



COMPARISON OF MUSLE, EPM AND PSIAC  
SEDIMENT ESTIMATION MODELS:  
CASE STUDY GEREB-SEGEN DAM WATERSHED, TIGRAY, ETHIOPIA

M.Sc. THESIS

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HAWASSA UNIVERSITY

HAWASSA

ETHIOPIA

OCTOBER, 2017

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SEDIMENT ESTIMATION MODELS:  
CASE STUDY GEREB-SEGEN DAM WATERSHED, TIGRAY, ETHIOPIA

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A THESIS SUBMITTED TO THE SCHOOL OF WATER RESOURCE  
ENGINEERING, INSTITUTE OF TECHNOLOGY, SCHOOL OF

GRADUATE STUDIES

HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE  
DEGREE OF  
MASTER OF SCIENCE IN DAM ENGINEERING

OCTOBER, 2017



**SCHOOL OF GRADUATE STUDIES  
HAWASSA UNIVERSITY  
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(Submission Sheet)**

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## **Acknowledgment**

First, and foremost, I want to thank the almighty God and His Mother, Saint Virgin Mary, for giving me the chance, strength and courage to continue my study and for all things done in my entire life. I can say it is with the mercy of God and his holy mother that I succeeded in finishing this paper.

Then, I would like to express my heartfelt gratitude to my advisor Dr. Mulugeta Dadi for his profound guidance, valuable comments and constant encouragement throughout the entire period of this thesis. My sincere appreciation also goes to my Co adviser Dr. Maltot Zewide for his give me support and guidance throughout my study.

I am also thankful to the Ministry of Water, Irrigation and Electricity, Mekelle University, Ethiopian Meteorological Agency Mekelle branch and the Regional State of Tigray Bureau of Water Resource for their relevant data's , instrument and documentations which were very essential for my study. In addition, I am most grateful to Dr. Asmelash Abay and Le-ake Belay.

Finally, I would like to express my gratitude to all my families for their encouragements and support. Especially, my appreciation goes to my wife Shewit Mekonen, and my daughter Hearani Solomon.

## **STATEMENT OF THE AUTHOR**

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## List of Acronyms

a.s.l	above sea level
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
ATSWC	Akam Three S Water Consultant
CNES	Center National D' Études Spatiales
DEM	Digital Elevation Model
DRM	Delivery Ratio Method
EPM	Erosion Potential Method
ENMA	Ethiopia National Metrological Agency
FAO	Food Association Organization
GPS	Global Positioning System
GIS	Geographical Information
HRUs	Hydrological Response Units
MUSLE	Modified Universal Soil Loss Equation
NASA	National Aeronautics and Space Administration
PSIAC	Pacific Southwest Inter – Agency Committee
RSTBOWR	Regional State of Tigray Bureau of Water Resource
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
SWAT	Soil and Water Assessment Tools
SLEMSA	Soli Loss Estimation Model for South Africa
T <sup>o</sup>	Temperature
USDA-ARS	United State Department of Agriculture _ Agricultural Research Service
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WEPP	Water Erosion prediction Project
Ws	Sub Watershed

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## **Abstract**

*Sedimentation of the dam reservoir is a serious problem in Ethiopia. It is also a major problem in many developing countries causing significant loss of water storage, loss of agricultural productivities, loss of electrical supply and ecological changes. The MUSLE, EPM, and PSIAC models are tested for the prediction of sediment yield at Gereb-segen watershed, Tigray, Ethiopia. Poor land use practices and improper management systems have played a significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients. The main objective of this study is comparison of sediment yield of the Gereb-segen dam reservoir, using the MUSLE, EPM and PSIAC models with the observed data and selection of appropriate model for the area. The research integrates the three models with Geographic information system (GIS), Remote sensing and Digital elevation model. Rain fall data, soil data, Geological data, Temperature, land use and land cover, crop management and conservation practices, infiltration rate of soil at field level were used as input data sets to generate the three model factor values. As a result, MUSLE estimates that sediment yield of the study area to the range between 3.89 & 26.45 ton/ha/yr where as EPM estimates the sediment yield in the range of 84.20 to 344.09 ton/ha/yr and PSIAC also estimate 0.16 to 8.90 ton/ha/yr. As they were, compared the three models used to estimate sediment yield of the target area with the measured data which studied by Haregeweyni et al.(2008) sediment yield of 11.82 ton/ha/yr, the MUSLE similar with 82.06% and the PSIAC model similar with 12.35% while the EPM model it is more differ from the measured data. Using the MUSLE model the Gereb-segen watershed sited 0.28% under low, 4.29% moderate, 48.64% high and 46.79% very sedimentation classes.*

(Key words: MUSLE, PSIAC, EPM, Sedimentation, Land use)

# **1 INTRODUCTION**

## **1.1 Background**

Sedimentation is the accumulation of surface soil particles from original location transported to new depositional area. The effects of erosion are both on-site and off-site. Sedimentation as off-site effect is considered to be critical in reservoirs and water bodies, both in reducing capacity as well as loss of value. According to World Commission on Dams, (2000) an estimated 0.5 – 1% of the total fresh water storage capacity of existing dam is lost each year in the absence of measures to control sedimentation. The study also indicated that the problem is more severe in developing countries. Various human activities disturb the land surface, and thereby induce significant alteration of natural erosion rates.

In Northwest China, a study had been conducted investigating how the changes of land use and land cover influence soil erosion and reservoir siltation on the upstream of Shiyang reservoir (Zhou, 2002). The study found out that 43 % of woodland areas turned into agricultural land and soil erosion intensity was more severe on cropped land. The author concluded that anthropogenic activities were the main causes of land use changes and siltation in the Shiyang Reservoir (Zhou, 2002).

In Ghana, Burekese reservoir, a similar study carried out. Land satellite images from 1973, 1986 and 2000 analyzed using Arc GIS to assess the impact of land use and land cover changes on Burekese catchment. Hydrographic surveys conducted during the study period at the same locality showed a decrease in storage capacity of 45 % due to siltation. The changes in land use and land cover that caused the siltation of the reservoir attributed to deforestation, population growth and lack of proper education of the communities in catchment management (Adjei et al., 2008).

Rapid population growth, cultivation on steep slopes, clearing of vegetation, and overgrazing are the main anthropogenic factors that accelerate soil erosion and sedimentation in Ethiopia (Reusing et al., 2000). Such unsustainable and exploitative land use practices could perhaps be due to increasing demand for food, fiber, and fodder by the growing human and livestock populations. These practices reduce the protective plant cover, thereby exposing the soil surface to the destructive impact of high-intensity rainfall.

The assessment of sedimentation on the reservoir level is important to sustained agricultural production. The quantification or identification of the amount sediment coming from the difference land use type of the watershed help full where the mitigation conservation measures to be taken and support in policy formulation for sustaining the environment as a whole (Kalpana and Bhaware, 2006).

The lack of information is one of the most important problems for statistical and analysis and studies of erosion and sediment. The problem more faced in the developing countries such as Ethiopia. In recent using the GIS (Geographic Information System) environment, it is possible to link data generated from the remote sensing with their spatial location, in the forms of aerial photographs. The satellite sensors data has been well recognized in mapping and assessing land scope attributes such as physiography, land use/land cover, and relief. In general, the use of GIS offer the following advantages in sediment yield estimation models. Fast and cost effective estimates, possibilities to investigate larger area and greater possibilities of continuous monitoring of these areas due to its powerful analytic capabilities (Dayawansa et al., 1997)

The main goal of this study by estimating the sedimentation yield of Gereb-segen dam watershed via Erosion Potential Method (EPM), Pacific Southwest Inter - Agency Committee( PSIAC ) and Modified Universal Soil Loss Equation (MUSLE) models using GIS environment and comparing them with the observed data's to select appropriate model for the area, and to estimate the life span of the reservoir .

## **1.2 Statement of the problem**

Worldwide Reservoir Sedimentation is a serious problem and reduces the fresh water existing for different purposes. The accumulation of sediments in reservoir can lead to arrange of problems such as increasing flood risk on influent streams, loss of flood storage for dawn stream channels, increasing spillway flows, the loss of storage capacity with associated loss of reservoir yield and difficulties in storage recovery and sever blockage of scour/draw off works. The resulting in periodic reservoir draw down to excavated sediment or abandonment of bottom out let facilities. The buildup of sediment against the upstream face of dam adversely affecting the stability of certain dam structures (Lal, 1990).

Tigray region is one of the environments that are highly degraded areas, due to population pressure in rural areas, steep slopes are still cultivated that exacerbate soil loss. Agricultural land is the dominant land use in almost all watersheds of the micro-dam irrigation projects, which are often susceptible to erosion. The soil mass eroded from these cultivated lands ended up at the reservoirs and the capacity of many dams is reducing quickly and in some cases the dams are completely silted up to dead storage level. In south of Tigary near to Gereb-segen dam a study were conducted how the sedimentation affect the functionality of the reservoir the result indicates Filigling the life time of the reservoir decrease from 30 years to 5.7 years and the Grashito from 20.6 years to 4.4 years (Aynekulu et. al, 2006).

The Gereb-segen dam constructed for the purpose of irrigation and water supply for Mekelle city. The city is one of among the severely affected scarcity of water supply .The Gereb-segen Catchment area is not well treated and it seriously affected by erosion hazards. From the field observation, some indicators such as the diversion structures constructed for irrigation in the upper catchment resulted in rapid siltation. The rapid sedimentation of reservoir affects the farmers' agricultural products and water supply for Mekelle city. That is why the main objective of this research is to estimate the annual sediment yield (ton/ha/year) and to propose the mitigation measures that are helpful for reducing the sediment load that is expected to be entered or reach to the reservoir.

### **1.3 Research objective**

#### **1.3.1 General Objective**

To compare the relative performance of sediment yield estimating models MUSLE, EPM and PSIAC at Gereb-segen dam watershed, and compare them with the existing situation (observed data ) so that to select appropriate model for the area.

#### **1.3.2 Specific objectives**

1. To predict, the impact of sedimentation on the life span of the dam.
2. To identify the sub watersheds which highly contribute to reservoir sedimentation

#### **1.3.3 Research questions**

The research focused on the suitability of the three models in estimating the sedimentation yield at Gereb-segen dam. The study attempted to answer the following questions:

1. From the three models used to estimate sediment yield which model is more appropriate / suitability to the area.
2. What is the current sedimentation rate of Gereb-segen dam reservoir?
3. What are the predictions the impact of sedimentation on the available life of the dam?
4. Within the watershed, which sub watersheds are highly, contributes to the reservoir sedimentation.

### **1.4 Scope of the study**

Since it is not possible to cover the whole aspects of the study area like conservation soil practice with the available time and budget, it is advisable to limit the scope of the problem to a sub manageable objective. Hence, the study focused on the dam reservoir sedimentation yield estimation .The scope limited to focus comparison on the annual sediment yield based on the observed data and the MUSLE ,EPM and PSIAC sediment yield estimating models at the Gereb-segen dam watershed.

### **1.5 Limitation of the study**

The study of sediment yield estimation models MUSLE, EPM, and PSIAC have the following limitation;

- The factors used to estimate the MUSLE, EPM, and PSIAC model such as coefficient of land use factor, present erosion type, coefficient of rock and soil, surface geological factor, support practices factor and vegetation and management factor the estimation matter requires certain experience, the values differed from one person to another person print of view.
- Only the observed data that was previously conducted by Survey method was found or available. Therefore, it was scientifically to earn more than two observed data for comparison with the models simulated results to find more precise and reliable result or data specifically represent the area of study.

### **1.6 Significance of the study**

The studies of the three different models applicability/suitability at the Gereb-segen dam reservoir were important for several reasons.

- I. By identifying and evaluating the factors that causes sedimentation, the study was identified the most appropriate model for the area then any person who went to study in the surrounding area it can be used as imputes/guidance.
- II. The sedimentation map prepared for sub-watershed with the objective of identifying sediment yields serve as a base map in planning appropriate conservation methods for mitigating of the sedimentation deposit in the reservoir.
- III. The data's prepared for this research work can be use as an input or base line data for other related studies in the area.

## **2 LITERATURE REVIEW**

### **2.1 General overview**

Reservoir sedimentation is a process that has been going on since the first dams were build and is a consequence of creating a calm reservoir lake where there used to be a fast flowing river. It eventually starts to influence the reservoir capacity and the river morphology. The siltation of the reservoir could hinder the usage of the dam and interfere with the functionality of the reservoir (Lal, 1990). With the sediments taking up space in the reservoir, the storage capacity of the reservoir is decreasing. If the sediments settle all the way towards the dam structure, the navigability of the river can be negatively influence because the river morphology is changing. It has an effect on the ecology too, since the continuous river flow interrupted and fragile ecological equilibriums will be disturbed.

There are a number of studies on sediment measurements, which conducted to estimate the deposit of sedimentation in reservoirs. The U.S. geological survey (USGS, 2005) has completed a number of reservoir sediment studies in Kansas using a combination of bathymetric surveying, sediment coring, chemical analysis, and statistical analysis. The results indicated that decreases in total water storage capacity ranged from less than 5% to about 55%.

In Africa, erosion and desertification have reduced agricultural productivity by 20% (Lal, 1990). The most well known effects of crop erosion include losses in replaceable and irreplaceable attributes of the soil, on-site and off-site sediment effects, release of particles into the air, and gully. The most harmful off-site effects are the in-stream biological impacts although the effects on navigation and the recreational sector such as swimming and boating accidents and recreational fishing should not be disregard. Erosion also enhances sediment accumulation in lakes and reservoirs, decreasing their water storage capacity, varying water temperature, and encouraging the growth of water consuming plants. Although it knows that flooding is not slowly due to sedimentation, it does indeed exacerbate the problem, it also causes clogging as water flows through water conveyance systems and increased water treatment needs and costs affect infrastructure and human populations directly.

In Ethiopia, soil erosion is a serious problem through increasing sedimentation of reservoirs and lakes (Bezuayehu, 2006). Hurni,(1993) estimates that soil loss due to erosion in Ethiopia amounts to 1493 million tons per year, of which about 42 ton/ha/yr is estimated to have come from cultivated fields. According to Kebede,(2012) description most of Ethiopia's hydroelectric power and irrigation reservoirs such as Aba-Samuel, Koka, Angerib, Melka Wonka, Borkena, Adarko and Legedadi has been affected by the heavy sedimentation. Thus, dams have been suffered from reduction in their capacity and life span, it require costly operation for removal and operation and loss their intended services. Bashar et al., (2010) conducted study the reservoir sedimentation in the Nile basin and the research carried out results the Angereb (1986 – 2005) loss storage capacity 15% and Koka (1960 – 1999) loss storage capacity 32%.

In catchment study, sediment deposition rate of 9.2 ton/ha/yr was estimated in Tigray northern Ethiopia (Nyssen et al., 2007) and while Hurni, (1985) had reported 30 ton/ha/yr .Both natural and human-induced processes are responsible for high erosion that causes rapid siltation of reservoirs in the Tigray region (Nyssen et al., 2007). The topography characterized with long and steep slope that provides high energy of water flow. Protective surface cover is low and the soil materials are largely loose due to the intensive cultivation of lands for long period, which can easily washed away. Rainfall is intensive and onsets after long dry season striking virtually an open soil with minimum surface protection. These attributes, combined with the prominent gullies, resulted in one of the most severe reservoir sedimentation problems in the region. According to Haregeweyn et al., (2005) lack of sediment yield data and appropriate methodologies for predicting sediment yield have contributed to poor planning resulting in rapid sedimentation in reservoirs and storage capacity loss, as a result 50% of the studied reservoirs in the region have lost their economic life before half of the design period because of siltation. Based on field measurements on 202 plots in 12 sites of Tigray highlands (Desta *et al.*, 2005) have found a mean annual soil loss from crop land in the absence of soil and water conservation measure was 57 ton/ha/yr. According Vanmaercke et al.,(2008) a study conducting to estimate sediment yields in the north of Ethiopia Geba catchment area of 5180 km<sup>2</sup> a result range between 400 and 2500 ton/km<sup>2</sup>/yr was obtained.

The Gereb-segen watershed one off the most affected by erosion hazards and a study conduct, on the reservoir sedimentation using the reservoir sediment survey methods by Haregeweyn et al.(2008) and Tamene et al.(2005) gotten measured values of 11.7 ton/ha/yr and 11.82 ton/ha/yr respectively.

The factors affecting erosion and sedimentations are soil, topography, climate, and vegetation. Properties of soils such as structure, biological and chemical composition, organic matter, texture, moisture content, and density directly affect the infiltration capacity of soil as well as its dispersion and transportation. On the other hand, high infiltration rates, higher percentage of organic matter in soil and improved soil structure enhance erosion resistance. Topographical features of the land such as slope may have a strong influence on erosion rates. At steeper angles, high flow velocities are generated which in turn enhance erosion considerably. The shape and size of the catchment along with the slope length, defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel (Renard, 1997) also play an important role in reservoir sedimentation.

Erosion by water defined as the removal of soil from any type of land by runoff generated by melting ice and snow, rain or any type of running water or as the detachment or entrainment of soil particles (Lal, 1990). Erosion by water adversely affects the sedimentation of reservoir, by reducing infiltration rates, water holding capacity, nutrients, and organic matter content of soil and by increasing the rate of soil erosion. It also causes, gully development, disturbance of water regime, environmental pollution, enhanced flood risks due to river sedimentation and reduced water reservoir capacity and damage to buildings and infrastructure especially reservoirs.

The Vegetation reduces soil loss by absorbing the rainfall energy of raindrops and reducing runoff, decreasing flow velocities, restricting soil movement by roots and weeds, improving porosity and aggregation and decreasing soil moisture by transpiration. Changes in vegetation, soil composition, compatibility, roughness, and soil cover account for the impact of land use on soil loss quantities. Therefore, land use and soil cover play a significant role when predicting soil loss or sediment yields and must always be included in erosion modeling (Aregay and Chadokar, 1993). Land uses that considered major sediment sources include construction sites,

roadway embankments, ditches, cuts, disturbed forestland, surface mines or quarries, agricultural lands and the natural geological eroding.

### **2.1.1 Causes of sedimentation**

#### **Catchment size**

The catchment size have in direct proportional with the sedimentation of dam reservoirs as the catchment size increase the sedimentation decrease and as the catchment size decrease the sedimentation increase due to the suspended load transportation effects. In most in the Northern Ethiopia, the sizes of the catchment have positively contributing to the sediment loads in the reservoirs. The smaller the catchment the greater the chances of suspended load being carried by the flood to reach the reservoir in a relatively shorter distance without settling somewhere in the watershed (Aynekulu et al., 2006). These results in the smaller catchment constructed dam have an appaurtinity to sediment load rapidly filling up the dead storage zone therefore reducing the useful life of reservoirs. In the larger catchment the suspended load being carried by the flood to reach the reservoir in a relatively takes long distance it have the appaurtinity of settling of some sediment before reaching the reservoir.

#### **Vegetation covers of the catchment**

The vegetation cover of the catchment controls the impact of soil erosion, in most area the sedimentation of dam reservoir happiness in short period of time due to the poor management of catchments. If catchment area covered with vegetation like mulching grass, plants, forest area, the soil held together by elaborate network of roots, which underlies the forest floor. This results in reduced sediments into the rivers and reservoirs. The catchment area is also protects from the effects of wind and rain erosion by the forest canopy above. While the catchment area with bare lands it facilitates the erosion process and large accumulation of sediments in the reservoirs (Haregeweyn et al., 2005).

#### **Topography of catchment area**

Topographic features that influence erosion is slope length and steepness shape (including Concave, uniform, or convex). The slope factors (LS) refer to topographic and/or relief factor. Steep and long slopes develop high velocity of flow, which cause more erosion there by making the river to carry subsequent amount of sediments. Eventually the sediments deposited into reservoirs where the river would be flowing. Erosion can be normal expected to increase

with increase in slope steepness and slope length because of respective increases in velocity and volume of surface runoff. Steeper continuous slopes cause higher runoff velocities; more splashes downhill, faster flow, and therefore contribute greater soil erosion.

### **Population increases**

The rapidity population growth led to fast land use changes, Cultivated land and livestock trampling, forest harvesting and urban development are land uses that act as influential sediment runoff sources on lotic habitats. The Various human activities that lead to disturb the land surface and induce significant alteration of natural erosion rates. The unplanned rapid population growth of human being leads to clearing of vegetation and hillside sloping cultivation and overgrazing are the main anthropogenic factors that accelerate soil erosion in Ethiopia (Reusing et al., 2000). These poor practices of the land use reduce the protective plant cover and organic content of the soils by exposing the soil surface to the destructive impact of high-intensity rainfall.

### **Climatic effect**

The Pug Sound region is expected to experience increases in the frequency of landslides and the rate of erosion and sediment transport in summer ,primarily in winter and spring these processes are expected to become less important in the future ,due to diminishing stream flow and river soils. Both natural Climate variability and human modification on the land scope have a strong effect on landslide and sediment processes, and continue to influence these processes in the future (Guillaume, 2016).

Climate is a major driver of erosion, sediment transport, and landslide hazards; they are other factors that can have an important effect on these processes. In particular, changes in land use and land cover both due to development and forest management can dramatically affect the likelihood of a landslide, the exposure of sediments to erosion, and the rate of stream flow and sediment transports, (Guillaume, 2016).

The major mechanisms linking climate with landslides, erosion, and sediment transport are:

### **Temperature**

High temperatures contribute to slope instability by enhancing the thermal breakdown of rock, decreasing the viscosity of ground water (i.e., more lubricating), and warmer frozen ground so more water infiltrates. Warm conditions can also cause increased evaporation, leading to drier soils and more stable conditions in deeper soils, especially in summer. Finally, warming can

intensify the cycling between wet and dry periods, which may act to widen gaps in rock and soil, contributing to a decrease in slope stability.

### **Precipitation**

Heavy rainfall events reduce slope stability by rapidly raising the water table (or groundwater elevation) and by enhancing water drainage through the soil to lower layer. In addition, intense rainfall can erode surface sediments, and higher stream flow during these events can transport more sediment downstream. The different patterns of rainfall affect slope destabilization and which increases the amount of erosion and sediment transports.

### **Soil Water Content**

Wetter soils are heavier, can absorb less precipitation (thus increasing runoff), and have greater lubrication among soil layers and it separates the interlocking between the soil layers and this facilitates to the soil erosion.

### **Stream flow**

Higher stream flow, which is common in summer, can erode stream banks, and transport more sediment within the stream and along the streambed. Low stream flow, which is common in winter results in lower rates of sediment transport. In winter, the reduction in transport can increase sediment buildup within stream channels and reduce the capacity for floodwater in subsequent events.

### **Vegetation**

Vegetation loss from water stress, wild fire, insect attacks, or disease can lead to increased soil surface erosion and sediment transport to streams during rain events. Loss of vegetation from fire temporarily reduces the ability of soils to absorb moisture, increases surface runoff, and increase sediment transport. In addition, the root decay following fires can weaken slopes, especially one to three years after a fire (Guillaume, 2016).

### **Sea level rise**

Sea level rise could trap sediment within rivers and exacerbate coastal erosion. Elevated sea level (for example, due to summer storm surge) could cause more sediment trapping within river and stream by reducing stream velocities, which promotes sediment deposition and reduces the size of the river channel. Higher sea levels also allow wave energy to reach further inland, eroding unarmored shorelines and redistributing beach (sandy) sediments.

### **Agricultural practices**

Erosion, sediment transport, and sedimentation are critical problems in our country. The level of degradation leading to erosion, sediment transport, and sedimentation are causing considerable loss of soil, deposition in rivers and reservoir and can cause irreversible level of degradation, loss of livelihood and already causing significant canal and reservoir sediment cleaning costs. Some analysis of data at various stations show that seasonal sediment distribution is highly variable and the highest sediment concentration occurs in the month of Jun and July, when most of the land is cultivated with traditional practice that leads to significant loss of soil and nutrient from the agricultural field in the form of erosion and sediment. The consequence is rapid accumulation and losses of capacity of small reservoirs built for agricultural or other water supplies and rapid filling of the dead storage of large reservoirs and lakes built for various purposes or exist naturally (Haregeweyn et al., 2005).

