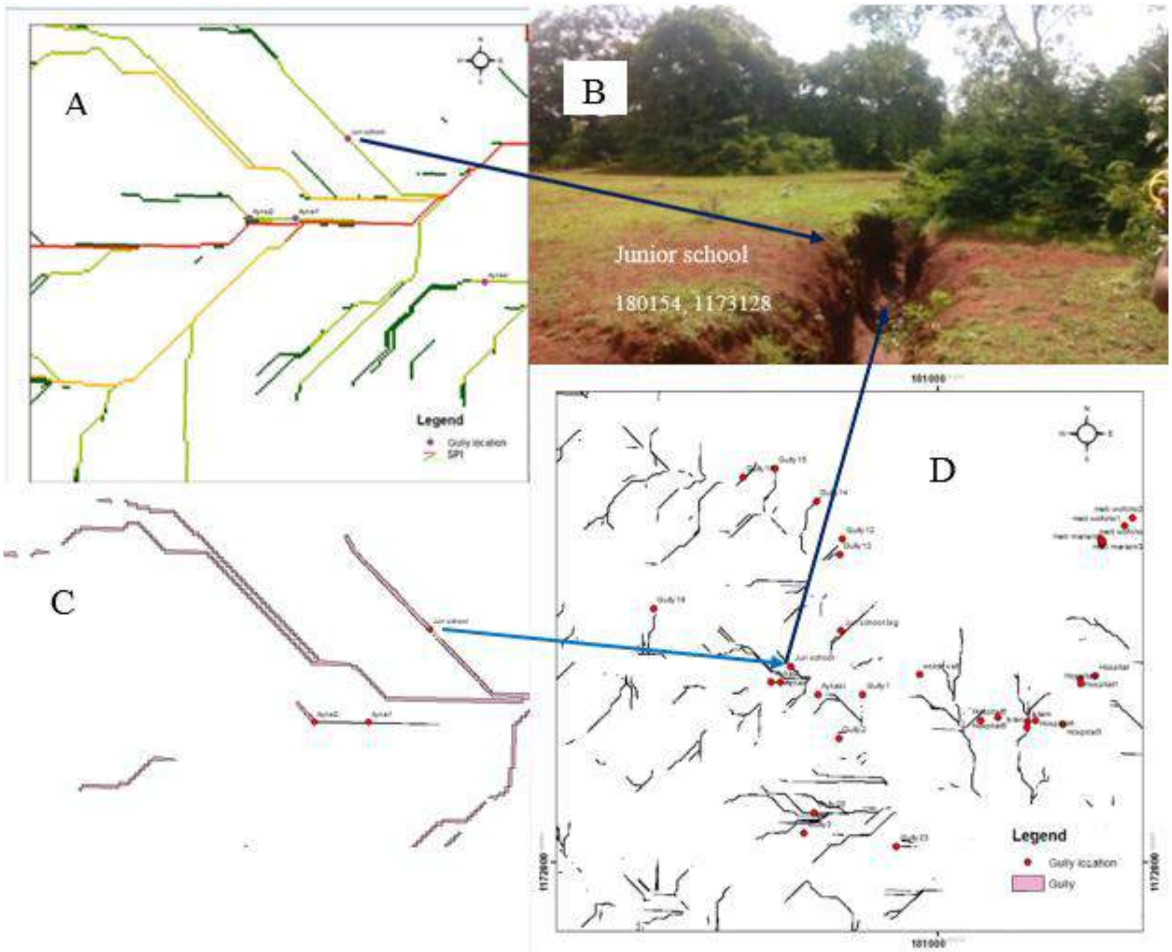
Appendix 3b. Gully measurement



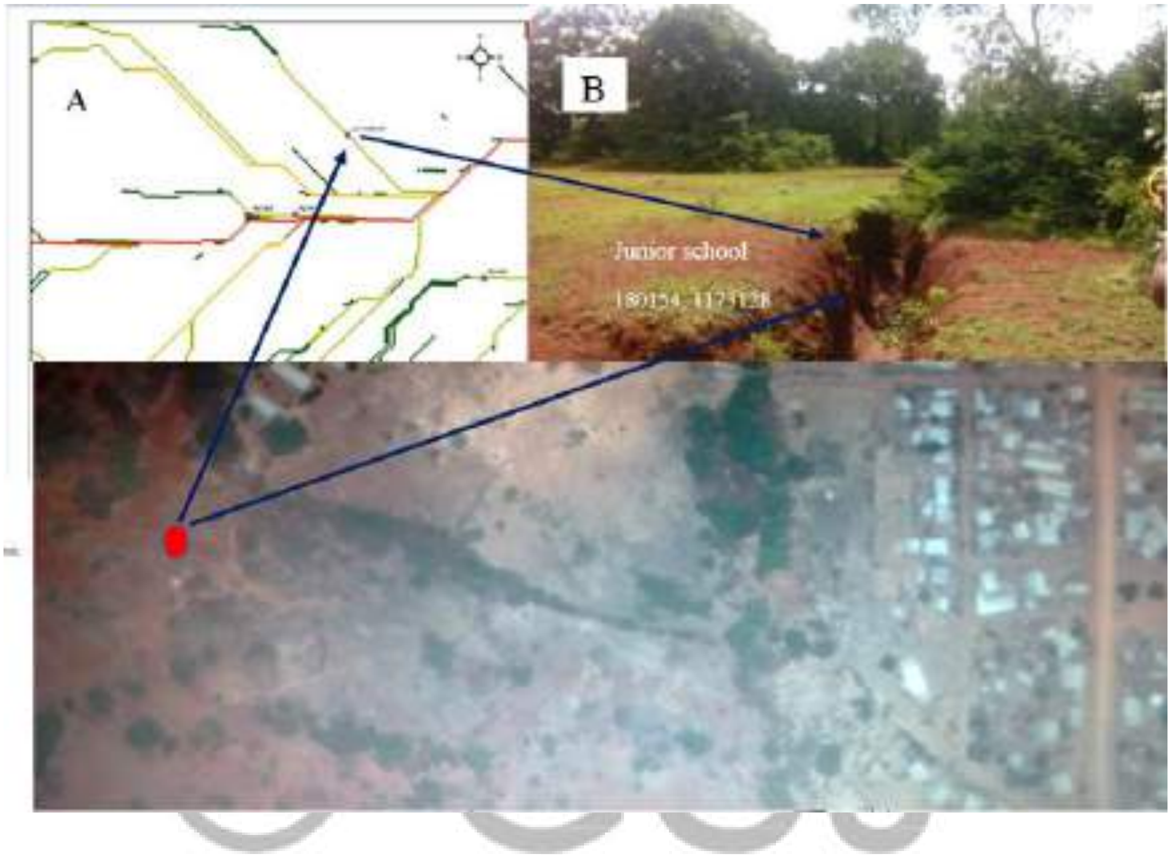
Appendix 4a. Deep well (source of water supply) Damaged due to erosion

Appendix 4b. Damaged reservoir due to riverbank erosion

Appendix 4c. A SPI shows gully location, B photo of gully, C & D Gully polygon captured by SPI



Appendix 4d. A SPI shows gully location, B photo of gully, satellite picture of gully



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Appendix 4h. Change of natural river channel.