Over ally land use and land cover change are the major causes of massive siltation of many dams. The spatial dimensions of land use and land cover need to known based on remote sensing satellite data and DEM (using Arc GIS software). This can be achieving through frequent mapping of reserved forests and woodlands thus generation of information for governments informing them of the magnitude of encroachment. According to Hill (1999) land use and land, cover change in Africa is currently accelerating and causing widespread sedimentation problems in many river catchments and thus has been need to map. This is important because the changing pattern of land use and land cover reflect changing economic and social conditions. Monitoring such changes is important for coordinated actions at the national and international levels in integrated catchment as well as basin management.

### **Conservation Practice**

Especially in agricultural and bare land areas, conservation practices such as contouring, strip cropping, or terracing, reduce soil losses. For instance, in areas where there is terracing, runoff speed can reduce with increased infiltration, ultimately resulting in lower soil loss and sediment delivery.

## **2.2 Sedimentation yield estimating Models**

Modeling is a useful tool for erosion scenario and sediment yield assessment that enables the adequate selection of erosion control measures (Morgan et al., 1984) . Wide variety of models is available for assessing sedimentation of reservoirs. The sediment estimation models can be classified in a number of ways. One may make a subdivision based on the time scale for which a model can be used; some models designed to predict long-term annual sedimentation of reservoir, while others predict single storm losses (event-based). Field studies for prediction and assessment of sedimentation are expensive, time-consuming and need to be collected data over many years. Though providing detailed understanding of the erosion processes, field studies have limitations because of complexity of interactions and the difficulty of generalizing from the results. The sediment yield estimating models can simulate sedimentation of the reservoir in the watershed and may be able to take into account many of the complex interactions that accelerate the rates of sedimentation. Therefore, the choice for a particular model largely depends on the purpose for which it is intended and the available data, time and money (Lal, 2001).

The sedimentation yield estimating models allow users to ascertain temporal trends, examine spatial variations, identify critical processes, and explore the possible impacts of remedial measures and the relative effectiveness of implementation strategies for sedimentation controls. Modeling in sedimentation is the process of mathematically describing soil particle deposition on the reservoirs. The objective of model is either predictability or explanatory (Petter, 1992). In general, the models fall into three main categories: conceptual, empirical, and physically based models.

**Conceptual models** are a mixture of empirical and physically based models and their application is therefore more applicable to answer general question. These models usually incorporate general descriptions of catchment processes without specifying process interactions that would require very detailed catchment information, and based on spatially lumped forms of water and sediment continuity equation. The Conceptual models that use simple mathematical equations to describe the main hydrologic processes such as, evapotranspiration, surface storage, percolation, snow melt, base flow, and runoff. The advantage of this approach is that the model is much simpler from a mathematical point of view. The processes are estimated

with simple equations rather than solving governing partial differential equations (Devia et al., 2015).

**Physically based models** represent natural processes by describing each individual physical process of the system and combining them into a complex model. Physical equations here by describe natural processes, such as stream flow or sediment transport, and incorporate the law of conservation of mass and energy. In theory, the parameters used in physical-based models are measurable and known. In practice, the large number of parameters involved and the heterogeneity of important characteristics, particularly in catchments, means that these parameters must often to be calibrating against observed data (Beck, 1987). Examples of physically based models are the Water Erosion Prediction Project (WEPP), the Soil and Water Assessment Tool (SWAT) and the equation of stream flow or sediment transport (Devia et al., 2015).

**Empirical models** are a simplified representation of natural processes based on empirical observations. Those models generally based on observations of the environment and thus, are often of statistical relevance. 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 and sediment yields (Merritt et al., 2003). The empirical models frequently utilized for modeling complex processes and in the context of erosion and soil erosion, particularly useful for identifying the sources of sediments (Devia et al., 2015).

Empirical models are generally the simplest of all three-model types. They are statistical in nature and bases primarily on the analysis of observations and seek to characterize response from these data. Some of the empirical models are the Soil loss estimation model for South Africa (SLEMSA), EPM, Delivery Ratio Method (DRM), USLE and RUSLE, MUSLE and PSIAC. The data requirements for such models are usually less as compared to conceptual and physical based models. Conceptual models play an intermediary role between empirical and physically based models. Physical process based models take into account the combination of the individual components that affect erosion, including the complex interactions between various factors and their spatial and temporal variability's. They are comparatively over-parameterized, designed for specific set of conditions of particular areas; they need information

related with soil type, land use, landform, climate, and topography to estimate soil loss. The PSIAC, EMP and MUSLE are some of empirical model used to assess sedimentation. Despite the availability of such a large number of empirical models, those models would be selected for this study because of its utilization in GIS environments and have similar assessing methods.

### **MUSLE (Modified Universal Soil Loss Equation) Model Description**

USLE model is the most widely and universally used model for erosion hazard assessment throughout the World. The first attempt to develop soil loss equation for areas such as Zingg (1940) introduced hill slopes and fields based on steepness (S) and slope length (L). Further developments led to addition of climatic factor based on the Maximum 30-min rainfall by Musgrave (1947). Then Smith, (1958) included a crop factor (C), a conservation factor (P) and soil erodibility factor (K). Wischmeier and Smith, (1965) produced the universal soil loss equation (USLE) by converging climatic factor to rainfall erosivity (R). Finally, Williams, (1975) by converging the rainfall erosivity to runoff factor (volume of runoff (Q) and peak flow rate (qp)) produced the modified universal soil loss equations. Advantages of replacing the rainfall energy factor with the runoff factor include:

- I. Increased accuracy because runoff generally explains more variation in sediment yield than rainfall does;
- II. Eliminates the need for delivery ratios because the runoff factor represents energy used in transporting as well as detaching sediment; and
- III. Applies to individual storms (an important attribute particularly in simulating water quality).

MUSLE model is a method of optimizing hydrological model parameters to estimate sediment yield. To formulate the hydrological processes of sediment yield, 778 individual storm events in 18 catchments with areas ranging from 15 to 1500 ha were investigated by Williams and Berndt, (1977). The MUSLE then successfully developed with a correlation coefficient of 92% for estimation of sediment yield on a storm basis.

### **EPM (Erosion Potential Method) Model Description**

Since 1963, Gavrilovic started an extensive study campaign for better understand soil loss phenomena and sediment yield from Alpine and semi Alpine region. Gavrilovic, (1988) has summed up all the work after more than 20 years of experimental observation in his work. The

method, called Erosion Potential Method, is fully empirical, and relies only on easy collectable data and simple mathematical formulas. The formula starts mapping three different coefficients named:  $\phi$ , Xa and Y. The first called Observed Erosion Coefficient and graded into ten values ranging from 0.1 to 1.0. It express the level of present erosion, following a reference table supplied in original work (Gavrilovic, (1988); the estimation is a matter of visual estimate and requires a certain experience (Gavrilovic, 1988). Xa is land-use coefficient and should estimate by aerial photos and deals with terrain coverage type: for instance woods, crops, hay meadows, bare soil and so on; values range from 0.05 to 1.0. Last, Y is coefficient of rock and soil resistance to erosion and depends by the pedological classes of soil. Gavrilovic gives a table of values also for this parameter. These values are combined together to obtain Z, the erosion coefficient intensity.

The EPM model was one of the most models used to estimate the sedimentation yield in Iran based on climatic conditions. Chamgardalan watershed, west of Iran was using the EPM model estimated sediment yield a result of 19.97 ton/ha/year were obtained while the observed total sediment was 22.60 ton/ha/year, therefore according to Yousefi et al.,( 2014) the model is more applicable in arid and areas of Iran. Karoon basin (Iran) using the EPM model with a geographical information systems the sediment yield results showed that 94.4% of the total watershed area had low sedimentation, 5.2% moderate sedimentation, 0.3% high sedimentation and 0.009% extremely high sedimentation(Al-saffar et al., 2012).

#### **PSIAC (Pacific Southwest Inter – Agency Committee) Model Description**

The PSIAC (Pacific Southwest Inter – Agency Committee) model (PSAIC, 1968) was developed primarily for application in arid and semi-arid areas in the southwestern USA, and it is believed that appropriate results obtained in the Iran similar climate conditions (Sadeghi, 1993). Although the procedure was developed for the Pacific Southwest, it included factors important in estimating sediment yield with a wide variety of conditions, in response to changes in grazing and vegetative cover, to compare measured and predicted sediment yields and to show how the method could be used in predicting the effects of rangeland management practices on sediment yield.

In Tanzania, the PSIAC model used to estimate the sedimentation yield and satisfactory result obtained as in the table below described (Ndomba, 2013).

Table 2.1: Sediment yield using PSIAC model in Tanzania (Ndomba, 2013)

Statistics	Lake Nyasa Basin		Lake Tanganyika Basin		Pangani Basin	
	Calibrated PSIAC (t/ha/yr)	Published Data (t/ha/yr)	Published data(t/ha/yr)	Calibrated PSIAC (t/ha/yr)	Published data(t/ha/yr)	Calibrated PSIAC (t/ha/yr)
Mean annual yield	5.064	5 - 7.5	6.5	5 - 7.5	5.05	2.5 – 5

In South Ethiopia, lake Hawassa using the PSIAC models an estimated values of annual sedimentation yield  $95 - 250 \text{ m}^3/\text{Km}^2/\text{Yr}$  of the 66.4% total area of the watershed and  $<95 \text{ m}^3/\text{Km}^2/\text{Yr}$  the 22.7% total area of the water shed were obtained Mulugeta, (2013).

The MUSLE, EPM, and PSIAC models are an empirical models used to estimate the sediment yields. Those models estimate the sediment yield with GIS environment conditions. Both the models have similar factors utilized to estimate sediment yield such as soil type, topography, land use/land cover, and rainfall are used. The PSIAC models have more factors than the two models. The EPM models factors such as rock and soil coefficient, land use coefficient and coefficient for the present erosion are subjective parameters (user specified parameters) than the two models.

## Lifespan of dam

Dams are built to serve for a long time of reliable and safe operation, which is monitored, for many dams since a long time. In the course of time during the operation of those dams partly the design philosophy and construction methods have changed to cope with the state of the art. Especially when designing dams which are built, abroad it is necessary to adapt the design prerequisites. It is of importance to reconsider under such circumstances loading conditions to minimize possible risks. Dam ageing is describing the long term behaviour which might be interpreted as any change in dam properties with the passage of time and might affect dam safety and it affects by Structural (geologic, hydraulic, and seismic design criteria), monitoring, operational and sedimentation affect (Wieland, 2010).

## **Structural**

Generally, several factors are considered in selecting the type of dam such as, topography, geology, seismic, foundation conditions, material availability, environment, and economic conditions. The development of rock mechanics and treatment of the foundation as an integral part of the overall bearing system has improved the situation. Whereas areas of uncertainties still exist due to a limited knowledge of rock characteristic along foundation, which is generally heterogeneous, inelastic, anisotropic and apparently with changing properties. The ageing process which modifies, the rock behaviour can be classified in change of stress and increase of joints together with a change in seepage conditions. This process should be self-stabilizing or needs certain external intervention, to prevent e.g. degradation of weak infillings. The design period of the dam failed due to the seepage failure, hydraulic failure and Structural failure. Most of the dams constructed in north Ethiopia, Tigary region failed due to the seepage failures and rapid sedimentations (Aynekulu et al., 2006 and Tamene et al., 2005)

## **Monitoring and Operational**

Dams of all types require regular surveillance if they are to be maintained in a safe and operationally efficient state. As with all structures, they are subject to a degree of long-term but progressive deterioration. Some of the latter may be superficial in relation to structural integrity, but the possibility of concealed and serious internal deterioration should be considered. Surveillance of dam minimizes the possibility of catastrophic failure of the dam by the timely detection of design inadequacies or regressive changes in behaviour (Wieland, 2010).

## **Sedimentation**

The reservoirs capacity is getting decaying due to filling up of sediments year after years. The reservoirs especially built for irrigation, water supply and power generation will hamper economics in a great extent and has environmental concerns. The estimation of sedimentation depends on variable parameters such as sediments and inflow rates of water. The sediment coming from catchment results in to loss of capacity of reservoir, there is direct relation between runoff and sediment yield. Sediment deposition into reservoirs that are built for power generation are adversely affected due to loss of storage, damage to equipment, bank erosion, etc(Kebede,2012). All the major rivers of Ethiopia are turbid watercourses affected by high sedimentation rates.

### 3 MATERIALS AND METHODS

#### 3.1 Description of the Study Area

##### 3.1.1 Location

The Gereb-segen dam is located in the northern part of Ethiopia, Tigray region state at the boundary of Hintalo Wajirat and Enederta woredas. The watershed of the Gereb-segen dam has an average elevation of 1823.20 m to 2744 m above sea level (asl) and average annual rainfall ranges from 497.38 mm to 660.45 mm. A catchment area of about 287.65 km<sup>2</sup>. The dam has crest length of 815 m, height 46 m and maximum storage capacity of 24.67 Mm<sup>3</sup> and dead storage of 6.68 Mm<sup>3</sup>. The Dam found approximately 800 km far from Addis Ababa and 17 km south of Mekelle. The geographical coordinates of the watershed lies between E 533674 N 1469811 and E 563947 N 1485072 N UTM, (RSTBOWR, 2014).

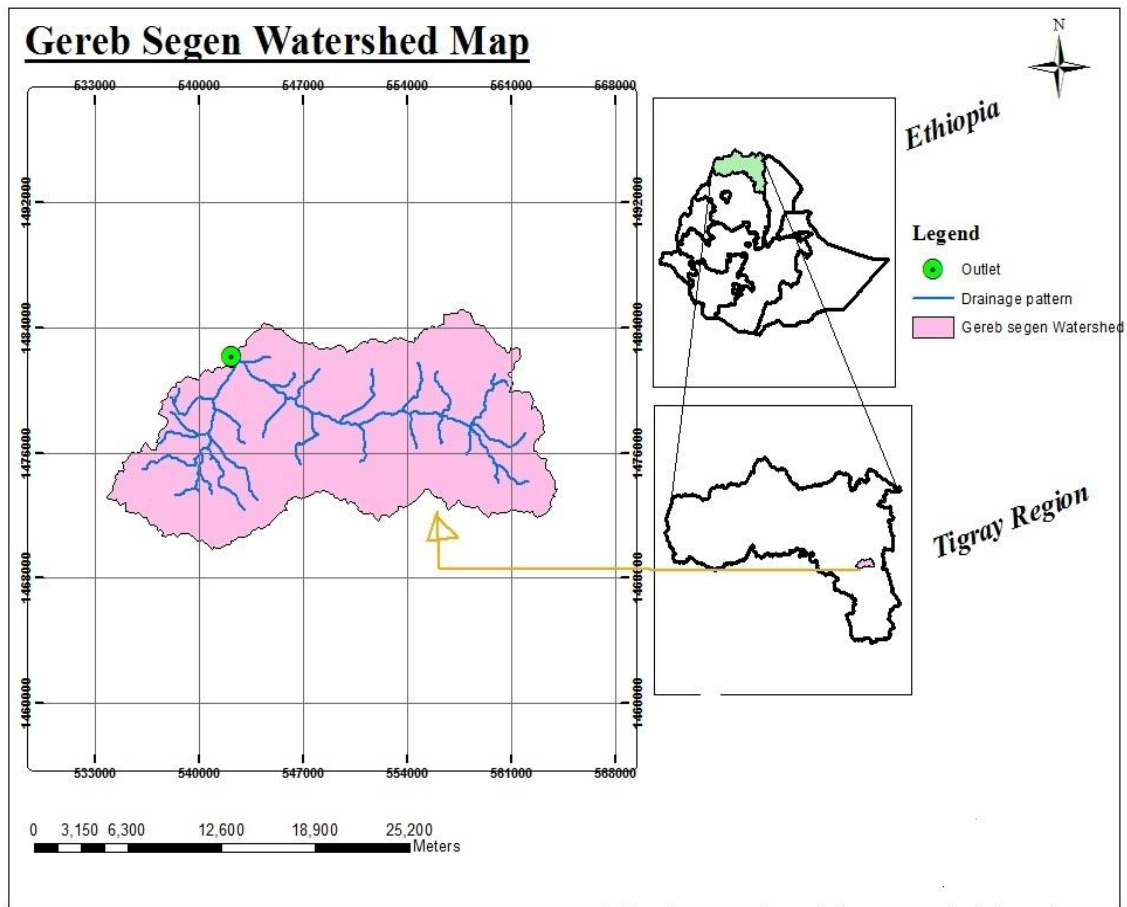


Figure 3.1: Location map of the study area

### 3.1.2 Climate

According to Hurni, (1986) description of agro climatic zones of Ethiopia, Gereb-segen watershed belongs to Weyna Dega agro climatic zone, the rainfall pattern in the study area shows that a strong peak in the summer months (June-September) and minor (short) rainfalls in the rest of the months. Annual rainfall of the study area is around 555.77 mm, mean annual maximum and minimum temperatures in the study area are 24.06 °c and 11.57 °c respectively using metrological data 1997-2016 (ENMA, 2017).

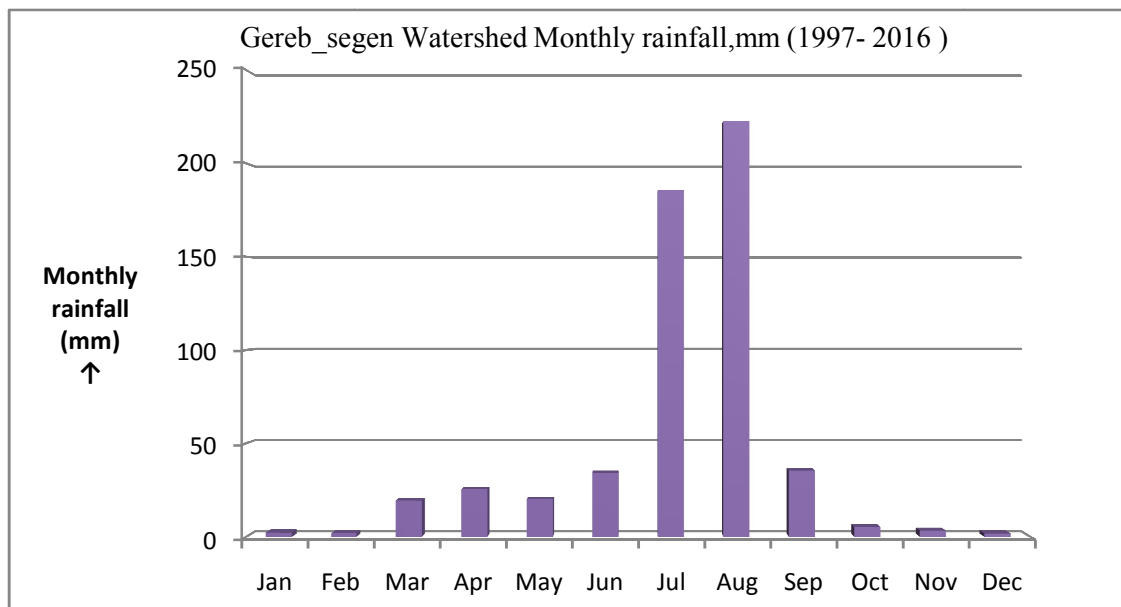


Figure 3.2: Mean Monthly Rain Fall of Gereb-segen watershed

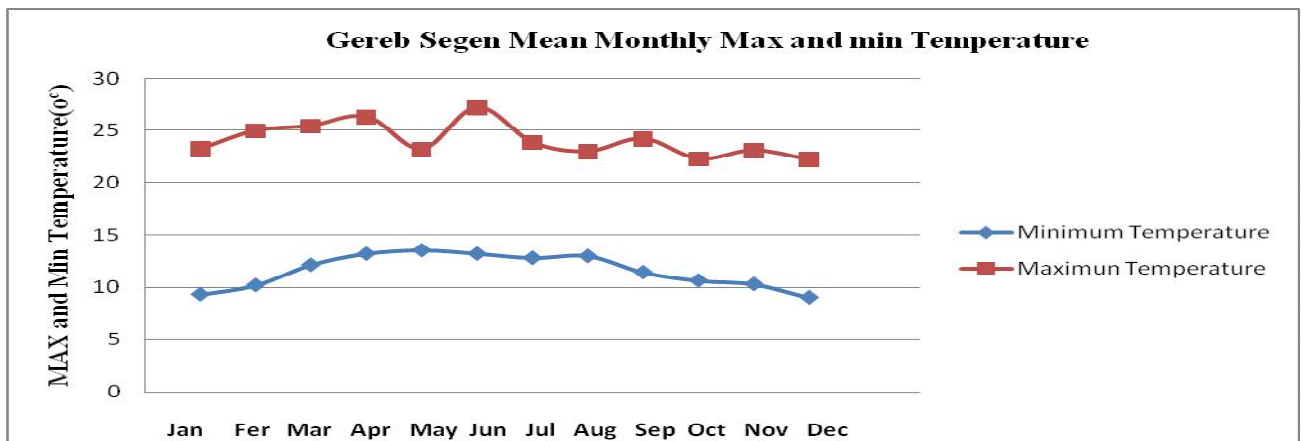


Figure 3.3: Mean Monthly Max &Min Temperature of Gereb-segen watershed

### 3.1.3 Topography

The altitude of the catchment area ranges from 1823.20 to 2744 m a.s.l. The major physiographic units in this area are undulating plains, valleys, steep stream banks, hills, and mountains. The catchment basin cut by a relatively dense drainage network and is characterized by moderate, steep to very steep side slopes of mountain. The Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. After the principal flow paths delineated, the watershed slope computed as the difference in elevation between the ends of principal flow path divided by the hydrologic length of flow path. Slope of the watershed shown below.

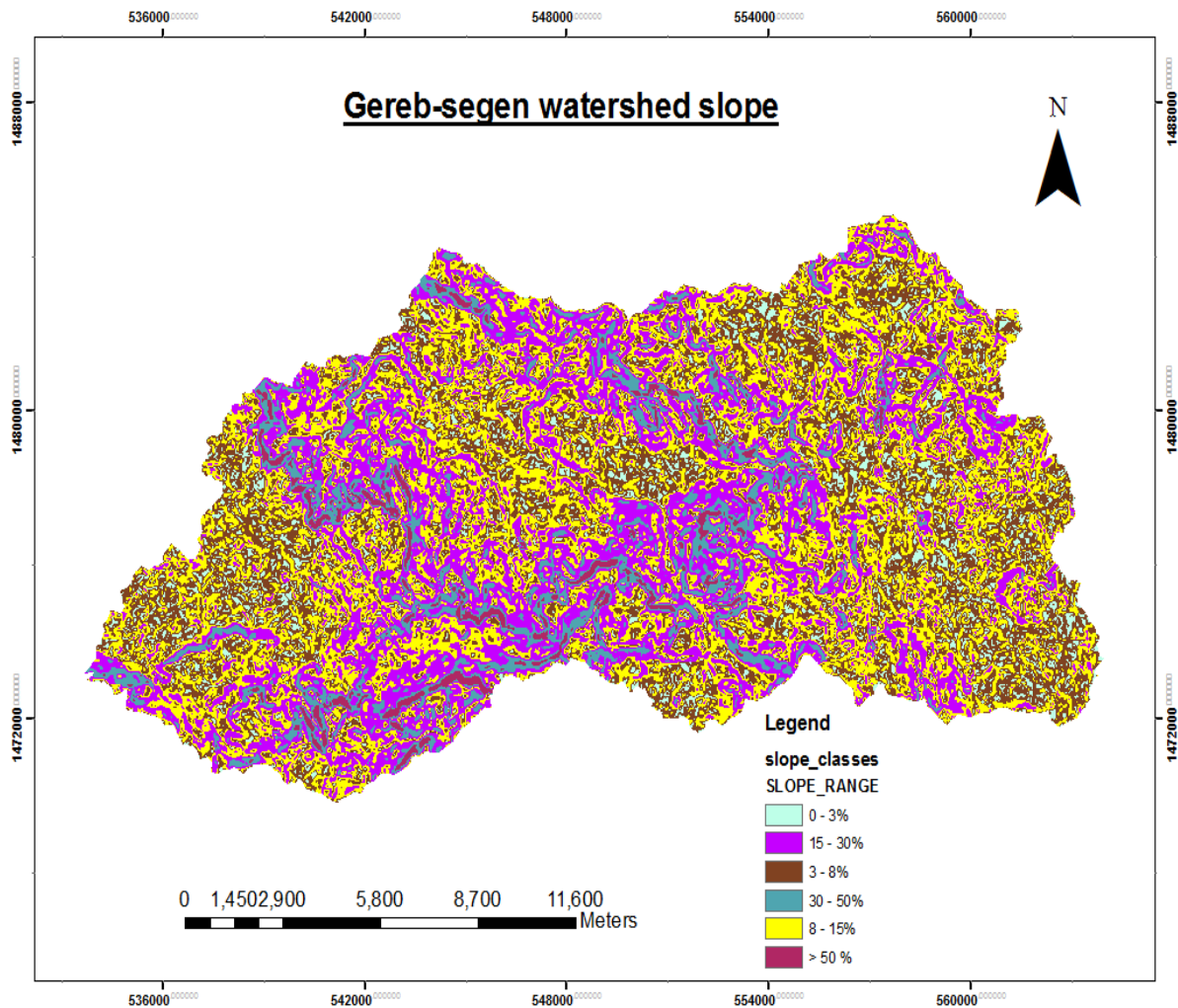


Figure 3.4: Slope of Gereb-segen watershed

Table 3.1: Slope of Gereb-segen Watershed

Slope of Watershed Gereb-segen							
Rowid	value	COUNT	Area- Km <sup>2</sup>	Area -ha	slope- Range	slope class	% of coverage
0	1	20231	18.9570	1895.70	0 - 3%	Flat	6.6
1	2	79475	74.4880	7448.80	3 - 8%	gently sloping	25.89
2	3	93673	87.7741	8777.41	8 - 15%	moderately sloping	30.51
3	4	81086	78.1514	7815.14	15 - 30%	moderately steep	27.17
4	5	24173	22.6508	2265.08	30 - 50%	Steep	7.87
5	6	6007	5.6287	562.87	> 50 %	very steep	1.96
Total			287.65	28,765			

### 3.1.4 Land use and land cover

Land use and land cover was one of the most important factors that affect runoff, and surface erosion in a watershed. The classification of the type of land use ( grass, wood, bush, water body, bare and cultivation lands) done according to James et al.,(1976) using the remote sensing satellite data, in Google internet access Image at 2017 CNES/Astrium to represent the land use according to the specific land cover types. The land use condition in the upper Gereb-segen catchment includes mainly of cultivated agricultural land, grassland, forestland, and bare lands. The cultivated land is intensively cultivated due to long time agricultural practices in the area losses its fertility this facilitates the soil erosion from cultivated lands. Practically all the land is opened up for cultivation and grazing. Over 67% of the land is under annual crops. Consequently, the ground is virtually bare during the dry season. The main land use activities are rain fed cultivation of sorghum, maize, and pulses and grazing on unimproved pasture and fallow. The types of land use of Gereb-segen watershed and its coverage is shown in figure 3.5 and table 3.2.

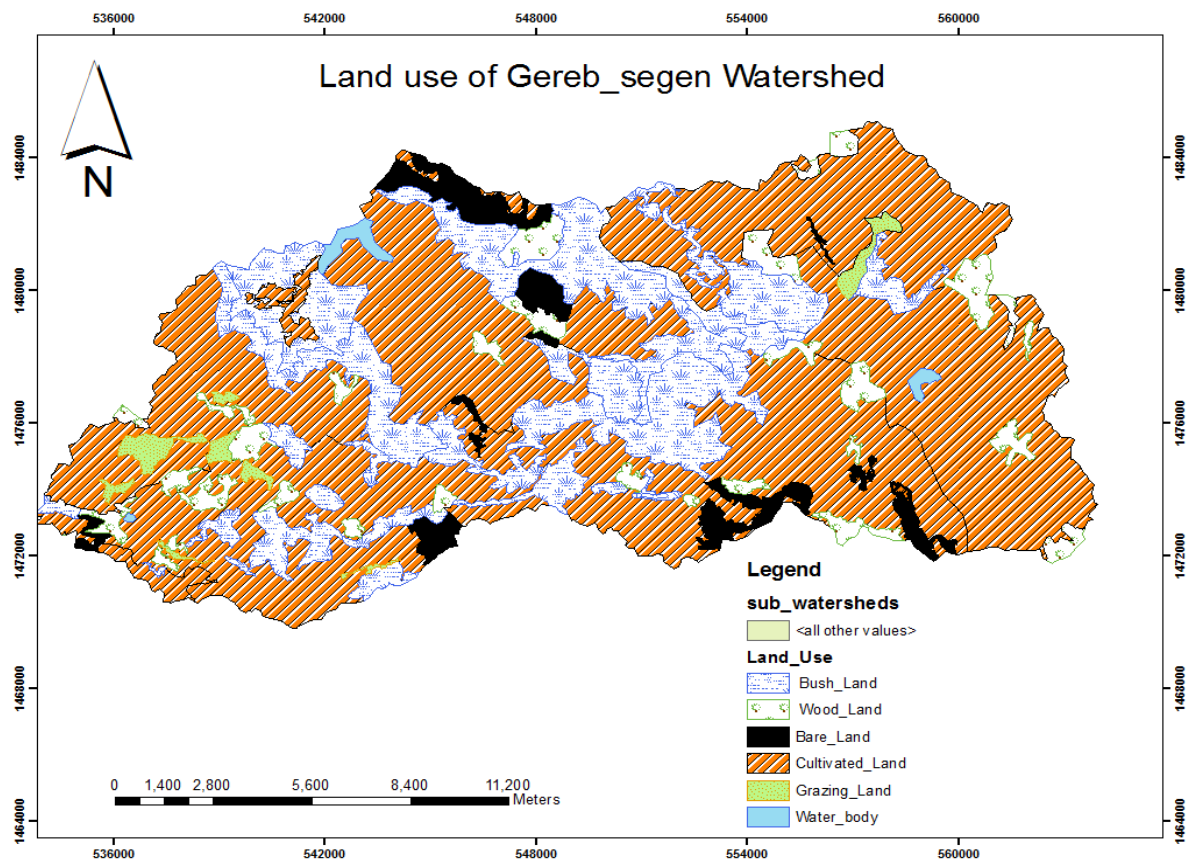


Figure 3.5: Land use type of Gereb-segen watershed

Table 3.2: Land use type of Gereb-segen watershed

Land use of Gereb-segen watershed							
OID	Land_Use	Count_Land_Use	Sum_Perimeter_m	Area_m <sup>2</sup>	Area_Km <sup>2</sup>	Area_ha	% of coverage
0	Bush_Land	23	321805.477	67249893.03	67.2499	6,724.99	23.38
1	Wood_Land	30	68737.89002	9374083.386	9.3741	937.41	3.26
2	Bare_Land	11	82919.8266	12429724.4	12.4297	1,242.97	4.32
3	Cultivated_Land	22	437894.9485	192721572.5	192.7216	19,272.16	67.00
4	Water body	3	11610.68391	1675354.939	1.6753	167.53	0.58
5	Grazing_Land	8	36420.7524	4199371.763	4.1994	419.94	1.46
Total			959,389.57843	287,650,000	287.65	28,765	

### 3.1.5 Soil type

Digital soil map of FAO, (1986) in shape file from the Ministry of Water, Irrigation and Electricity has been used for this study in order to develop soil map in the estimation of sediment yields. The soil type of the study area classified as Vertic cambisols, Lithosols, Calcic cambisols, the properties of the soil types are described in figures 3.6 and table 3.3.

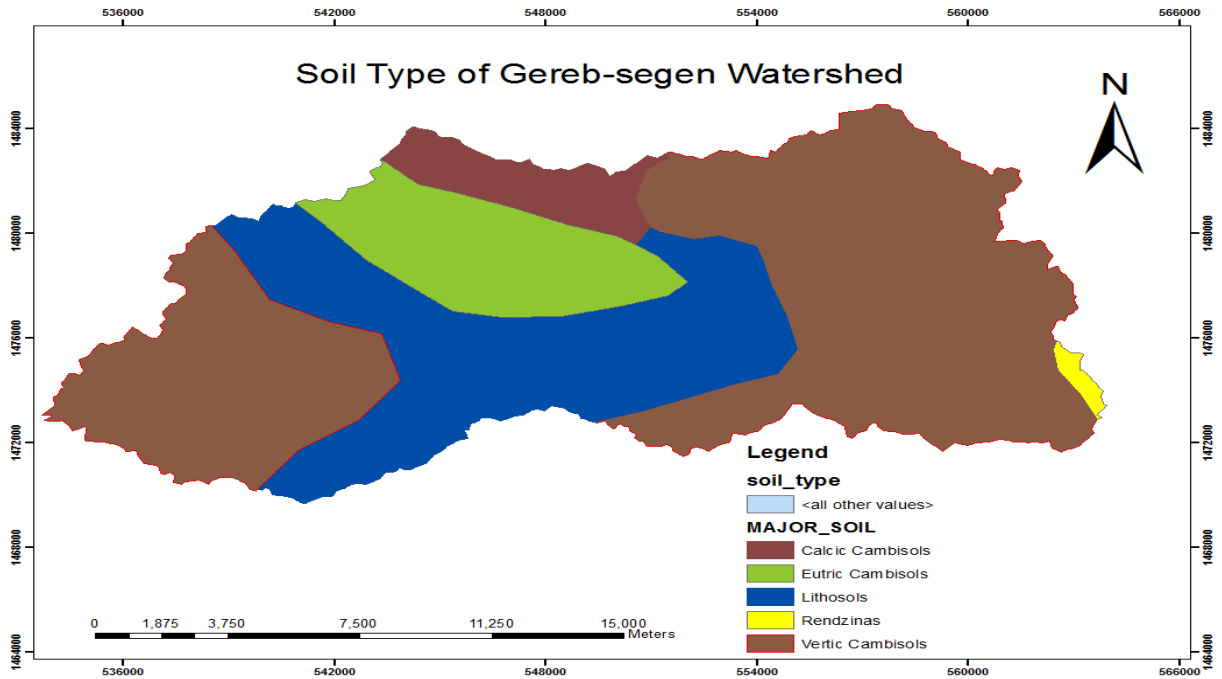


Figure 3.6: Soil type of Gereb-segen watershed

Table 3.3: Soil type of Gereb-segen watershed

Gereb-segen watershed Soil type				
MAJOR_SOIL TYPE	Perimeter_m	Area- m <sup>2</sup>	Area – ha	% of coverage
Vertic Cambisols	98635.097	161627680	16,162.768	59.19
Lithosols	59686.301	75738400	7,573.84	26.33
Calcic Cambisols	22479.4	14924300	1,492.429	5.19
Rendzinas	7433.2598	1578270	157.827	0.55
Eutric Cambisols	27058	33781400	3,378.138	11.74
Total	215,292.0578	287,650,000	28,765.00	

### **Cambisol**

According to FAO World reference base for soil resources the cambisol horizon differentiation is weak. This is evident from weak, mostly brownish discolouration or structure formation in the soil profile. Cambisols are developed in medium and fine textured materials derived from a wide range of rocks, mostly in alluvial, and aeolian deposits. Most of these soils made good agricultural land and are intensively used. Cambisols in temperate climates are among the most productive soils on earth. The parent material of cambisols mostly young and are easily exposed to active erosion (FAO, 2007).

### **Lithosols**

Most lithosols found in very steep, mountainous regions where erodible material is so rapidly removed by erosion that a permanent covering of deep soil can not establish itself. The lithosols are usually extreme shallow soils and found in steep slopes and this consequent them to high erosion hazard (FAO, 2007).

### **Rendzians**

Rendzians soils typically develop from solid or unconsolidated rocky material that is carbonate or sulphaterich. Alongside physical weathering, which breaks down the structure of rocky material, chemical weathering, in particular the dissolution of carbonate, contributes to rendzians development (FAO, 2007).

### **Vertisol**

Vertisol is a soil in which there is a high content of expansive clay, known that forms deep cracks in drier seasons or years. The alternate shrinkage and swelling of vertisols causes self-mulching, where the soil material consistently mixes itself. The heavy texture and unstable behaviour of the soil makes it difficult for many tree species to grow, and forest is uncommon. The shrinking and swelling of vertisols can lead to the cricking and landslides along the river morphologies and damage buildings and roads, leading to extensive subsidence (FAO, 2007).

### 3.1.6 Surface Geology type

Using the geological map prepared by Geological survey of Ethiopia sheet ND 37-11 with scale of 1:2500, 000 the Gereb-segen watershed have five rock types and their coverage area is presented in figure 3.7 and table 3.4 and their properties described below .

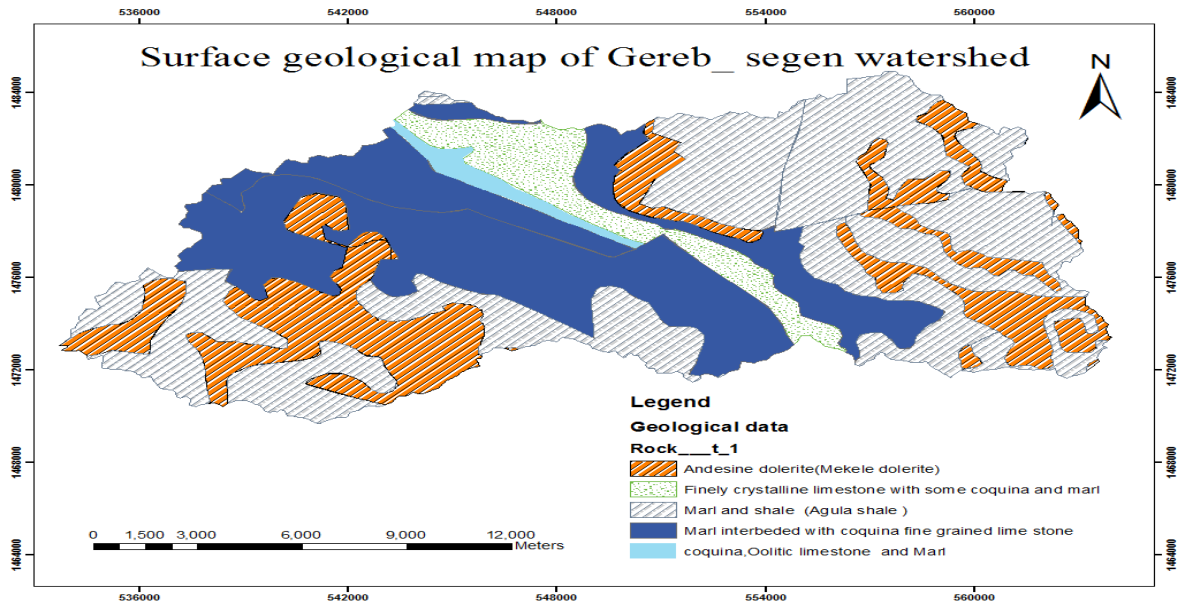


Figure 3.7 : Surface geological of Gereb-segen watershed

Table 3.4: Surface geology of Gereb-segen watershed

Shape *	Rock type	Area_m <sup>2</sup>	Area-Ha	Remark
Polygon	Andesine dolerite(Mekele dolerite)	60,216,768.78	6,021.68	hard rock
Polygon	Finely crystalline limestone with some coquina and marl	19,584,711.68	1,9 58.47	Hard rock but some soft limestone(coquina)
Polygon	Marl interbedded with coquina fine grained lime stone	87,243,772.28	8,724.38	moderately soft &moderately weather
Polygon	coquina,Oolitic limestone and Marl	4,398,363.86	439.84	soft &easily weather
Polygon	Marl and shale (Agula shale )	114,034,773.4	11,403.48	soft &easily weather
	Total	287,650,000	28,765	

**Shale**

Shale is a fine-grained sedimentary rock that forms from the compaction of silt and clay size mineral particles. The rock of shale is most often associated with landslides. Weathering transforms the shale into a clay-rich soil which normally has a very low shear strength - especially when wet. When these low-strength materials are wet and on a steep hillside, they can be slowly or rapidly move down slope. Overloading or excavation by humans will often trigger failure Smith and Minty,(2002).

**Dolerite**

Dolerite, an igneous rock type that is not easily weathered especially the fresh dolerite rock is considered to be very strong and is not greatly affected by weathering Smith and Minty,(2002).

**Limestone**

Limestone is a very compact rock that takes polish very well and has low porosity and weather resistant. It is a sedimentary rock that is usually formed at the bottom of lakes and oceans and is calcium-rich Smith and Minty,(2002).

**Marl**

Marl is an unconsolidated sedimentary rock or soil consisting of clay and lime. Those types of rocks are looses and crumbling earthy deposit consisting mainly of calcite or dolomite and easily eroded by water Smith and Minty,(2002).

### **3.2 Data sources**

This research result of the sediment estimating models and its parameters achieved with the utilization of different materials, both the utilization of primary and secondary data's. The primary data collected from field using field application of infiltration rate of the soil type in the watershed area.

In the other case the secondary data, such as; Image remote sensing satellite data for land use/land cover, meteorological data, soil data, topographic maps in shape file, Geological map, and design of the Gereb-segen dam document were collected from Ministry of Water, Irrigation and Electricity, Mekelle University, Ethiopian Meteorological Agency Mekelle branch and the Regional State of Tigray Bureau of Water Resource.

#### **3.2.1 Materials and Softwares used**

The material used during study period includes:

- ❖ Meteorological data, particularly rainfall and temperature time series data from 1997s to 2016 were collected from National Meteorological service Agency Mekelle branch
- ❖ GPS and Digital Camera: GPS used for the metrological data station and the infiltration rate of the soil type taken site to indicate and the digital camera to take features of the watershed and the dam reservoirs.
- ❖ ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) NASA source DEM with a spatial resolution of 30 m , soil map in shape file was collected from Ministry of Water, Irrigation and Electricity.

The data collected processed using some software. These are

- ❖ Global Mapper and GIS for watershed (study area) delineation.
- ❖ Arc GIS 9.3 for GIS based DEM processing and overlay analysis.
- ❖ Micro soft office packages for chart making, tabulation, and word processing.

#### **3.2.2 Checking the Consistency of Data of Rain Gauge station**

Sometimes a significant change may occur in and around a particular rain gauge stations. Such a change in a particular year will start affecting the rain gauge data, had been reported from that particular station. After a number of years, it may be felt that the data of that station is not giving consistent rainfall values. In order to detect any such in consistency , and to correct and adjust the reported rain fall values, a technique called double mass curve method, is generally adapted by Garg, (2006) was used in Gereb-segen watershed .

The doubtful station and the neighboring average annual rainfall stations arranged serially in a reverse chronological order (i.e., the latest year getting the first entry). The cumulative some values for both the neighboring average annual rainfall and the doubtful annual rainfall are worked out, then the doubtful in the "Y"-axis and the neighboring in the "X"-axis plotted on a graph paper in Microsoft office Excel work sheet. Then from the graph by identifying the inconsistency has been occurred year the correction ratio for the doubtful can be getting (Garg, 2006).

$$Px' = Px \left( \frac{M'}{M} \right) \text{----- (1)}$$

Where

$Px'$  = Corrected doubtful station Rainfall

$Px$  = Original record rainfall

$M'$  = Corrected slope of the double mass curve

$M$  = Original slope of the double mass curve

Table 3.5: Checking the consistency of annual Rainfall data at station Aynallem

Checking the consistency of annual Rainfall data at station Aynallem					
Year	annual RF of station Aynallem(mm)	Ccumulative Annual RF of station Aynallem(mm)	sumof Annual RF of 3 stations surrounding Aynallem(mm)	Average Annual RF of 3 stations surrounding Aynallem(mm)	Cumulative Ave. Annual RF of 3 stations surrounding Aynallem(mm)
2016	677.2	677.2	1987.4	662.4667	662.4667
2015	369.5	1046.7	1563.2	521.0667	1183.533
2014	731.3	1778	1765	588.3333	1771.867
2013	391.4	2169.4	1631.15	543.7167	2315.583
2012	560	2729.4	2142.4	714.1333	3029.717
2011	467.9	3197.3	1627.5	542.5	3572.217
2010	556.6	3753.9	1904.9	634.9667	4207.183
2009	398.9	4152.8	1506.9	502.3	4709.483
2008	245.2	4398	1077.5	359.1667	5068.65
2007	528.3	4926.3	1973.2	657.7333	5726.383
2006	641.6	5567.9	2150	716.6667	6443.05
2005	579.2	6147.1	1675	558.3333	7001.383
2004	345.8	6492.9	1148	382.6667	7384.05
2003	445.7	6938.6	1510.7	503.5667	7887.617
2002	422.7	7361.3	1297.5	432.5	8320.117
2001	557	7918.3	2047.1	682.3667	9002.483
2000	446.4	8364.7	1559	519.6667	9522.15
1999	805.9	9170.6	1998.82	666.2733	10188.42
1998	669.4	9840	2676.73	892.2433	11080.67
1997	512.8	10352.8	1638.63	546.21	11626.88

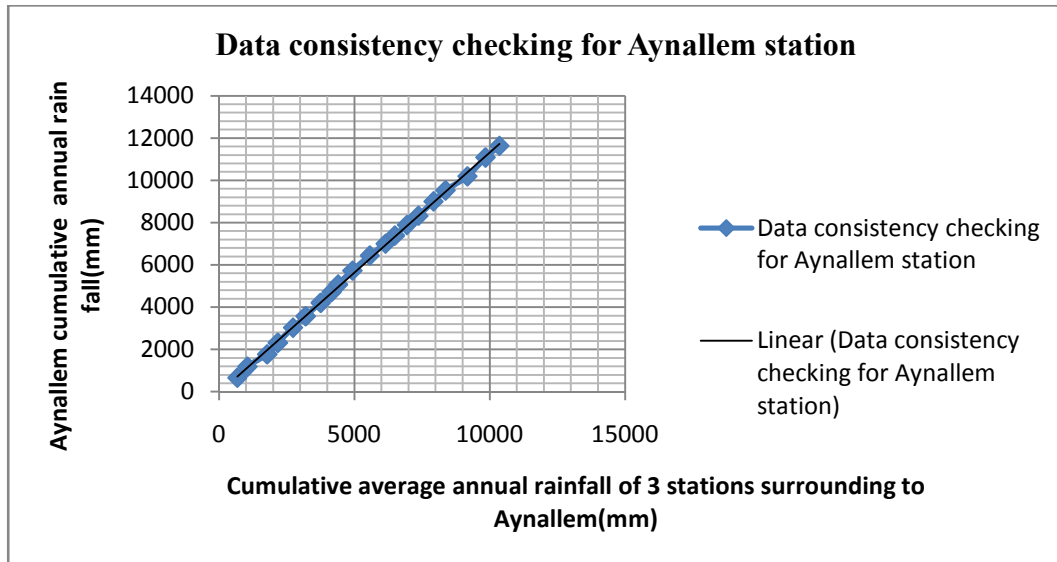


Figure 3.8: Checking the consistency of annual Rainfall data at station Aynallem

Table 3.6: Checking the consistency of annual Rainfall data at station Adigudom

Checking the consistency of annual Rainfall data at station Adigudom					
year	annual RF of station Adigudom (mm)	Cumulative Annual RF of station Adigudom(mm)	sumof Annual RF of 3 stations surrounding Adigudom(mm)	Average Annual RF of 3 stations surrounding Adigudom(mm)	Cumulative Ave. Annual RF of 3 stations surrounding Adigudom(mm)
2016	589.2	589.2	2075.4	691.8	691.8
2015	482.5	1071.7	1450.2	483.4	1175.2
2014	547.93	1619.63	2168.2	722.7333	1897.933
2013	552.11	2171.74	1263.4	421.1333	2319.067
2012	510.96	2682.7	2063.7	687.9	3006.967
2011	427.9	3110.6	1667.5	555.8333	3562.8
2010	399.5	3510.1	2062	687.3333	4250.133
2009	381.6	3891.7	1524.2	508.0667	4758.2
2008	283.2	4174.9	1039.5	346.5	5104.7
2007	584.6	4759.5	1916.9	638.9667	5743.667
2006	630	5389.5	2161.6	720.5333	6464.2
2005	343.8	5733.3	1910.4	636.8	7101
2004	241.2	5974.5	1252.6	417.5333	7518.533
2003	415.1	6389.6	1541.3	513.7667	8032.3
2002	286.7	6676.3	1433.5	477.8333	8510.133
2001	624.1	7300.4	1980	660	9170.133
2000	458.6	7759	1546.8	515.6	9685.733
1999	553.9	8312.9	2250.82	750.2733	10436.01
1998	735.67	9048.57	2242.63	747.5433	11183.55
1997	416.3	9464.87	1735.13	578.3767	11761.93

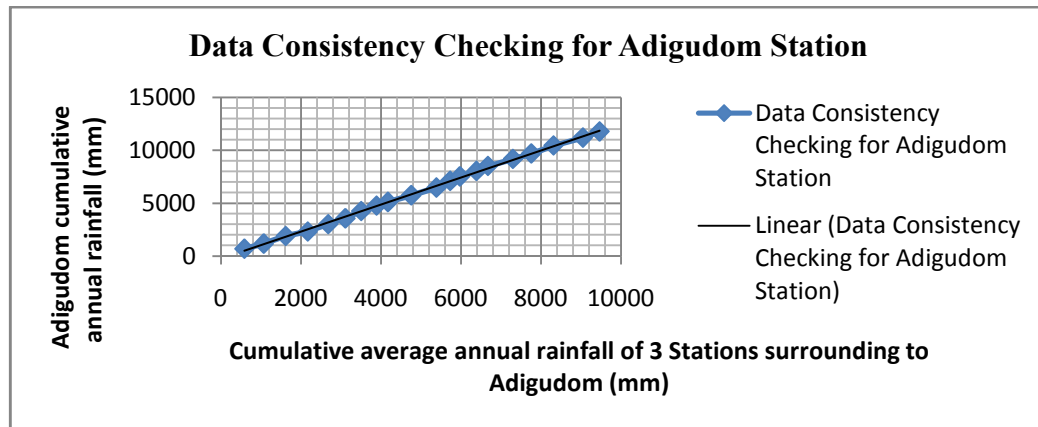


Figure 3.9: Checking the consistency of annual Rainfall data at station Adigudom

As shown in the table 3.5 the rainfall correction factors values 0.667, 0.8, 0.7273 and 1.67 for the 1998, 2012, 2013 and 2014 respectively were adjusted.

Table 3.7: Checking the consistency of annual Rainfall data at station Dengolat

Checking the consistency of annual Rainfall data at station Dengolat					
year	annual RF of station Dengolat(mm)	Cumulative Annual RF of station Dengolat(mm)	sumof Annual RF of 3 stations surrounding Dengolat(mm)	Average Annual RF of 3 stations surrounding Dengolat(mm)	Cumulative Ave. Annual RF of 3 stations surrounding Dengolat(mm)
2016	650	650	2014.6	671.5333	671.5333
2015	580.6	1230.6	1352.1	450.7	1122.233
2014	767.5	1998.1	1728.8	576.2667	1698.5
2013	625.2	2623.3	1397.35	465.7833	2164.283
2012	991.7	3615	1710.7	570.2333	2734.517
2011	668.8	4283.8	1426.6	475.5333	3210.05
2010	834.9	5118.7	1626.6	542.2	3752.25
2009	708.5	5827.2	1197.3	399.1	4151.35
2008	507.4	6334.6	815.3	271.7667	4423.117
2007	769.3	7103.9	1732.2	577.4	5000.517
2006	764.8	7868.7	2026.8	675.6	5676.117
2005	731.9	8600.6	1522.3	507.4333	6183.55
2004	516.8	9117.4	977	325.6667	6509.217
2003	568.8	9686.2	1387.6	462.5333	6971.75
2002	542	10228.2	1178.2	392.7333	7364.483
2001	785.7	11013.9	1818.4	606.1333	7970.617
2000	644.8	11658.7	1360.6	453.5333	8424.15
1999	727.7	12386.4	2077.02	692.34	9116.49
1998	819.8	13206.2	2526.33	842.11	9958.6
1997	671.5	13877.7	1479.93	493.31	10451.91

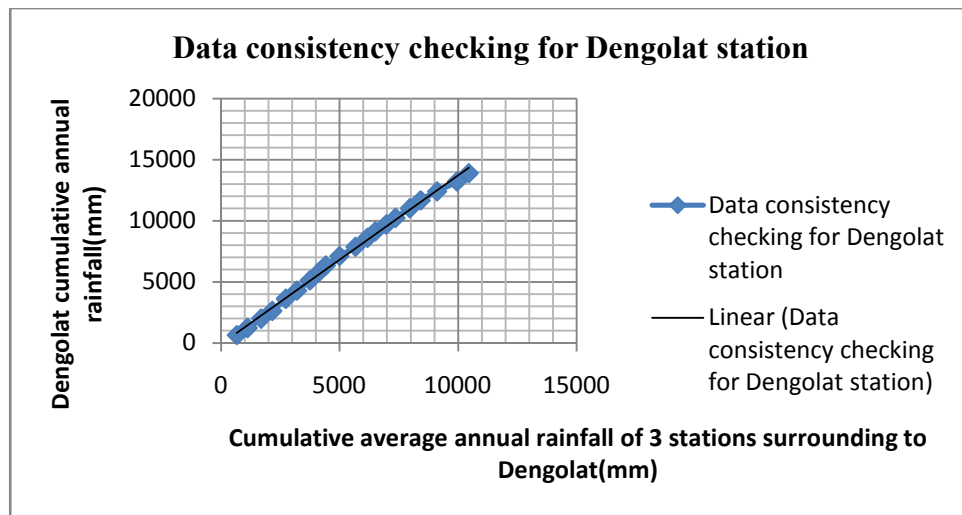


Figure 3.10: Checking the consistency of annual Rainfall data at station Dengolat

Table 3.8: Checking the consistency of annual Rainfall data at station Mekelle

Checking the consistency of annual Rainfall data at station Mekelle					
year	annual RF of station Mekelle(mm)	Cumulative Annual RF of station Mekelle t(mm)	sumof Annual RF of 3 stations surrounding Mekelle(mm)	Average Annual RF of 3 stations surrounding Mekelle(mm)	Cumulative Ave. Annual RF of 3 stations surrounding Mekelle(mm)
2016	748.2	748.2	1916.4	638.8	638.8
2015	500.1	1248.3	1432.6	477.5333	1116.333
2014	669.4	1917.7	1826.9	608.9667	1725.3
2013	246.8	2164.5	1775.75	591.9167	2317.217
2012	512	2676.5	2190.4	730.1333	3047.35
2011	530.8	3207.3	1564.6	521.5333	3568.883
2010	670.5	3877.8	1791	597	4165.883
2009	416.8	4294.6	1489	496.3333	4662.217
2008	286.9	4581.5	1035.8	345.2667	5007.483
2007	619.3	5200.8	1882.2	627.4	5634.883
2006	755.2	5956	2036.4	678.8	6313.683
2005	599.3	6555.3	1654.9	551.6333	6865.317
2004	390	6945.3	1103.8	367.9333	7233.25
2003	526.8	7472.1	1429.6	476.5333	7709.783
2002	468.8	7940.9	1251.4	417.1333	8126.917
2001	637.3	8578.2	1966.8	655.6	8782.517
2000	455.6	9033.8	1549.8	516.6	9299.117
1999	717.22	9751.02	2087.5	695.8333	9994.95
1998	753.43	10504.45	2592.7	864.2333	10859.18
1997	550.83	11055.28	1600.6	533.5333	11392.72

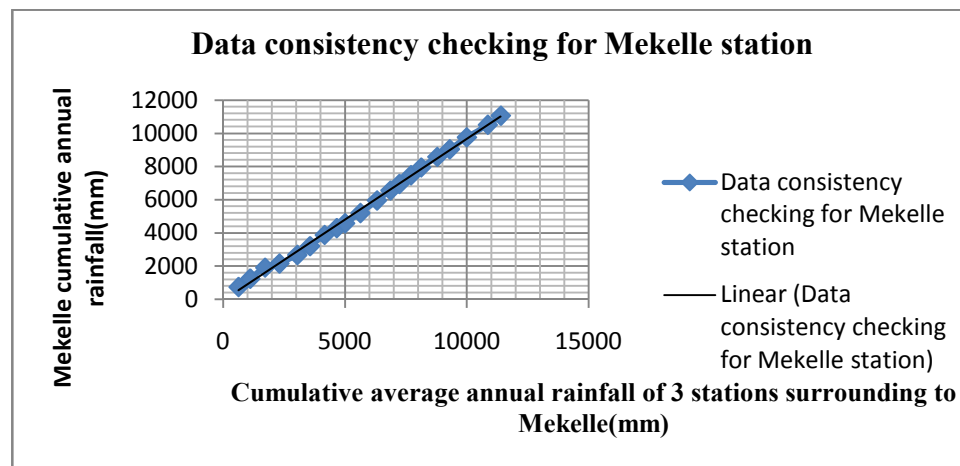


Figure 3.11: Checking the consistency of annual Rainfall data at station Mekelle

As of the aforementioned in Figure 3.8, 3.10 and 3.11 the rainfall data is consistent; therefore, it does not need correction ratio (the slope of variations is below 10%).

### 3.3 Sediment yield estimating models

Empirical based models developed for Gereb-segen dam to assess the applicability/suitability of different models and to estimate the annual sediment yield of the reservoir. The MUSLE, EPM and PSIAC models were selected to estimate the sedimentation yields, due to;

- I. The capability of Geographic Information System and Remote Sensing in geospatial data analysis ( Ouyang and Bartholic , 2001).
- II. Similar assessment method used for the factors of slope, soil and geology and land uses.

#### 3.3.1 MUSLE (Modified Universal Soil Loss Equation ) Model

The MUSLE estimates average sediment yield form a given area as a function of six major factors (Equation 2). According to Williams (1975), the factors affecting sedimentation are runoff factor, soil erodibility, topography, land cover, and supporting practices, and the equation given as:

$$A = 11.8(Q \cdot q_p)^{0.56} \times K \times LS \times C \times P \quad \text{----- ( 2 )}$$

Where: A = Mean annual sediment yield (ton/ha/yr)

Q = Volume of runoff (m<sup>3</sup>)

q<sub>p</sub> = peak flow rate in 1mm runoff depth (m<sup>3</sup> /s)

K = Soil erodibility factor (Mg MJ<sup>-1</sup> mm<sup>-1</sup>)

LS = L and S are the slope length and steepness factors, respectively (dimensionless)

C = Vegetation and Management Factor (dimensionless)

P = Support Practice Factor (dimensionless)

#### Runoff factor (Q & q<sub>p</sub> )

The runoff factor is the combination of volume of runoff and peak flow rate.

#### Calculation of Runoff (Q)

The runoff calculated based on the widely used Soil Conservation Service (SCS, now Natural Resources Conservation Service (NRCS)) curve number method. This method was developed and published in 1954 in the National Engineering Handbook Section 4: Hydrology (NEH-4). As Ponce and Hawkins, (1996) pointed out, the curve number method owes its popularity among hydrology practitioners to its simplicity, predictability, and stability. The theory of the curve number method is that for a given rainfall event, the ratio of runoff depth to rainfall is

equal to the ratio of actual retention (the rain not converted to runoff) after runoff begins to the potential maximum retention after runoff begins (NRCS, 2004). It shown with equation

$$\frac{F_a}{s} = \frac{P_e}{P - I_a} \text{----- (3)}$$

Where:  $I_a$  = initial abstraction (mm)

$P_e$  = rainfall excess or runoff (mm)

$F_a$  = continuing abstraction (mm)

$P$  = total rainfall (mm) for one day (24 hrs rainfall)

$S$  = maximum retention (mm)

From the continuity principle

$$P = P_e + I_a + F_a \text{----- (4)}$$

Combining both equation (3) and equation (4) to solve for “ $P_e$ ” gives

$$P_e = \left( \frac{(P - I_a)^2}{(S + P - I_a)} \right) \text{----- (5)}$$

Equation (4) is the basic equation for computing the depth of excess rainfall or direct runoff depth from a storm by the SCS method. By study of results from many small experimental watersheds, an empirical relation developed:

$$I_a = 0.2 S \text{----- (6)}$$

On the other basis substituting  $I_a = 0.2 \cdot S$  in equation (5) gives:

$$P_e = \left( \frac{(P - 0.2S)^2}{(P + 0.8S)} \right) \text{----- (7)}$$

Plotting the data for  $P$  and  $P_e$  from many watersheds, the SCS found curves. To standardize those curves, a dimensionless curve number  $CN$  is defined such that  $0 \leq CN \leq 100$ . For Impervious and water surface  $CN = 100$ ; for natural surfaces  $CN < 100$ . The  $CN$  and  $S$  related by:

$$CN = \left( \frac{1000}{10 + S} \right) \text{----- (8)}$$

$$S = Z \left( \frac{100}{CN} - 1 \right) \text{-----} (9)$$

Where: Z = 10 for English measurement units (inch), or 254 for metric (mm)

CN = runoff curve number

$$Q = Pe * A \text{-----} (10)$$

Q = total runoff volume (m<sup>3</sup>)                      A = area of basin (km<sup>2</sup>)

**Calculation of peak rate of discharge (q<sub>p</sub>)**

Peak rate of discharge created by 1 mm run off depth (excess rain fall) was calculated based on the Federal Democratic Republic of Ethiopia Ministry of Water, Irrigation and electricity (2002) developed guide line manual .

$$q_p = \frac{0.21A}{t_p} \text{-----} (11)$$

Where: q<sub>p</sub> = is peak rate of discharge (m<sup>3</sup>/s) taking 1 mm run off depth

A = area of catchment (km<sup>2</sup>)    and    t<sub>p</sub> = time to peak (hr)

$$t_p = 0.5 D + 0.6 T_c \text{-----} (12)$$

Where: t<sub>p</sub> = time to peak (hr),                      D = rainfall excess duration (hr)

T<sub>c</sub> = time to concentration (hr)

Time to concentration given as;

$$T_c = \frac{1}{3000} \left( \frac{L}{S^{0.5}} \right)^{0.77} \text{-----} (13)$$

Where:

T<sub>c</sub> = time to concentration (hr)

S = slope of the main water course (%),                      L = the stream length (m)

Rainfall excess duration (D) given as:

$$D = \frac{T_c}{6} \text{ if } T_c < 3 \text{ hrs} \text{ ----- (14)}$$

$$D = 1 \text{ hr. if } T_c > 3 \text{ hrs} \text{ ----- (15)}$$

Where: D = rainfall excess duration (hr) and  $T_c$  = time to concentration (hr)

**Soil erodibility (K) Factor**

The K factor was a measure of the inherent erodibility of the soil or surface material at a particular site under standard experimental conditions. Values for K typically range from about 0.013 to 0.059 SI units or (0.10 to 0.45 US customary units) (Foster *et al.*, 1981). High-sand and high-clay content soils have the lower values whereas high-silt content soils have higher values. The value of K is a function of the particle-size distribution, organic-matter content, structure, and permeability of the soil or surface material. The erodibility of soils as defined by Hurni, (1985) in the adaptation to Ethiopia condition considers the soil color has relation with erodibility factor.

Table 3.9: Soil erodibility values (K) adapted for Ethiopia according to Hurni, (1985).

Soil colour	Black	Brown	Red	Yellow
K- Factor values	0.15	0.20	0.25	0.30

**Slope Length and slope steepness (LS – Factor)**

The topographic factor, LS, is a combined factor that accounts for the effect of slope length (L) and slope steepness (S) factors on the site erosion potential. Erosion increases as slope length increases, and considered by the slope length factor (L). Slope length defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel (Wischmeier and Smith, 1978). The slope steepness factor (S) reflects the influence of slope gradient on erosion. Develop several methods of LS factor determination with different GIS professionals at different time. Initially, Wischmeier and Smith, (1978) defined the L-factor as the ratio of soil lost from a horizontal slope length to the corresponding loss from the slope length of a unit plot (22.13 m). According to this definition, slope length is the distance from the point of origin of overland flow to the point where either the slope gradient decreases

enough for deposition to start, or runoff water streamed into a channel. According to this simple definition, the L-factor can be representing as:

$$L = \left( \frac{\lambda}{22.13} \right)^m \text{----- (16)}$$

Where  $\lambda$  = Flow length (m) and m is equivalent to 0.5 for slopes steeper than 5%, 0.4 for Slopes 3% \_ 4%, 0.3 for the slopes 1% \_3%, and 0.2 for slopes less than 1%.

The S-factors calculated using the Renard et al., (1997) adopted this algorithm in MUSLE for the S-factor estimation based on the slope gradient:

$$S = 10.8 * \sin \theta + 0.03, \text{ where slope gradient} < 0.09 \text{----- (17)}$$

$$S = 16.8 * \sin \theta - 0.5, \text{ where slope gradient} \geq 0.09 \text{----- (18)}$$

Where  $\theta$  = the gradient of slope in degrees.

Maidment and Tarboton, (2011) based the calculation of the slope length and slope steepness on computation of slope Prepared as:

$$L = \{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2\}^{1/2} \text{----- (19)}$$

$$D = \{(X_2 - X_1)^2 + (Y_2 - Y_1)^2\}^{1/2} \text{----- (20)}$$

Where

L = slope (flow) length (m)

D = the run or horizontal distance (m)

$X_1$  &  $X_2$  = the starting and ending Easting reading of GIS (m)

$Y_1$  &  $Y_2$  = the starting and ending Northing reading GIS (m)

$Z_1$  &  $Z_2$  = the starting and ending Elevation of the water shed above sea level (m)

The slope gradient(S) given as follow:

$$S = \frac{\Delta Z}{D} \text{----- (21)}$$

Where  $\Delta Z = Z_2 - Z_1$

A 30 m resolution DEM first pre-processed to drive the LS factor after appropriate size of the study area clipped. Then the values of flow accumulation and slope gradient's were deriving from DEM .However, the flow accumulation has been derived from the DEM after conducting fill and flow direction process in Arc GIS 9.3.

### **Land Use/Land Cover (C – Factor)**

The C- factor used within MUSLE to reflect the effect of cropping and management practices on erosion rates, the factor used most often to compare the relative impacts of management options on conservation plans. The crop cover factor *C* measures the combined effect of all the interrelated cover and management variables (Wischmeier and Smith, 1978). The assessment of land use/land cover type, done separately using the remote sensing satellite data Image at 2017 CNES/Astrium. For each land unit and the corresponding value for land use/land cover obtained. According to Hurni, (1985) the crop cover factor (C- factor) adapted to Ethiopia condition was mention below. In the study area, the type of land use/land cover had done using the remote sensing satellite data Image at 2017 CNES/Astrium. According this classification rain fed cultivated land with major sorghum and maize cropland covers 67% of the study area, while natural forest, bush land, bare land, and grazing land cover system together accounts 33% of the area. This condition explains more the significant correlation of the C factor with the erosion processes.

Table 3.10: Land cover (C) values adapted for Ethiopia conditions according to Hurni, (1985).

Type of land cover	C values	Type of land cover	C values	Type of land cover	C values
Dense forest	0.001	Fallow ploughed	0.60	Cereals, Pulses	0.15
Dense grass	0.01	Sorghum, Maize	0.10	Ethiopian teff	0.25
Badland hard	0.05	Badland soft	0.40	Continuous fallow	1.0
Degraded grass	0.05	Fallow hard	0.05	Other forest	0.01– 0.05

### **Support Practice (P) Factor**

The support practice factor (P) in MUSLE was the ratio of soil loss with a specific support practices to the corresponding loss with up slope and down slope tillage. These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster, 1991). This factor is a ratio between erosion occurring in a field treated with conservation measures and another reference plot without treatment. According to the Bewket and Tefri,(2009) conducted P values for various support practices and land use cover given in table 3.10.

Table 3.11: Management factor which adapted from Bewket and Teferi (2009) for Ethiopia conditions.

Land use land cover type	Slope (%)	p-factor values
Farm land	0 – 5	0.11
	5 – 10	0.12
	10 – 20	0.14
	20 – 30	0.22
	30 – 50	0.31
	50 – 100	0.43
Other land	All	1

According to Gelagay, (2016) sediment yield classification, the estimated sediment yield of Gereb-segen sub watershed using the MUSLE model, were classified in to low, moderate, high and very high sediment classifications.

Table 3.12: According to Gelagay, (2016) the sediment yield classification

Numeric range of sediment yield(to/ha/yr)	Sediment load class
0 – 5	Low
5 – 10	Moderate
10- 20	High
>20	Very high

### 3.3.2 EPM (Erosion Potential Method) Model

The EPM estimates average annual sediment yield form a given area as a function of six major factors (Equation 22). According to Gavrilovic, (1988) the coefficient values affecting sedimentation are: coefficient of rock and soil erosion , land use coefficient , coefficient of the present erosion type, average land slope, temperature coefficient and mean annual precipitations, and the equation given as :

$$W_{sp} = T * H * \Pi * Z^{1.5} \text{-----}(22)$$

Where

$W_{sp}$  = average annual specific production of sediment ( $m^3 / km^2 / yr$ ),

T = Temperature coefficient ( $^0c$ )

H = Mean annual precipitation (mm)

$\Pi$  = constant (3.14),

$Z$  = coefficient of erosion intensity

### **Coefficient of erosion intensity (Z)**

The coefficient of erosion intensity obtained from the coefficients of rock and soil, land use, the present soil erosion type and average land slopes. The coefficient of erosion intensity will increase as the coefficient values increases.

$$Z = Y * X_a * (\varphi + I^{0.5}) \text{-----} (23)$$

Where  $Z$  = coefficient of erosion intensity,  $Y$  = coefficient of rock and soil

$X_a$  = land use coefficient,  $\varphi$  = coefficient of the present erosion type,

$I$  = average land slope (%)

### **Land-use coefficient (Xa)**

This coefficient calculating starting from the water maps delineation using GIS, DEM (digital elevation model) and using Remote Sensing that facilitates studying by enhancing the process of land use types. Multi-temporal satellite images provide valuable information related to seasonal land use dynamics. The territory divided into homogeneous zones; each area has a feature called description where the land coverage been stated. The land use classification done separately using the remote sensing satellite data Image at 2017 CNES/Astrium and a priori assignation has made to each description of a correspondent  $X_a$  value, and field visits where done to crosscheck the maps. The land use coefficient value ranges from 0.05 to 1.

### **Coefficient of observed erosion ( $\varphi$ )**

The types of erosion in the watershed identified using the drainage density in the watershed as described in table 3.21. The coefficient of observed erosion value ranges from 0.1 to 1.

### **Coefficient of rock and soil resistance to erosion(Y)**

The values of coefficient of rock and soil resistance to erosion were obtained from the geological map of Gereb-segen watershed from Mekelle university department of Earth science Engineering which was formerly prepared by Geological survey of Ethiopia sheet ND 37-11 with scale of 1:2500, 000. Lastly, by digitizing the geological map in the Arc-GIS software, shape file of each geological rock type delineated. According to Smith and Minty,(2002) and Geoffrey Mibei, (2014) Engineering classification of rock, and ATSWC,(2014) the coefficient of rock and soil erosion were computed by interpreted the rock hardness from the Geological map of Gereb-segen watershed.

Table 3.13: Coefficient values EMP model (Al-saffar et al., 2012).

Land use coefficient	Xa
Mixed and dense forest	0.05 – 0.2
Thin forest with grove	0.2 – 0.3
Coniferous forest with little grove, scarce bushes, bushy prairie	0.3 – 0.4
Damaged forest and bushes , pasture	0.4 – 0.6
Damaged pasture and cultivated land	0.6 – 0.8
Area without vegetal cover	0.8 – 1
Coefficient of rock and soil erosion	Y
Hard rock erosion resistance	0.25 – 0.5
Rock with moderate erosion resistance ,alluvium	0.5 – 0.6
Black hydro morph soils	0.6 – 0.8
Mountain soils	0.8 - 0.9
Hard doll stone	0.9 – 1
Clastic schist ,mica schist, gneiss	1 – 1.1
Red sand stone ,serpentine ,fly sch	1.1 – 1.2
Weathered limestone and marl	1.2 – 1.6
Loess , tuff, salty soil, steeply soil	1.6 - 2
Sand , granular, schist	2
Coefficient for present erosion type	$\phi$
Little erosion on watershed	0.1 – 0.2
Erosion in waterways on 20 -50% of the catchment area	0.3 - 0.5
Erosion in river, gullies, alluvial deposits ,Kars tic erosion	0.6 – 0.7
50 – 80 % of the catchment area affected by surface erosion and land slides	0.8 – 0.9
Whole watershed affected by erosion	1

### Land slope (I)

The topographic factor slope gradient (I) in the watershed was the major factors for erosion and sediment consequences. Erosion and sediment yield increases as slope gradient increases, the slope factor (S) reflects the influence of slope gradient on erosion. The slope gradient was deriving from digital elevation model (DEM).

### Temperature coefficient (T)

A temperature (T) coefficient needed to calculate the specific sediment yield from basins.

$$T = \left( \frac{t}{10} + 0.1 \right)^{0.5} \text{----- (24)}$$

Where “t” is the mean annual temperature posed in <sup>0</sup>c. The data collected from the Meteorological agency of Ethiopia Mekelle branch.

### Mean annual rainfalls (H)

The parameter H is the mean rainfall value expressed in mm/year. Mean rainfalls of the watershed collected from the metrological agency of Ethiopia Mekelle branch.

According to Gavrilovic et al., (2008), coefficient of erosion intensity (Z) classification, the watershed of Gereb-segen classified in to excessive erosion, heavy erosion, medium erosion, slight erosion and very slight erosions classifications

Table 3.14: EPM Erosion and torrent categorization in Gavrilovic et al., (2008)

Erosion and torrent category	Qualitative name of erosion category	Range of values of coefficient (Z)
I	Excessive erosion- deep erosion process (gullies, rills rockslides and similar)	$Z > 1$
II	Heavy or milder forms of excessive erosion	$0.71 < Z < 1$
II	Medium erosion	$0.41 < Z < 0.71$
IV	Slight erosion	$0.2 < Z < 0.4$
V	Very slight erosion	$Z < 0.19$

### 3.3.3 PSIAC (Pacific Southwest Inter Agency Committee) Model Description

The PSIAC model estimates average sediment yield form a given area as a function of nine major factors (Equation 25). The method used with the estimation of the factors of sedimentation to obtain location-specific results. PSIAC, (1968) model factors used to estimate sediment yield are the surface geology, soil, climate, runoff, topography, ground/land cover, land use, upland erosion and channel erosion, and the equation given as:

$$Q_s = 0.253e^{0.036R} \text{-----} (25)$$

Where

$Q_s$  = average annual sediment yield ( $m^3/km^2/yr$ )

$e$  = constant values equal to 2.718

$R$  = runoff effective factor ( $m^3/km^2/yr$ )

$$R = X_1 + 16.67X_2 + X_3 + X_4 + X_5 + 0.2X_6 + [20 - 0.2X_7] + X_8 + X_9$$

Where

$X_1$  through  $X_9$  are geology, soil, climate, runoff, topography, land cover, land use, upland erosion, and channel erosion factors respectively.

Table 3.15: PSIAC parameters and their diagnostic criteria [modified after PSIAC, (1968)]

PSIAC parameters	Description	Included in this factor	Diagnostic criteria	Unit
X <sub>1</sub> = Surface geology	Resistance of the surface rocks to erosion and sediment yield		Surface geology types	class
X <sub>2</sub> = Soils	Resistance of the soil against erosion	Soil type	Soil colour	K value
X <sub>3</sub> = Climate	Aggressiveness of the rainfall to cause erosion		Rainfall erosivity (to be derived from rainfall amount)	Value of R
X <sub>4</sub> = Runoff	Potential of runoff generation		Hydrologic soil group classes	
X <sub>5</sub> = Topography	Contribution of topography for runoff generation and erosion processes		Slope	class
X <sub>6</sub> = Ground cover	Availability of covering material on or above the surface of the ground against the effect of precipitation	The land wit out cover	The percentage coverage of bare land from the total area	% value
X <sub>7</sub> = Land use	Type and intensity of use of the land by human (degree of natural vegetative cover	The land covers by vegetation	The percentage coverage of vegetation from the total area	% value
X <sub>8</sub> = Upland erosion	Existence and extent of rill, sheet and gully erosion		Observed erosion	class
X <sub>9</sub> = Channel erosion and sediment transport	Transport expectancy of the streams		Shape of the channel, flow duration, channel cross section, drainage density, channel gradient,	

Table 3.16: PSIAC factor ratings and degree of limitation modified after PSIAC, (1968).

Land quality	Quantitative Ratings	Qualitative Ratings	Degree of limitation	Description of suitability classes
Surface geology (X <sub>1</sub> )	0	Low	Nil	(a) massive hard formations
	5	Moderate	Slight –to– moderate	(a) rocks of medium hardness, (b) moderately weathered, (c) moderately fractured
	10	High	Severe-to– very severe	(a) marine shales and related mudstones and siltstone
Soils (X <sub>2</sub> )	0	Low	Nil	(a) high percentage rock fragments, (b) aggregated clays, (c) high in organic matter
	5	Moderate	Slight –to– moderate	(a) medium texture, (b) occasional rock fragments, (c) caliche layers
	10	High	Severe-to– very severe	(a) fine texture, easily dispersed, saline–alkaline, high shrink–swell characteristics, (b) single grain silts and fine sands
Climate (X <sub>3</sub> )	0	Low	Nil	(a) humid climate with rainfall of low intensity, (b) precipitation in form of snow, (c) arid climate with low-intensity storms, (d) arid climate with rare convective storms
	5	Moderate	Slight –to– moderate	(a) storms of moderate duration and intensity, (b) infrequent convective storms
	10	High	Severe-to– very severe	(a) storms of several days duration with short periods of intense rainfall, (b) frequent intense convective storms, (c) freeze–thaw occurrence
Runoff (X <sub>4</sub> )	0	Low	Nil	(a) low peak flows, (b) low volume of runoff per unit area, (c) rare runoff events
	5	Moderate	Slight –to– moderate	(a) moderate peak flows, (b) moderate volume of flow per unit area
	10	High	Severe-to– very severe	(a) high peak flows, (b) large volume of flow per unit area
Topography (X <sub>5</sub> )	0	Low	Nil	(a) gentle upland slopes (<5%), (b) extensive alluvial planes
	10	Moderate	Slight –to– moderate	(a) Moderate upland slopes (<20%) (b) moderate floodplain development
	20	High	Severe-to– very severe	(a) steep upland slopes (>30%), high relief, little or no floodplain development
Ground cover (X <sub>6</sub> )	-10	Low	Nil	(a) completely protected by vegetation, rock fragments, litter; little opportunity for rainfall to reach erodible material
	0	Moderate	Slight –to– moderate	(a) cover <40%; noticeable litter, (b) if trees present understory not well developed
	10	High	Severe-to– very severe	(a) ground cover <20%, vegetation sparse, little or no litter, (b) no rock in surface soil
Land use (X <sub>7</sub> )	-10	Low	Nil	(a) no cultivation, (b) no recent logging, (c) low-intensity grazing
	0	Moderate	Slight –to– moderate	(a) <25% cultivated, (b) 50% or less recently logged, (c) <50% intensively grazed, (d) ordinary road and other construction
	10	High	Severe-to– very severe	(a) >50% cultivated, (b) almost all of the area intensively grazed, (c) all of area recently burned
Upland erosion (X <sub>8</sub> )	0	Low	Nil	(a) no apparent signs of erosion
	10	Moderate	Slight –to– moderate	(a) about 25% of the area characterized by rill and gully or landslide erosion, (b) wind erosion with deposition in stream channels
	25	High	Severe-to– very severe	(a) >50% of the area characterized by rill and gully or landslide erosion
Channel erosion and sediment transport (X <sub>9</sub> )	0	Low	Nil	(a) wide shallow channels with flat gradients, short flow duration (b) channels in massive rock, large boulders or well vegetated, (c) artificially controlled channels
	10	Moderate	Slight –to– moderate	(a) moderate flow depths medium flow duration with occasionally eroding banks or bed

### **Surface Geology**

The geological map of Gereb-segen watershed where computed similar manner with the EPM models. Then sensitivity to erosion factors on surface geology ( $X_1$ ) according to their hardness evaluated. The score of each unit of surface geology was determined from the scale between 0 for the most resistant face, to 10 for the most sensitive face to erosion.

### **Soil Erodibility**

Soil factor ( $X_2$ ) was determined based on soil erodibility factor (K). The erodibility of soils as defined by Hurni, (1985) in the adaptation of RUSLE to Ethiopia considers the soil colour to have relation with erodibility even though others consider soil texture and structure to determine the value of soil erodibility factor. It was determined similar manner with the MUSLE model described above.

$$Y_2 = 16.67X_2 \text{ ----- (26)}$$

### **Climate ( $X_3$ ) factor**

Climatic aggressiveness is one of the most important factors in relief dynamic. From the climatic parameters, the rainfall is directly involved in versant dynamic in the loss of soil quality and through pluvial denudation and the processes associated with it, through the erosivity of torrential rain. We analyzed rainfall aggressiveness based on highest mean monthly and annual average values of the precipitation through the Fournier's index (Fournier,1960) and Morgan, (1976, cited in Mulugeta,(2013)) obtained significant correlation between  $P_{\max}^2/p$  and drainage texture (defined as the number of first-order streams per unit area). In this study, the climatic factor rating done based on Fourier Index (FI), which computes rainfall erosivity based on maximum monthly rainfall amount and mean annual rainfall amount.

$$FI = P_{\max}^2/p \text{ ----- (27)}$$

Where  $P_{\max}$  = the highest monthly rainfall (mm)

P = mean annual rainfall (mm)

Table 3.17: Fourier index and its climate rating values Mulugeta, (2013)

Fourier index ( $p_{\max}^2/p$ )	Climate rating values	Fourier index ( $p_{\max}^2/p$ )	Climate rating values
$\leq 15$	1	20	6
16	2	21	7
17	3	22	8
18	4	23	9
19	5	$\geq 24$	10

### Runoff factor

To determine the runoff factor first the type of soil in the watershed has be known by getting Digital soil map of FAO, (1986) in shape file from the Ministry of Water, Irrigation, and Electricity. Then the runoff rating values assigned to each of the soil types of the watershed. As a procedure, the infiltration capacity for each soil type measured in the field using double-ring infiltrate meter. The double-ring infiltrate meter is a simple and routinely with dimensions of diameter 60 cm the outer and 30 cm, the inner ring and both height of 25 cm used to determine the infiltration rate of water into the soil. The water drops within specified time limit be recorded, and at the first reading stages the water level in the inner ring was maintained above half heights by adding water to maintain the elevation differences in order to minimize the miss reading.

According to United States Department of Agriculture –Natural Resources Conservation Service Part 630 Hydrology National Engineering Handbook (210–VI–NEH, 2007)

As described below in table 3.17: the soil infiltration rates were grouped to their specifics hydrologic soil groups.

Table 3.18: Criteria for assignment of hydrological soil groups

Soil property	Hydrologic soil group A	Hydrologic soil group B	Hydrologic soil group C	Hydrologic soil group D
Hydraulic conductivity of soil	$>40.0 \mu\text{m/s}$ ( $>5.67 \text{ in/hr}$ )	$\leq 40.0$ to $>10.0$ $\mu\text{m/s}$ ( $\leq 5.67$ to $>1.42$ $\text{in/hr}$ )	$\leq 10.0$ to $>1.0$ $\mu\text{m/s}$ ( $\leq 1.42$ to $>0.14$ $\text{in/hr}$ )	$\leq 1.0 \mu\text{m/s}$ ( $\leq 0.14 \text{ in/hr}$ )



Figure 3.12: Field measurement of infiltration capacity using double-ring infiltrometer

Table 3.19: Hydrological soil groups and PSIAC rating values Mulugeta, (2013)

Hydrological soil group	PSIAC rating values
A	1
B	4
C	7
D	10

### Topographic factor

The topographic factor the slope ( $X_5$ ) in the watershed is the major factors for erosion and sedimentation. Erosion and sediment yield increases as slope steepness increases, the slope factor ( $X_5$ ) reflects the influence of slope gradient on erosion. The slope gradient has been determined using digital elevation model (DEM) as of the MUSLE model used.

Table 3.20: Factors of topography and PSIAC rating values in Mulugeta, (2013)

Slope %	Point values	Slope %	Point values	Slope %	Point values	Slope %	Point values
>30	20	24	14	15-17	8	6-8	2
29	19	23	13	14-15	7	5-6	1
28	18	22	12	12-14	6	< 5	0
27	17	21	11	11-12	5		
26	16	18-20	10	9-11	4		
25	15	17-18	9	8-9	3		

**Land cover factor (X<sub>6</sub>)**

According to the PSIAC model, the land cover is the percentage of bare land without any cover. Using the remote sensing satellite data Image at 2017 CNES/Astrium the bare land area of the Gereb-segen watershed were identified and then land cover percentage has been Computed by dividing to the total area coverage . The rating values computes as follow:

$$Y_6 = 0.2X_6 \text{ -----(28)}$$

**Land use factor (X<sub>7</sub>)**

The main characteristics considered as land use are litter (rubbish) and vegetations, according to Avenant and Collett, (2013) the vegetation coverage it includes grass, legumes, woody fodder plants, cropping, perennial horticulture, grazing, conservation area and land reclamation.

The land use-rating factor value been done in a similar manner with the land cover factor. The rating values computes as follow:

$$Y_7 = 20 - 0.2X_7 \text{ ----- (29)}$$

**Up land erosion factor**

The up land erosion factor was determined by assessing type of erosion in the watershed using drainage density in table 3.21.

**Channel erosion and sediment transport rating**

This rating done based on the spatial distribution of the drainage density in the watershed. For calculating the drainage density for a basin or sub-basin, all the lengths of all channels within

the basin's boundaries (rivers, streams, etc.), were summed, and then divided to the area of their basins. Drainage density calculated using the formula:

$$\text{Drainage Density} = \frac{L \text{ (km)}}{A \text{ (km}^2\text{)}} = \text{km}^{-1} \text{----- (31)}$$

L= Total length channels (km), A = Area of basin (km<sup>2</sup>)

This technique adopted from Stroosnijder and Eppik, (1993) in which an erosion class is attached to an elementary watershed depending on its drainage density.

Table 3.21: Erosion class based on drainage density Stroosnijder and Eppik ,(1993)

Class	Erosion Degree	Drainage density (km/km <sup>2</sup> )	Rating value
1	Slight	< 0.1	2
2	Moderate	0.1 ≤ 0.5	4
3	High	0.5 ≤ 1.0	6
4	Severe	1.0 ≤ 2.0	8
5	Very severe	Greater or equal to 2	10

### Arithmetic procedure for erosion/sediment risk assessment

The sediment yield index is the sum of values for the appropriate characteristics of each of the nine factors. According to the PSIAC model the final sediment yield results are categorized into 5 Classes.

Table 3.22: PSIAC model sediment classes Mulugeta, (2013)

Erosion class	Rating	Qs(sediment yield=total volume sediment/Sediment production area),(m <sup>3</sup> /Km <sup>2</sup> /yr)	Class
I	<25	<95	Very low
II	25 – 50	95- 250	Low
III	50 – 75	250- 450	Moderate
IV	75- 100	450 – 1450	High
V	>100	>1450	Very high

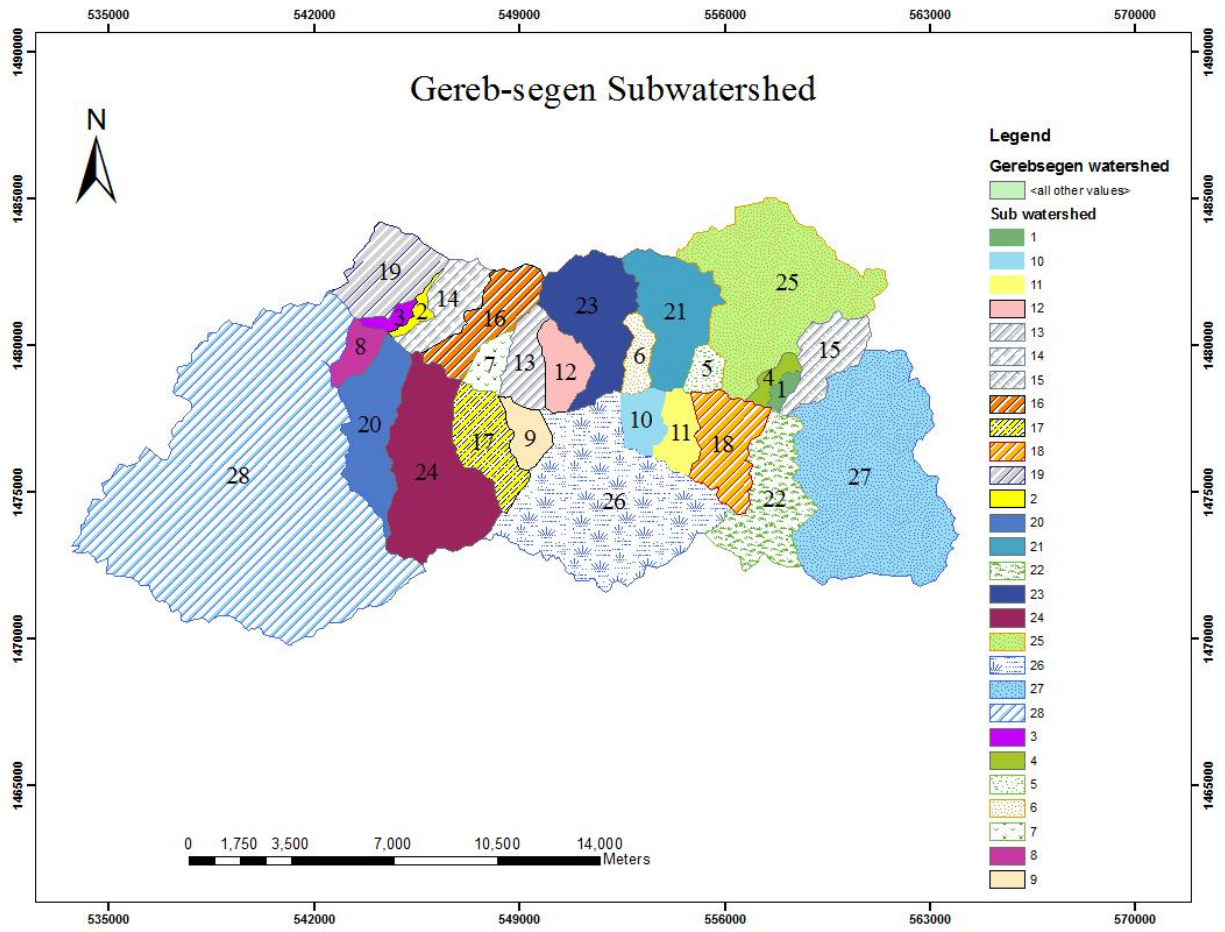


Figure 3.13: Gereb-segen Sub watershed

Table 3.23: Gereb-segen sub watershed and its coverage area

FID	Shape *	ID	GRIDCODE	Perimeter_m	area_km <sup>2</sup>	area_ha	Code	S_No
24	Polygon	1	542365	4391.14	0.7882	78.82	ws_a3	1
5	Polygon	1	542365	7203.58	0.8422	84.22	ws_a2	2
2	Polygon	1	542365	5498.46	0.9526	95.26	ws_a1	3
23	Polygon	1	542365	6341.28	1.2172	121.72	ws_az	4
20	Polygon	1	542365	5352.00	1.7324	173.24	ws_ay	5
16	Polygon	1	542365	7427.05	2.1052	210.52	ws_ax	6
10	Polygon	1	542365	6805.35	2.1261	212.61	ws_aw	7
3	Polygon	1	542365	7668.03	2.221	222.10	ws_av	8
12	Polygon	1	542365	7176.12	2.5934	259.34	ws_au	9
18	Polygon	1	542365	7252.81	2.9053	290.53	ws_at	10
19	Polygon	1	542365	8267.42	3.1904	319.04	ws_as	11
13	Polygon	1	542365	8478.02	3.8343	383.43	ws_ar	12
11	Polygon	1	542365	9518.09	3.8829	388.29	ws_aq	13
6	Polygon	1	542365	11356.21	4.9627	496.27	ws_ap	14
25	Polygon	1	542365	11952.54	5.2604	526.04	ws_ao	15
7	Polygon	1	542365	13244.68	6.2330	623.30	ws_an	16
9	Polygon	1	542365	11929.44	6.3162	631.62	ws_am	17
22	Polygon	1	542365	13439.37	7.1427	714.27	ws_al	18
1	Polygon	1	542365	11994.94	7.4259	742.59	ws_ak	19
4	Polygon	1	542365	17309.91	8.8829	888.29	ws_aj	20
17	Polygon	1	542365	15293.87	9.6549	965.49	ws_ai	21
26	Polygon	1	542365	18428.32	10.1265	1,012.65	ws_ah	22
14	Polygon	1	542365	17213.13	10.5811	1,058.11	ws_ag	23
8	Polygon	1	542365	20632.37	17.0301	1,703.01	ws_af	24
21	Polygon	1	542365	26472.52	23.8824	2,388.24	ws_ae	25
15	Polygon	1	542365	27035.19	28.8614	2,886.14	ws_ad	26
0	Polygon	1	542365	28535.39	34.7728	3,477.28	ws_ac	27
27	Polygon	1	542365	47089.85	78.1260	7,812.60	ws_ab	28
Total					287.65	28,765		

As described in the above figure 3.12 and table 3.23 the watershed divided to sub watersheds in order to get manageable watershed and accurate sediment yield results.

## 4 Results and discussions

### 4.1 Result of Sediment Yield Estimation by MUSLE Model

#### 4.1.1 Runoff factor

##### 1. Runoff volume

The curve number values of the sub watersheds are determined using the land use, the soil groups (Appendix Table 5), and the result of runoff volume is present in table 4.1.

Table 4.1: Result of runoff volume for each sub water of Gereb-segen watershed

Ws	CN	P (mm)	$S(\text{mm})=254 \left\{ \left( \frac{100}{\text{CN}} \right) - 1 \right\}$	$Pe(\text{mm}) = \left\{ \frac{(p - 0.2S)^2}{(p + 0.8S)} \right\}$	Area(km <sup>2</sup> )	Q (m <sup>3</sup> ) = pe*Area
ws - a3	83	40.17	52.02	10.83	0.788191	8.54
ws - a2	69.23	41.48	112.89	2.71	0.84217	2.28
ws - a1	75.35	41.48	83.09	5.72	0.952636	5.45
ws - az	81.04	47.4	59.42	13.28	1.217242	16.17
ws - ay	70.76	41.48	104.96	3.35	1.732401	5.80
ws - ax	61.51	41.48	158.94	0.56	2.105179	1.17
ws - aw	67.6	41.48	121.74	2.11	2.126067	4.49
ws - av	73.88	41.48	89.80	4.88	2.220919	10.84
ws - au	62.39	41.48	153.12	0.72	2.593401	1.86
ws - at	72.48	41.48	96.44	4.15	2.905296	12.06
ws - as	69.47	41.48	111.62	2.80	3.190395	8.95
ws - ar	67.5	41.48	122.30	2.08	3.834317	7.97
ws - aq	66.82	41.48	126.13	1.86	3.882857	7.20
ws - ap	65.43	41.48	134.20	1.44	4.962665	7.15
ws - ao	79.6	40.17	65.09	7.99	5.260424	42.04
ws - an	62.54	41.48	152.14	0.75	6.233034	4.66
ws - am	69.76	41.48	110.10	2.92	6.316243	18.46
ws - al	81.66	40.17	57.05	9.64	7.142657	68.86
ws - ak	72.31	41.48	97.26	4.07	7.425907	30.20
ws - aj	67.33	41.48	123.25	2.02	8.882868	17.96
ws - ai	77.35	41.48	74.38	7.01	9.654941	67.67
ws - ah	82.4	40.17	54.25	10.29	10.126473	104.16
ws - ag	78.08	41.48	71.31	7.56	10.581073	79.56
ws - af	70.36	41.48	107.00	3.17	17.030074	54.03
ws - ae	81.54	47.4	57.50	13.80	23.882375	329.52
ws - ad	67.66	41.48	121.41	2.13	28.861409	61.59
ws - ac	82.68	40.17	53.21	10.54	32.601157	343.57
ws - ab	79.65	50.06	64.91	13.48	78.126021	1053.02

## 2. Result of Peak discharge

To determine the peak discharge the stream slope using DEM, stream length using Arc-Hydro the longest flow path were determined and the results presented in table 4.2 below.

Table 4.2: Result of peak discharge for each sub water of Gereb-segen watershed

peak discharge rate of Gereb-segen sub watershed							
Ws	Stream Slope %	L(stream length).m	$T_c(\text{hr})=1/3000* \left(\frac{L}{S^{0.5}}\right)^{0.77}$	$D(\text{hr})=T_c/6$	$T_p(\text{hr})=0.5D+0.6T_c$	Area (km <sup>2</sup> )	$q_p(\text{m}^3/\text{s})=0.21A/T_p$
ws - a3	0.7	399.28	0.039	0.006	0.027	0.788191	6.22
ws - a2	3.5	1048.5	0.043	0.007	0.030	0.84217	5.95
ws - a1	0.70	921.34	0.076	0.013	0.052	0.952636	3.88
ws - az	1.70	1331.04	0.069	0.012	0.047	1.217242	5.40
ws - ay	1.81	908.59	0.050	0.008	0.034	1.732401	10.57
ws - ax	8.70	1824.76	0.047	0.009	0.032	2.105179	13.75
ws - aw	5.00	1025.96	0.037	0.006	0.026	2.126067	17.46
ws - av	5.80	1442.26	0.046	0.008	0.031	2.220919	14.84
ws - au	5.60	1483.37	0.047	0.008	0.032	2.593401	16.82
ws - at	6.80	1293.9	0.040	0.007	0.027	2.905296	22.57
ws - as	5.10	2289.11	0.069	0.011	0.047	3.190395	14.24
ws - ar	4.20	2630.66	0.082	0.014	0.056	3.834317	14.34
ws - aq	4.50	2767.35	0.083	0.014	0.057	3.882857	14.35
ws - ap	6.40	3687.78	0.091	0.015	0.062	4.962665	16.76
ws - ao	3.60	4172.05	0.125	0.021	0.085	5.260424	12.93
ws - an	4.70	4065.35	0.111	0.018	0.076	6.233034	17.30
ws - am	8.90	3499.56	0.077	0.013	0.053	6.316243	25.18
ws - al	4.70	3472.27	0.098	0.016	0.067	7.142657	22.45
ws - ak	6.20	2786.47	0.074	0.012	0.051	7.425907	30.75
ws - aj	7.10	5194.86	0.113	0.019	0.078	8.882868	24.04
ws - ai	5.0	5308.38	0.132	0.022	0.090	9.654941	22.50
ws - ah	2.30	5256.61	0.177	0.029	0.121	10.12647	17.62
ws - ag	5.90	5425.28	0.126	0.021	0.086	10.58107	25.75
ws - af	4.70	6369.15	0.156	0.026	0.107	17.03007	33.47
ws - ae	0.54	8486.53	0.447	0.074	0.305	23.88238	16.42
ws - ad	1.30	8650.64	0.327	0.055	0.223	28.86141	27.12
ws - ac	0.10	7412.79	0.759	0.126	0.519	32.60116	13.20
ws - ab	1.60	16356.38	0.484	0.081	0.331	78.12602	49.59

#### 4.1.2 Soil erodibility factor results

According to the FAO soil classification the major soil type of the study area described as Vertic cambisols, Lithosols, calcic cambisols, Rendzinas, and Eutric cambisols. The soil erodibility factors values of the area presented in figure 4.1 and table 4.3 and Appendix Table 5.

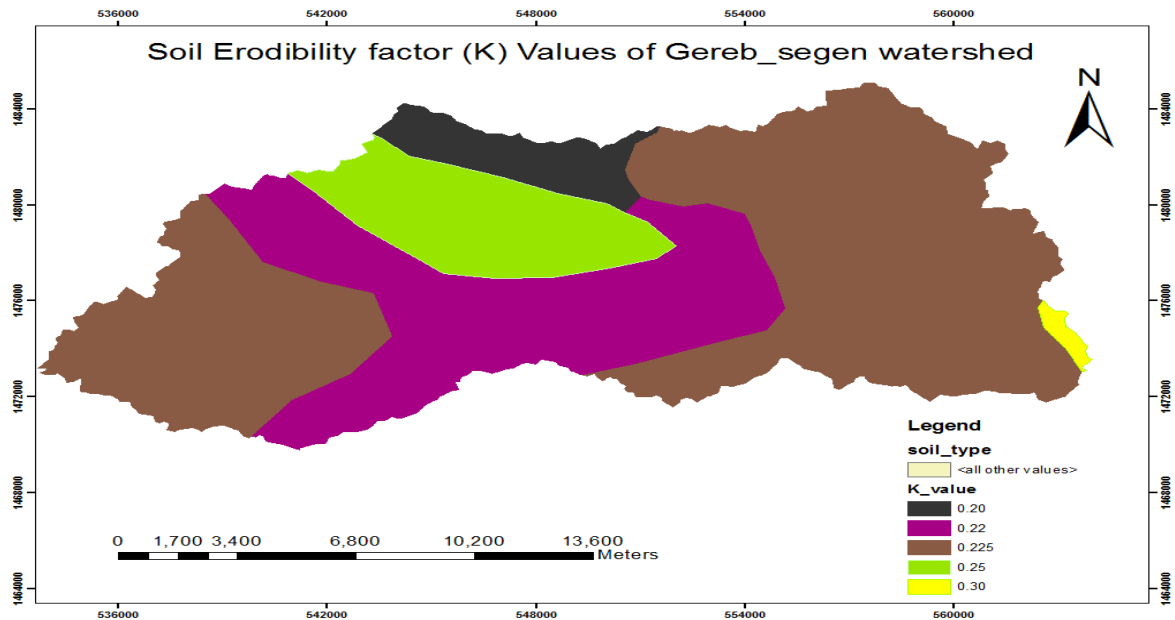


Figure 4.1: Soil erodibility (K) factor value of Gereb-segen watershed

Table 4.3: The soil type of Gereb-segen Watershed and its soil erodibility values according to Hurni, (1985)

Gereb segen watershed Soil type				
FAO_CLASS	MAJOR_SOIL	Area-ha	Soil color	k-value
Vertic Cambisols/Eutric Cambisols	Vertic Cambisols	16,162.768	Red Brown	0.225
Lithosols	Lithosols	7,573.84	Blue Brown	0.22
Calcic Cambisols/Vertic Cambisols	Calcic Cambisols	1,492.429	Brown	0.20
Rendzinas/Lithosols	Rendzinas	157.827	Yellow	0.30
Eutric Cambisols	Eutric Cambisols	3,378.138	Yellow brown	0.25
Total		28,765		

### 4.1.3 Slope Length and Slope Steepness Factor

The topographic factor (LS factor) was estimated using equation 16, 17, &18. The sub watershed of W<sub>s</sub>-ai, W<sub>s</sub>-ae and W<sub>s</sub>-ab with coverage of 11,166.33(38.82% from total area) lies under moderate conditions (LS values 0.7 - 3.2). The sub watersheds W<sub>s</sub>-av, W<sub>s</sub>-at, W<sub>s</sub>-ap, W<sub>s</sub>-ao, W<sub>s</sub>-am, W<sub>s</sub>-al, W<sub>s</sub>-ak, W<sub>s</sub>-aj, W<sub>s</sub>-ah, W<sub>s</sub>-ag, W<sub>s</sub>-af, W<sub>s</sub>-ad and W<sub>s</sub>-ac with coverage of 14,648.90 ha (50.93%) lies under steep conditions (LS values 3.3 - 10), and the rest sub watersheds with area coverage of 2,949.77 ha (10.25%) lies under very steep conditions. The slope factor value of the sub watershed is presented in figure 4.2 and table 4.4.

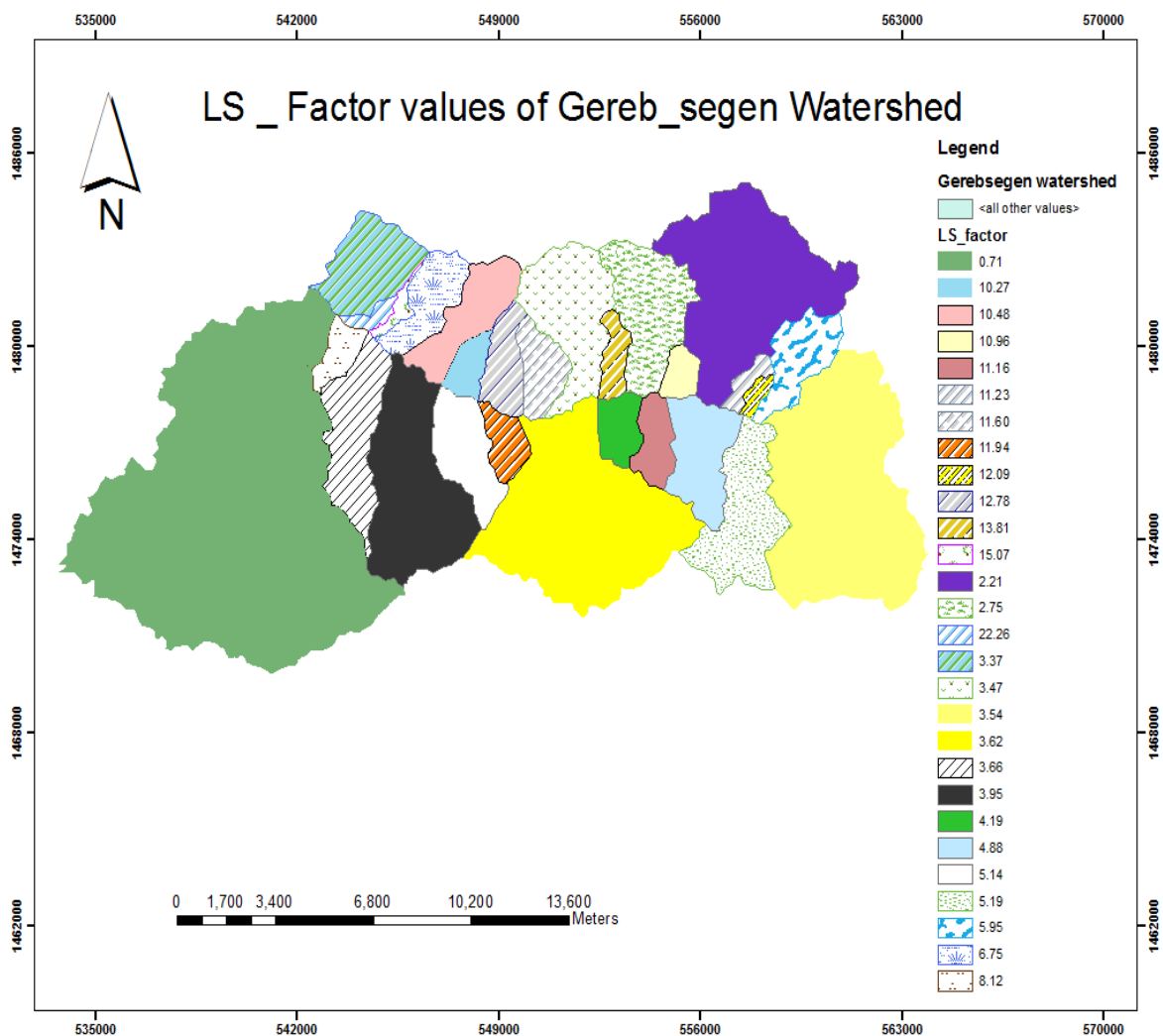


Figure 4.2 : LS – factor of value of Gereb-segen sub watershed

Table 4.4: The LS\_ factor value of Gereb-segen sub watershed

LS – factor values of Gereb-segen sub watershed							
Ws	L –factor	S-factor	LS-factor	Ws	L –factor	S-factor	LS-factor
ws - a3	1.73	6.997	12.09	ws – ao	1.73	3.45	5.95
ws - a2	1.78	8.44	15.07	ws – an	2.44	4.29	10.48
ws - a1	2.00	11.13	22.26	ws – am	1.60	3.21	5.14
ws – az	1.63	6.88	11.23	ws – al	1.89	2.58	4.88
ws – ay	1.68	6.53	10.96	ws – ak	1.98	1.70	3.37
ws – ax	2.08	6.65	13.81	ws – aj	1.95	1.88	3.66
ws – aw	1.73	5.94	10.27	ws – ai	1.59	1.73	2.75
ws – av	1.97	4.11	8.12	ws – ah	1.54	3.37	5.19
ws – au	2.15	5.54	11.94	ws – ag	1.95	1.78	3.47
ws – at	2.15	1.95	4.19	ws – af	1.64	2.41	3.95
ws – as	2.12	5.26	11.16	ws – ae	2.03	1.09	2.21
ws – ar	1.98	5.87	11.60	ws – ad	2.07	1.75	3.62
ws – aq	2.11	6.05	12.78	ws – ac	1.18	3.01	3.54
ws – ap	2.42	2.78	6.75	ws – ab	2.61	0.27	0.71

#### 4.1.4 Land use/Land cover factor (C)

The results of land use factor are presented in table 4.5 and figure 4.3 below.

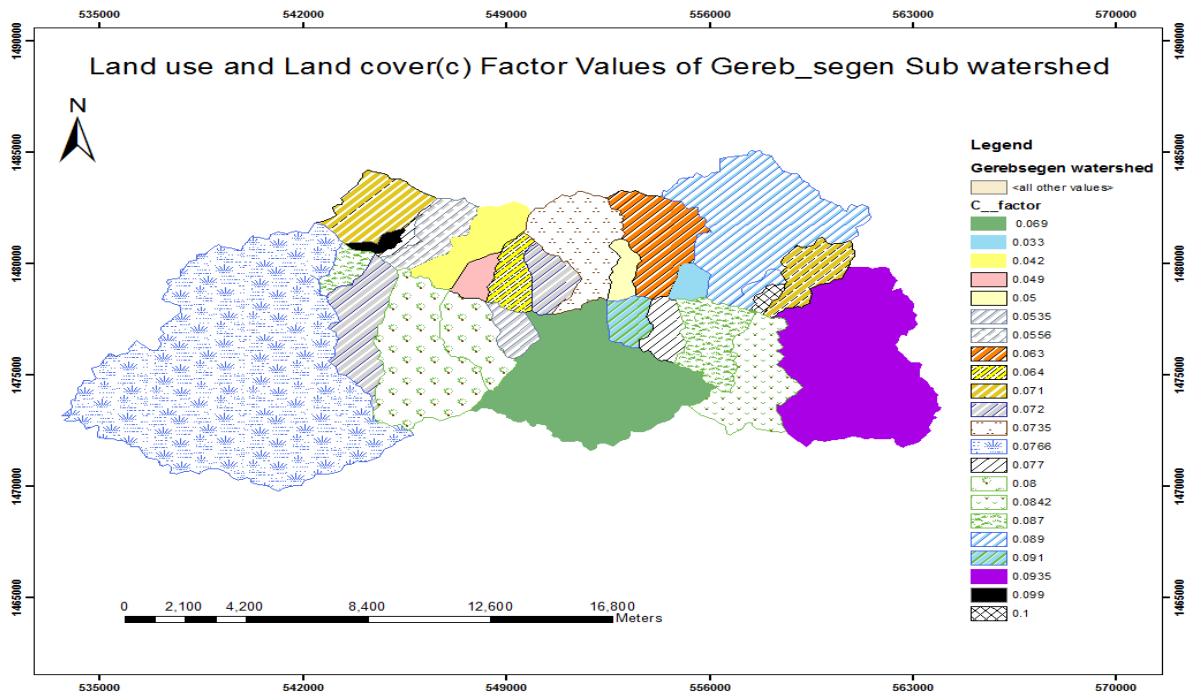


Figure 4.3: Land use /Land cover factor values of Gereb-segen Sub watershed

Table 4.5: Land use and land cover (C) factor values of Gereb-segen sub watershed

C -factor values for the Gereb-segen sub watershed					
Ws	C-factor value	Ws	C-factor value	Ws	C-factor value
ws - a3	0.1	ws – as	0.077	ws – ai	0.063
ws - a2	0.077	ws – ar	0.072	ws – ah	0.0842
ws - a1	0.099	ws – aq	0.064	ws – ag	0.0735
ws – az	0.089	ws – ap	0.0556	ws – af	0.08
ws – ay	0.033	ws – ao	0.071	ws – ae	0.089
ws – ax	0.05	ws – an	0.042	ws – ad	0.069
ws – aw	0.049	ws – am	0.08	ws – ac	0.0935
ws – av	0.087	ws – al	0.087	ws – ab	0.0766
ws – au	0.0535	ws – ak	0.071		
ws – at	0.091	ws – aj	0.072		

According to Hurni (1985) which adapted for Ethiopia, condition the land cover factor 67% of the area has 0.1 values this indicates the land cover values more correlates with cultivation land coverage's of the area.

#### 4.1.5 Support Practice factor (P) results

According the Management factor, which adapted from Bewket and Teferi, (2009) for the Ethiopia condition the support practice factor 33% of the watershed area, has 1 values. Due to lack of cultures in conservation of soil and water practices and the long period of cultivation lands most of area posses safer many year ago. To address the regional state adapted the soil and water conservation measures but steel know it does not cover the whole area that need conservation. The Gereb-segen watershed one of among the watersheds, not treated in the region. The watershed is highly affected by erosion hazard. The values of support practice factor are presented in figure 4.4 and table 4.6 below.

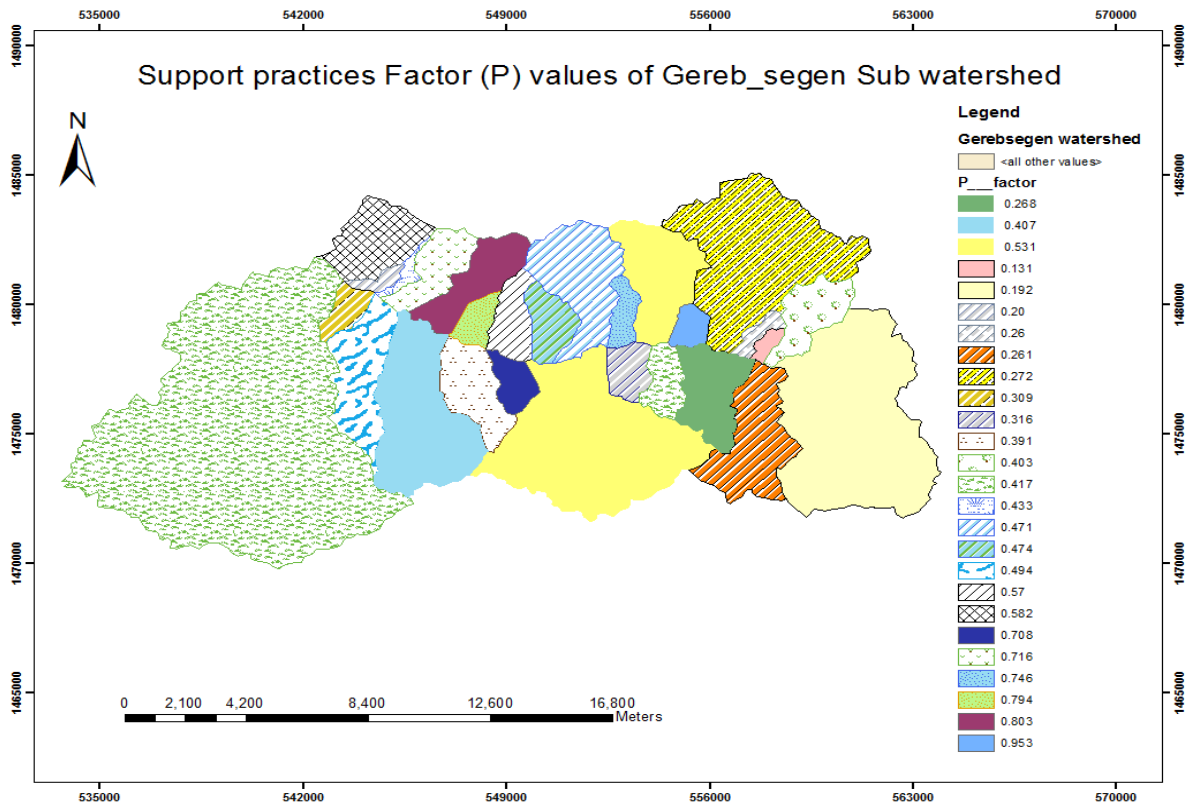


Figure 4.4 : Support practices factor values of Gereb-segen sub watershed

Table 4.6: Support practices factor (P) values of Gereb-segen sub watershed

P -factor values for the Gereb-segen sub watershed					
Ws	P-factor value	Ws	P-factor value	Ws	P-factor value
ws - a3	0.131	ws – as	0.417	ws – ai	0.531
ws - a2	0.433	ws – ar	0.474	ws – ah	0.261
ws - a1	0.2	ws – aq	0.57	ws – ag	0.471
ws – az	0.26	ws – ap	0.716	ws – af	0.407
ws – ay	0.953	ws – ao	0.403	ws – ae	0.272
ws – ax	0.746	ws – an	0.803	ws – ad	0.531
ws – aw	0.794	ws – am	0.391	ws – ac	0.192
ws – av	0.309	ws – al	0.268	ws – ab	0.417
ws – au	0.708	ws – ak	0.582		
ws – at	0.316	ws – aj	0.494		

#### 4.1.6 MUSLE Model

Using MUSLE model estimated sediment yield, the Gereb-segen watershed suited at low sedimentation the sub watershed of Ws- a3 with coverage of 78.82 ha (0.28%). Moderate sedimentation the sub watersheds of Ws-a2, Ws-a1, Ws-az, Ws-ay, Ws-ax, Ws-au and Ws-at with coverage of 1234.83 ha (4.29%). High sedimentation the sub watersheds of Ws-aw, Ws-av, Ws-as, Ws-ar, Ws-aq, Ws-ap, Ws-ao, Ws-an, Ws-am, Ws-al, Ws-ak, Ws-aj, Ws-ai, Ws-ah, Ws-ae and Ws-ac with coverage of 13,991.49 ha (48.64%), and very high sedimentation the sub watersheds of Ws-ag, Ws-af, Ws-ad and Ws-ab with coverage of 13,459.86 ha (46.79%). According the above description the watershed of Gereb-segen more suited at high to very high conditions and the mean annual sediment yield with 13.944 ton/ha/yr was suited at the high sediment yield classifications. The sediment using MUSLE model results are presented in figure 4.5 and table 4.7 below.

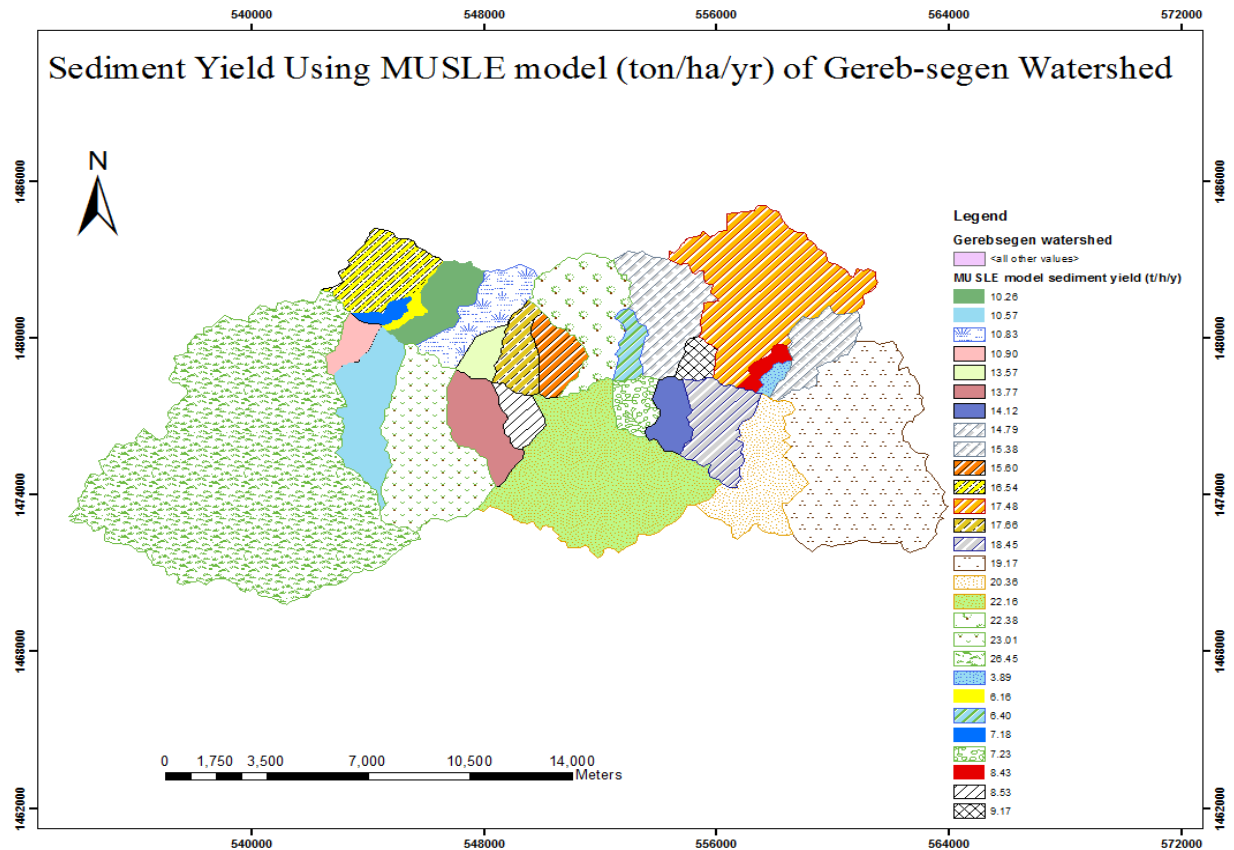


Figure 4.5: Sediment yield using MUSLE model values of Gereb-segen watershed

Table 4.7: Sediment yield using MUSLE model Gereb-segen sub watershed

Ws	Factor values							Annual sediment yield $S=11.8(Qqp)^{0.56}$ *K*L*S*C*P (ton/ha/yr)
	Qp (m <sup>3</sup> /s)	Q (m <sup>3</sup> )	L – factor	S- factor	C- factor	P- factort	K- factor	
ws - a3	6.22	8.54	1.73	6.997	0.1	0.131	0.225	3.89
ws - a2	5.95	2.28	1.78	8.44	0.077	0.433	0.241	6.16
ws - a1	3.88	5.45	2.00	11.13	0.099	0.2	0.25	7.18
ws – az	5.40	16.17	1.63	6.88	0.089	0.26	0.225	8.43
ws – ay	10.57	5.80	1.68	6.53	0.033	0.953	0.225	9.17
ws – ax	13.75	1.17	2.08	6.65	0.05	0.746	0.222	6.40
ws – aw	17.46	4.49	1.73	5.94	0.049	0.794	0.25	13.57
ws – av	14.84	10.84	1.97	4.11	0.087	0.309	0.246	10.90
ws – au	16.82	1.86	2.15	5.54	0.0535	0.708	0.232	8.53
ws – at	22.57	12.06	2.15	1.95	0.091	0.316	0.22	7.23
ws – as	14.24	8.95	2.12	5.26	0.077	0.417	0.221	14.12
ws – ar	14.34	7.97	1.98	5.87	0.072	0.474	0.235	15.60
ws – aq	14.35	7.20	2.11	6.05	0.064	0.57	0.239	17.66
ws – ap	16.76	7.15	2.42	2.78	0.0556	0.716	0.222	10.26
ws – ao	12.93	42.04	1.73	3.45	0.071	0.403	0.225	15.38
ws – an	17.30	4.66	2.44	4.29	0.042	0.803	0.222	10.83
ws – am	25.18	18.46	1.60	3.21	0.08	0.391	0.233	13.77
ws – al	22.45	68.86	1.89	2.58	0.087	0.268	0.225	18.45
ws – ak	30.75	30.20	1.98	1.70	0.071	0.582	0.219	16.54
ws – aj	24.04	17.96	1.95	1.88	0.072	0.494	0.23	10.57
ws – ai	22.50	67.67	1.59	1.73	0.063	0.531	0.225	14.79
ws – ah	17.62	104.16	1.54	3.37	0.0842	0.261	0.225	20.36
ws – ag	25.75	79.56	1.95	1.78	0.0735	0.471	0.221	22.38
ws – af	33.47	54.03	1.64	2.41	0.08	0.407	0.227	23.01
ws – ae	16.42	329.52	2.03	1.09	0.089	0.272	0.225	17.48
ws – ad	27.12	61.59	2.07	1.75	0.069	0.531	0.222	22.16
ws – ac	13.20	343.57	1.18	3.01	0.0935	0.192	0.229	19.17
ws – ab	49.59	1053.02	2.61	0.27	0.0766	0.417	0.224	26.45
Total sum								390.43
Mean annual sediment yield( ton/ha/yr)								13.944

## 4.2 Result of Sediment Yield Estimation by EPM Model

### 4.2.1 Mean annual precipitation (mm)

The mean annual precipitations of Gereb-segen watershed data collected for 20-year records (1997-2016) from metrological agency of Ethiopia Mekelle branch. By taking the GPS reading of stations then filed in the XL folder and saving using CSV(comma delimited) after that, using the GIS soft ware Thiessen polygen methods the influential area was known (figure 4.6), according this the area coverage of four metrological stations and mean annual precipitation were mention in figure 4.6 table 4.8 below.

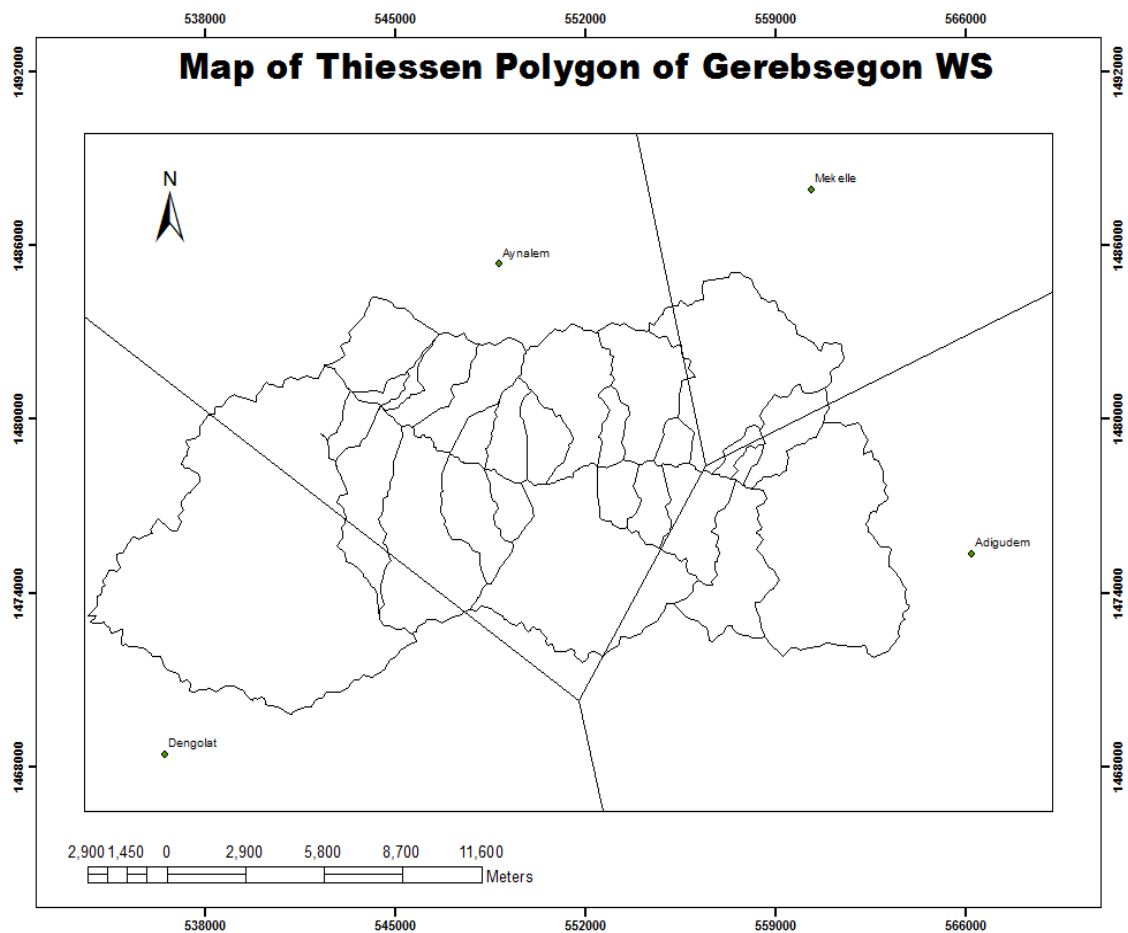


Figure 4.6: Thiessen polygon method of Gereb-segen watershed metrological station

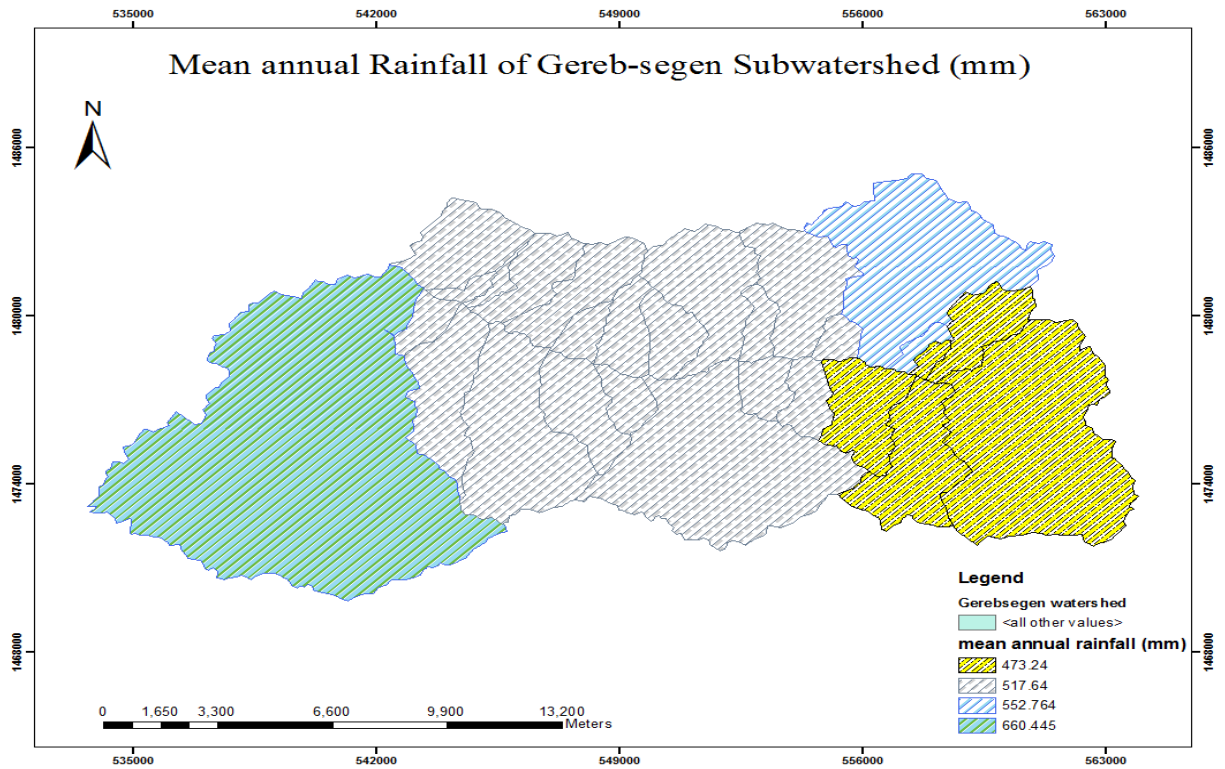


Figure 4.7: Mean annual rainfall of Gereb-segen Sub watershed

Table 4.8 : Mean annual Rain fall of Gereb-segen sub watershed

Mean annual rain fall of Gereb-segen watershed (mm)					
Ws	P (mm)	Ws	P (mm)	Ws	P (mm)
ws - a3	473.24	ws - as	517.64	ws - ai	517.64
ws - a2	517.64	ws - ar	517.64	ws - ah	473.24
ws - a1	517.64	ws - aq	517.64	ws - ag	517.64
ws - az	552.764	ws - ap	517.64	ws - af	517.64
ws - ay	517.64	ws - ao	473.24	ws - ae	552.764
ws - ax	517.64	ws - an	517.64	ws - ad	517.64
ws - aw	517.64	ws - am	517.64	ws - ac	473.24
ws - av	517.64	ws - al	473.24	ws - ab	660.445
ws - au	517.64	ws - ak	517.64		
ws - at	517.64	ws - aj	517.64		

#### 4.2.2 Mean annual temperature coefficient values (T)

The mean annual temperature coefficient value is represented in table 4.9.

Table 4.9: Mean annual temperature of Gereb-segen watershed

Mekelle Metrological station						
X – coordinate	Y- coordinate	Z (elevation)	Mean annual Max T <sup>o</sup> (°c)	Mean annual Min T <sup>o</sup> (°c)	Mean annual T <sup>o</sup> (°c)	Temperature coefficient = $\left(\frac{t}{10} + 0.1\right)^{0.5}$
560350	1487901	2256	24.06	11.57	17.82	1.372

#### 4.2.3 Land use coefficient (Xa)

According Al-saffar et al., (2012) table 3.12 for each land use type the values woodland 0.25, cultivated land 0.7, bushland 0.5, bareland 0.7 and grazing land 0.5 were determined and the result of land use coefficient is presented in figure 4.8 and table 4.10.

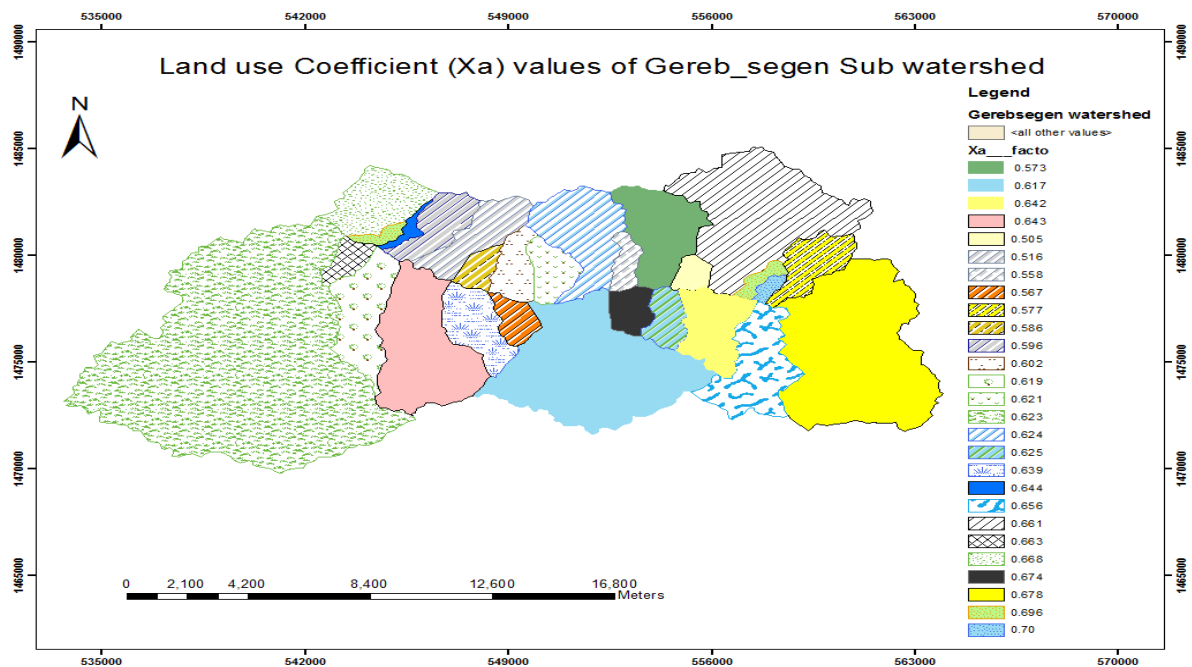


Figure 4.8: Land use coefficient values of Gereb-segen sub watershed

Table 4.10: Land use coefficient (Xa) values Gereb-segen sub watershed

land use coefficient (Xa) values					
Ws	Xa-value	Ws	Xa-value	Ws	Xa-value
ws - a3	0.7	ws - as	0.625	ws - ai	0.573
ws - a2	0.644	ws - ar	0.621	ws - ah	0.656
ws - a1	0.696	ws - aq	0.602	ws - ag	0.624
ws - az	0.67	ws - ap	0.596	ws - af	0.643
ws - ay	0.505	ws - ao	0.577	ws - ae	0.661
ws - ax	0.558	ws - an	0.516	ws - ad	0.617
ws - aw	0.586	ws - am	0.639	ws - ac	0.678
ws - av	0.663	ws - al	0.642	ws - ab	0.623
ws - au	0.567	ws - ak	0.668		
ws - at	0.674	ws - aj	0.619		

#### 4.2.4 Coefficient of rock and soil erosion

According Al-saffar et al., (2012) table 4.10 for coefficient of rock and soil erosion the values Mekelle dolerite 0.25 which is fully hard rock, and finely crystalline limestone with some coquina and marl 0.5 the rock is hard but it some coquina soft rock. Marl interbeded with coquina fine grained limestone 1.4 the rock type moderately weathered. Coquina, Oolitic limestone and Marl 1.6 and Agula shale 1.6 these type of rocks are softy and easily weathered rocks. The coefficient of rock and soil erosion values is presented in table 4.11 and figure 4.9.

Table 4.11: Coefficient of rock and soil erosion values of Gereb-segen sub watershed

Coefficient values of rock and soil erosion					
Ws	Y values	Ws	Y values	Ws	Y values
ws - a3	1.017	ws - as	1.316	ws - ai	1.600
ws - a2	0.932	ws - ar	0.711	ws - ah	1.263
ws - a1	1.508	ws - aq	1.070	ws - ag	1.201
ws - az	0.899	ws - ap	0.753	ws - af	1.260
ws - ay	1.600	ws - ao	1.113	ws - ae	1.345
ws - ax	1.561	ws - an	0.952	ws - ad	1.333
ws - aw	1.005	ws - am	1.404	ws - ac	1.116
ws - av	1.400	ws - al	1.417	ws - ab	1.016
ws - au	1.400	ws - ak	1.083		
ws - at	0.830	ws - aj	1.377		

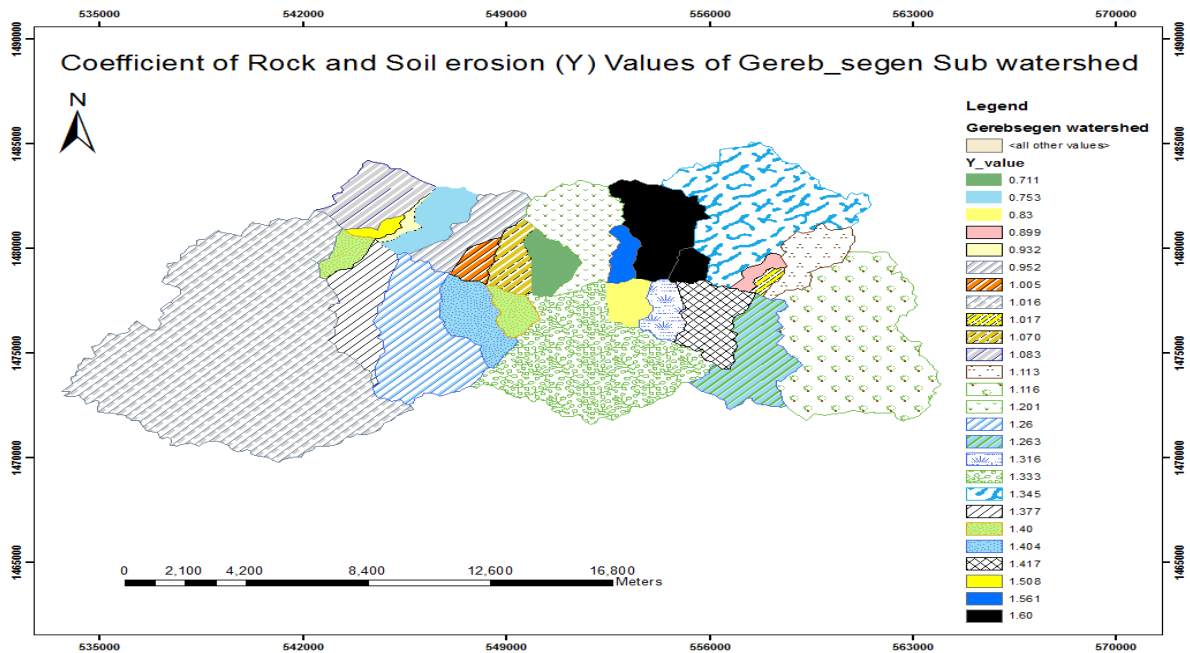


Figure 4.9: Coefficient of rock and soil erosion vales of Gereb-segen sub watershed

#### 4.2.5 Coefficient for present erosion type

According Stroosnijder and Eppik ,(1993) drainage density classification of erosion hazard table 3.21, the Gereb-segen watershed suited from low to moderate the sub watershed of Ws-a3, Ws-a2, Ws-a1, Ws-az, Ws-ax ,Ws-at ,Ws-ay,Ws-aw Ws-av, Ws-au, Ws-as, Ws-ar,Ws-aq, Ws-ap, Ws-ao, Ws-an, Ws-am, Ws-al, Ws-ak, Ws-aj, Ws-ai, Ws-ah, Ws-ae and Ws-ac with coverage of 15,305.14 ha (53.21%), at high and very high the sub watersheds of Ws-ag, Ws-af, Ws-ad and Ws-ab with 13,459.86 ha coverage (46.79%).

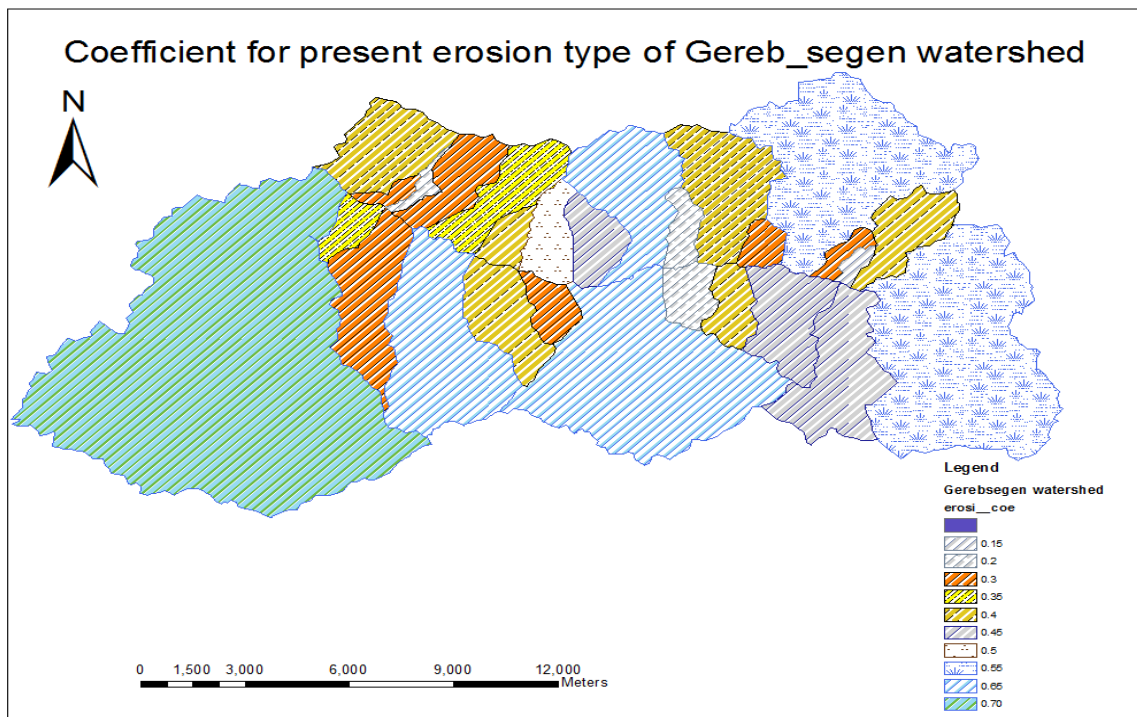


Figure 4.10: Coefficient for present erosion type of Gerseb-segen watershed

Table 4.12: Coefficient for present erosion type of Gerseb-segen sub watershed

Coefficient for present erosion type					
Ws	$\varphi$ _ value	Ws	$\varphi$ _ value	Ws	$\varphi$ _ value
ws - a3	0.15	ws - as	0.4	ws - ai	0.4
ws - a2	0.2	ws - ar	0.45	ws - ah	0.45
ws - a1	0.3	ws - aq	0.5	ws - ag	0.65
ws - az	0.3	ws - ap	0.3	ws - af	0.65
ws - ay	0.3	ws - ao	0.4	ws - ae	0.55
ws - ax	0.2	ws - an	0.35	ws - ad	0.65
ws - aw	0.4	ws - am	0.4	ws - ac	0.55
ws - av	0.35	ws - al	0.45	ws - ab	0.7
ws - au	0.3	ws - ak	0.4		
ws - at	0.2	ws - aj	0.3		

#### 4.2.6 Land Slope

The computation of the land slope was similar manner with MUSLE, which derived from DEM with the Arc GIS soft ware and the result of land slope shown in figure 4.11 and table 4.13 below.

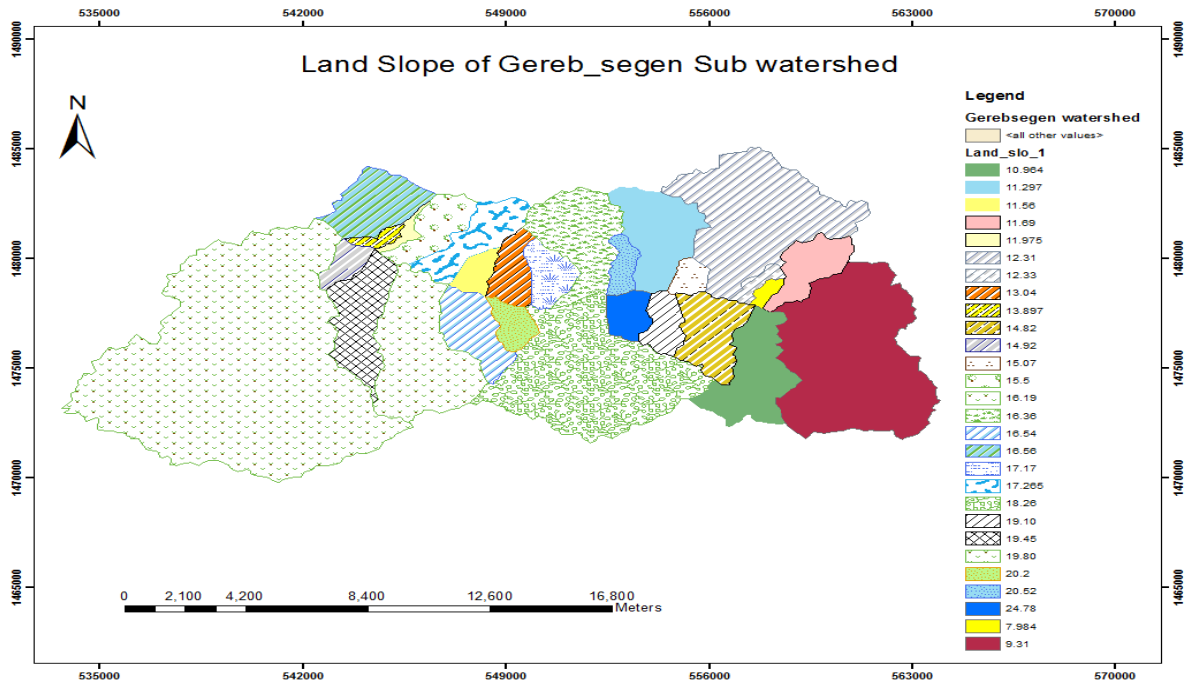


Figure 4.11 : Land slope of Gereb-segen Sub watershed

Table 4.13: land slope of Gereb-segen Sub watershed

slope of sub-watershed					
Ws	Slope %	Ws	Slope %	Ws	Slope %
ws - a3	7.984	ws - as	19.1	ws - ai	11.297
ws - a2	11.975	ws - ar	17.17	ws - ah	10.964
ws - a1	13.897	ws - aq	13.04	ws - ag	16.36
ws - az	12.33	ws - ap	15.5	ws - af	19.8
ws - ay	15.07	ws - ao	11.69	ws - ae	12.31
ws - ax	20.52	ws - an	17.265	ws - ad	18.26
ws - aw	11.56	ws - am	16.54	ws - ac	9.31
ws - av	14.92	ws - al	14.82	ws - ab	16.19
ws - au	20.2	ws - ak	16.56		
ws - at	24.78	ws - aj	19.45		

### 4.2.7 EMP model

The results of EPM model sediment yield are presented in figure 4.12 and table 4.14.

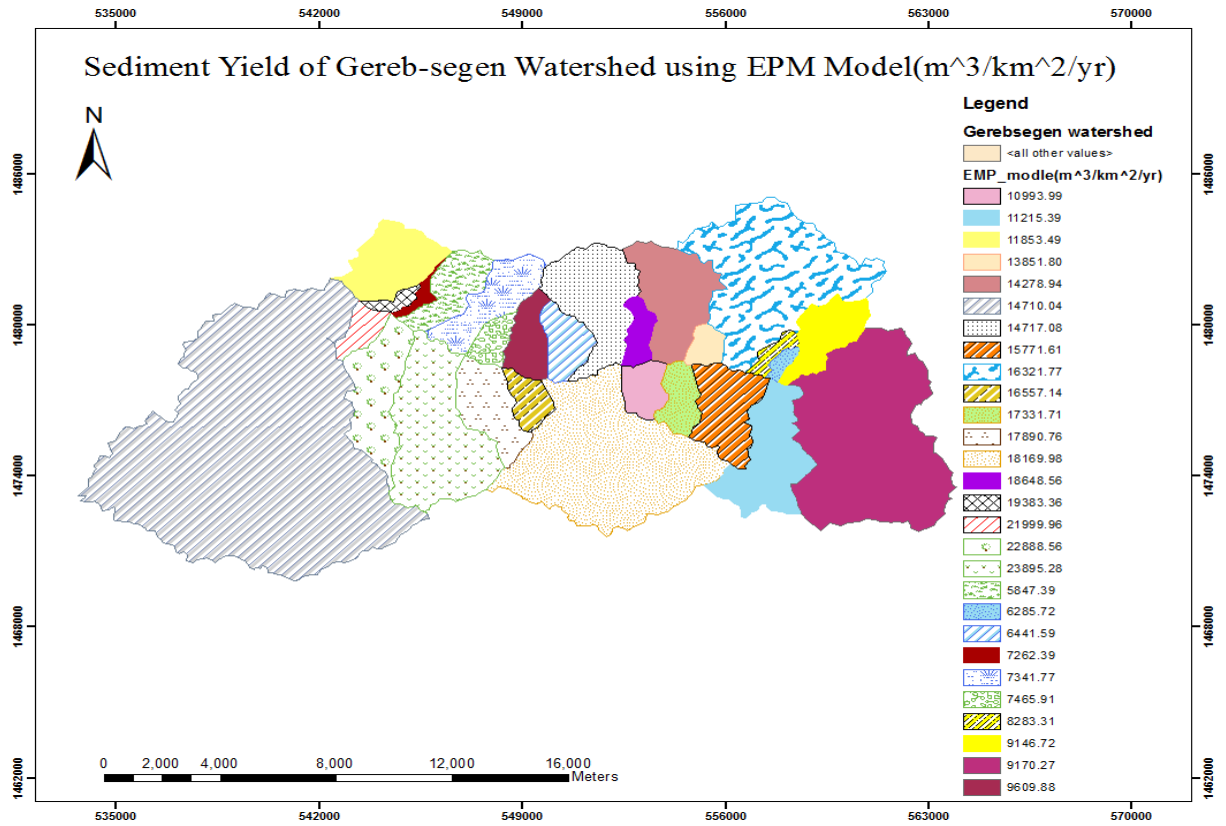


Figure 4.12: Sediment yield of Gereb-segen watershed using EPM model

Table 4.14: Sediment yield of Gereb-segen watershed using EPM model

Annual sediment yield using EPM model ( m <sup>3</sup> /km <sup>2</sup> /yr)									
Ws	$\phi$ - value	Y <sub>-</sub> values	Xa	I (%)	$Z=Y*Xa$ $*(\phi+I^{0.5})$	T(°C)	H(mm)	Π	$Wsp=T*H*$ $\Pi*Z^{1.5}$
ws - a3	0.15	1.017	0.7	7.984	2.118	1.372	473.24	3.14	6,2685.72
ws - a2	0.2	0.932	0.644	11.975	2.197	1.372	517.64	3.14	7,262.29
ws - a1	0.3	1.508	0.696	13.897	4.227	1.372	517.64	3.14	19,383.86
ws - az	0.3	0.899	0.67	12.33	2.296	1.372	552.764	3.14	8,283.31
ws - ay	0.3	1.6	0.505	15.07	3.379	1.372	517.64	3.14	13,851.80
ws - ax	0.2	1.561	0.558	20.52	4.120	1.372	517.64	3.14	18,648.56
ws - aw	0.4	1.005	0.586	11.56	2.238	1.372	517.64	3.14	7,465.91
ws - av	0.35	1.4	0.663	14.92	3.910	1.372	660.445	3.14	21,999.59
ws - au	0.3	1.4	0.567	20.2	3.806	1.372	517.64	3.14	16,557.14
ws - at	0.2	0.83	0.674	24.78	2.897	1.372	517.64	3.14	10,993.99
ws - as	0.4	1.316	0.625	19.1	3.924	1.372	517.64	3.14	17,331.71
ws - ar	0.45	0.711	0.621	17.17	2.028	1.372	517.64	3.14	6,441.59
ws - aq	0.5	1.07	0.602	13.04	2.648	1.372	517.64	3.14	9,609.88
ws - ap	0.3	0.753	0.596	15.5	1.901	1.372	517.64	3.14	5,847.39
ws - ao	0.4	1.113	0.577	11.69	2.452	1.372	552.764	3.14	9,146.72
ws - an	0.35	0.952	0.516	17.265	2.213	1.372	517.64	3.14	7,341.77
ws - am	0.4	1.404	0.639	16.54	4.007	1.372	517.64	3.14	17,890.76
ws - al	0.45	1.417	0.642	14.82	3.911	1.372	473.24	3.14	15,771.61
ws - ak	0.4	1.083	0.668	16.56	3.233	1.372	473.24	3.14	11,853.49
ws - aj	0.3	1.377	0.619	19.45	4.014	1.372	660.445	3.14	22,888.56
ws - ai	0.4	1.6	0.573	11.297	3.448	1.372	517.64	3.14	14,278.94
ws - ah	0.45	1.263	0.656	10.964	3.116	1.372	473.24	3.14	11,215.39
ws - ag	0.65	1.201	0.624	16.36	3.518	1.372	517.64	3.14	14,717.08
ws - af	0.65	1.26	0.643	19.8	4.132	1.372	660.445	3.14	23,895.28
ws - ae	0.55	1.345	0.661	12.31	3.608	1.372	552.764	3.14	16,321.77
ws - ad	0.65	1.333	0.617	18.26	4.049	1.372	517.64	3.14	18,169.88
ws - ac	0.55	1.116	0.678	9.31	2.725	1.372	473.24	3.14	9,170.27
ws - ab	0.7	1.016	0.623	16.19	2.990	1.372	660.445	3.14	14,710.04
Total Sum									377,334.27
Mean annual sediment yield (m <sup>3</sup> /km <sup>2</sup> /yr)									13,476.22

The watershed of Gereb-segen using the coefficient of erosion intensity (Z) classification suited the entire watershed at Excessive erosion type of category.

### 4.3 Result of Sediment Yield Estimation by PSIAC Model

#### 4.3.1 Surface geology

The surface geology type of the Gereb-segen watershed is described in figure 3.7 and table 3.4. According to PSIAC (1968) table 3.16 for the geological surface factor values Mekelle dolerite 0 which is fully hard rock, and finely crystalline limestone with some coquina and marl 5 the rock is hard but it some coquina soft rock. Marl interbedded with coquina fine grained limestone 5 the rock type moderately weathered. Coquina, Oolitic limestone and Marl 10 and Agula shale 10 these type of rocks are softy and easily weathered rocks. According the above mention the values coefficient of rock and soil erosion presented below.

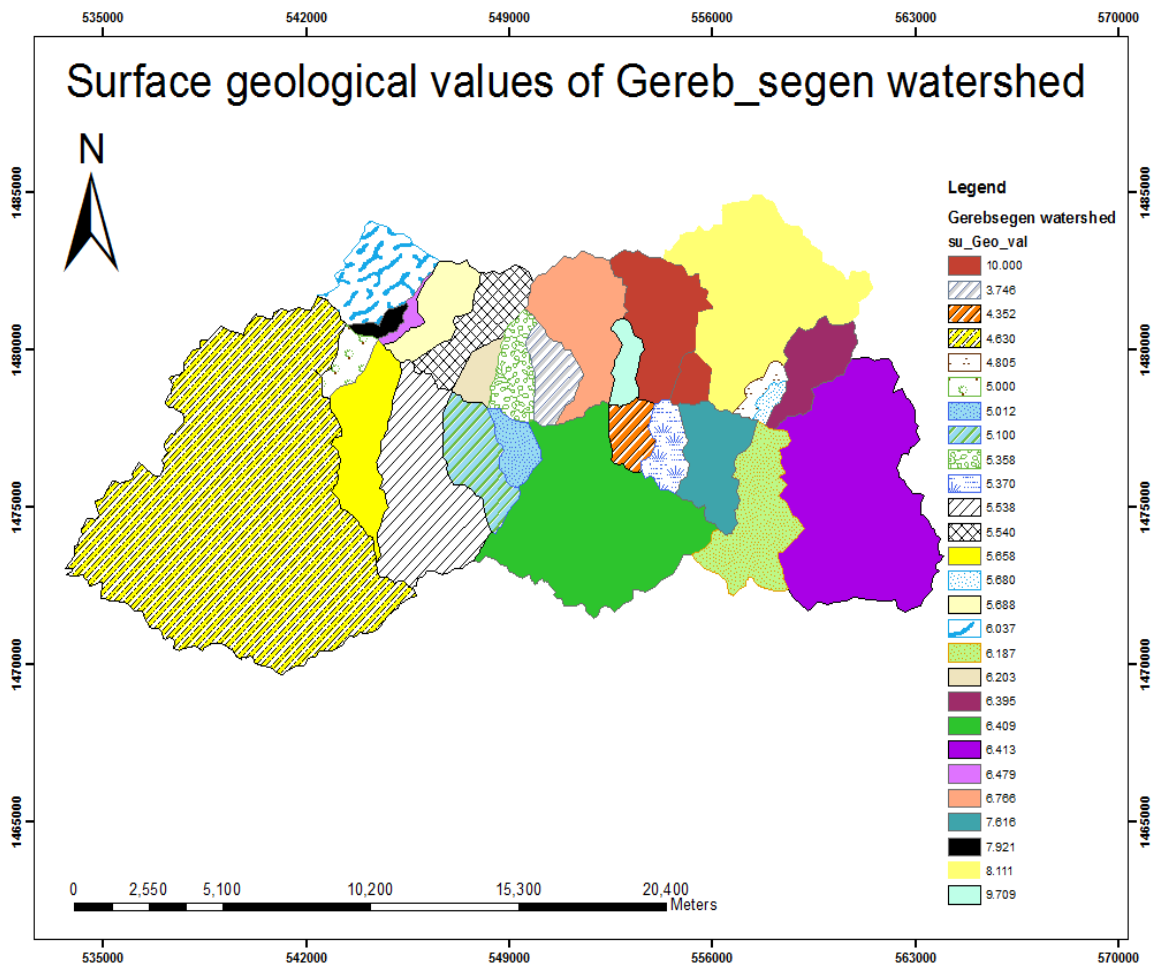


Figure 4.13 : Surface geological values of Gereb-segen sub watershed

Table 4.15: Surface geology values of Gereb-segen sub Watershed

Surface geology values of Gereb-segen Watershed					
Ws	x _ values	Ws	x _ values	Ws	x _ values
ws - a3	5.68	ws – as	5.37	ws – ai	10
ws - a2	6.479	ws – ar	3.746	ws – ah	6.187
ws - a1	7.921	ws – aq	5.358	ws – ag	6.766
ws – az	4.805	ws – ap	5.688	ws – af	5.538
ws – ay	10	ws – ao	6.395	ws – ae	8.111
ws – ax	9.709	ws – an	5.54	ws – ad	6.409
ws –aw	6.203	ws – am	5.1	ws – ac	6.413
ws – av	5	ws – al	7.616	ws – ab	4.63
ws – au	5.012	ws – ak	6.037		
ws – at	4.352	ws – aj	5.658		

### 4.3.2 Soil erodibility (K)

The soil erodibility factor were determined as similar ways to that of MUSLE based on the FAO soil classification and for the Ethiopian case according to Hurni,(1985) using soil colour and the results shown in table 4.16 and Appendix.table 1.

Table 4.16: Soil erodibility factor ( $Y_2$ ) values

Soil erdibility ( $Y_2$ ) values of sub watershed of Gereb -segen watershed								
Ws	$X_2$ (K – factor)	$Y_2=16.67*x_2$	Ws	$X_2$ (K – factor)	$Y_2=16.67*x_2$	Ws	$X_2$ (K – factor)	$Y_2=16.67*x_2$
ws - a3	0.225	3.751	ws – as	0.221	3.684	ws – ai	0.225	3.751
ws - a2	0.241	4.017	ws – ar	0.235	3.917	ws – ah	0.225	3.751
ws - a1	0.25	4.168	ws – aq	0.239	3.984	ws – ag	0.221	3.684
ws – az	0.225	3.751	ws – ap	0.222	3.701	ws – af	0.227	3.784
ws – ay	0.225	3.751	ws – ao	0.225	3.751	ws – ae	0.225	3.751
ws – ax	0.222	3.701	ws – an	0.222	3.701	ws – ad	0.222	3.701
ws –aw	0.25	4.168	ws – am	0.233	3.884	ws – ac	0.229	3.817
ws – av	0.246	4.101	ws – al	0.225	3.751	ws – ab	0.224	3.734
ws – au	0.232	3.867	ws – ak	0.219	3.651			
ws – at	0.22	3.667	ws – aj	0.23	3.834			

### 4.3.3 Climate factor

The climate factor for the watershed areas, four metrological stations have be taken of 20-year records and the maximum monthly rainfall were computed for each year from the years the largest values that rained in the wettest season was taken. The metrological station in the

watershed and near to the watersheds were taking GPS readings by filed in EXL folder and saved in the CSV (comma delimited) then mapped to the watershed by adding the XY data's in the GIS software. Then influential area of each metrological station determined using the Thiessen's polygon method (figure 4.6). Dengolat station covers the sub watershed of ws-ab with area of 7812.60 ha. Mekelle station covers the sub watershed of ws -ae and ws-az with area of 2509.96 ha. Adigudom station covers sub watershed of ws-ac,ws-al,ws-a3,ws-ah and ws-ao with area of 5283.02 ha and Aynalem station covers the sub watershed of ws-a2,ws-a1,ws-ay,ws-ax,ws-aw,ws-av,ws-au,ws-at,ws-as,ws-ar,ws-aq,ws-ap,ws-an,ws-am,ws-ak,ws-aj,ws-ai,ws-ag,ws-af and ws-ad with area of 13,159.42 ha.

Table 4.17: Special distribution of Metrological Station with in and near to the study area

s.n	Station Name	X Coordinate (m)	Y Coordinate (m)	Elevation (m.a.s.l)	Mean annual RF(P) in(mm)	Rain fall of wettest month( $p_{max}$ ) in(mm)	Fourier index ( $p_{max}^2/p$ )	Climate Rating value
1	Adigudom	591205	1704629	2107	473.24	80.5	13.69	1
2	Dengolat	557350	1495810	2371	660.445	82.5	10.31	1
3	Mekelle	572398	1493635	2256	552.764	74.9	10.15	1
4	Aynalem	588318	1522440	2189	517.64	102.8	20.42	7

#### 4.3.4 Infiltration rate

First, the soil type in the watershed were known using the soil classification based on FAO in the Arc GIS soft ware .According this there are five major soil types. For each soil type to take the field double ring infiltration capacity measurement first site observation was made and for the largest watershed soil type by selecting two site for the small soil type one site the test in the field were taken. The results of infiltration capacity of each major soil type and the infiltration rating values were mention in table 4.18 and the location of the infiltration capacity taken site in figure 4.14 below.

Table 4.18: Infiltration capacity and its PSIAC rating values

Gereb-segen Watershed infiltration rate and PSIAC rating values							
X-coordinate	y-coordinate	Soil type	Specific site name	Infiltration rate (cm/hr)	Infiltration rate (in/hr)	Soil group	PSIAC rating
550165	1478523	Euratic cambisols	Mrgaf-negaday	6.02	2.37	B	4
547772	1481578	calcic combisols	Adi-ne-kele	10.52	4.14	B	4
556464	1482050	vertic cambisols	Chelekot	3.03	1.19	C	7
559298	1475909	vertic cambisols	Chelekot	3.32	1.31	C	7
562951	1474744	Rendzinas	May-qeyah	1.86	0.73	C	9
538356	1478113	vertic cambisols	Donsa	3.94	1.55	B	4
538734	1473390	vertic cambisols	Donsa	3.28	1.29	C	7
541725	1479216	Lithosols	Adeka-agera	5.06	1.99	B	4
550291	1475878	Lithosols	Adeka-agera	4.58	1.80	B	4

(Source: Findings of field measurement)

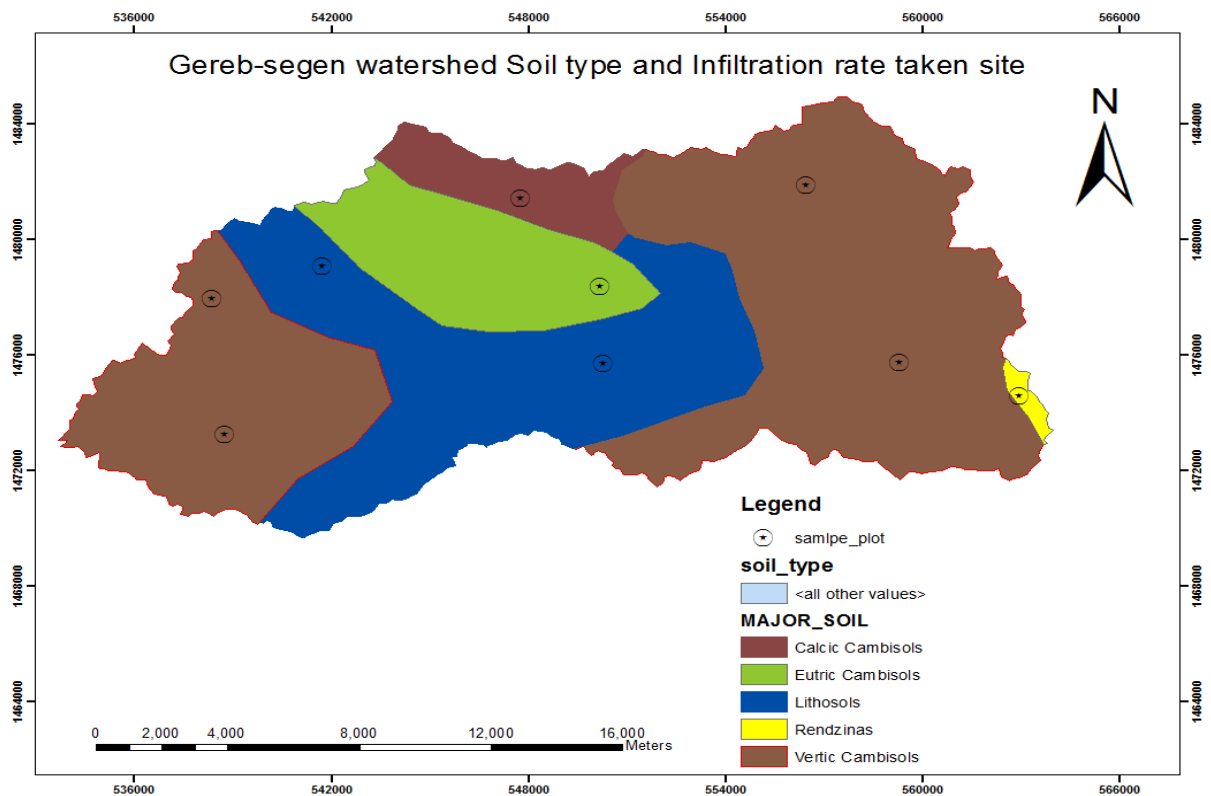


Figure 4.14 : Gereb-segen watershed Soil type and infiltration rate taken site

### 4.3.5 Topography factor

The topography factor for each of the sub-watershed were determined similar manner to the MUSLE model and the topography result values shown in figure 4.15 and table 4.19 below.

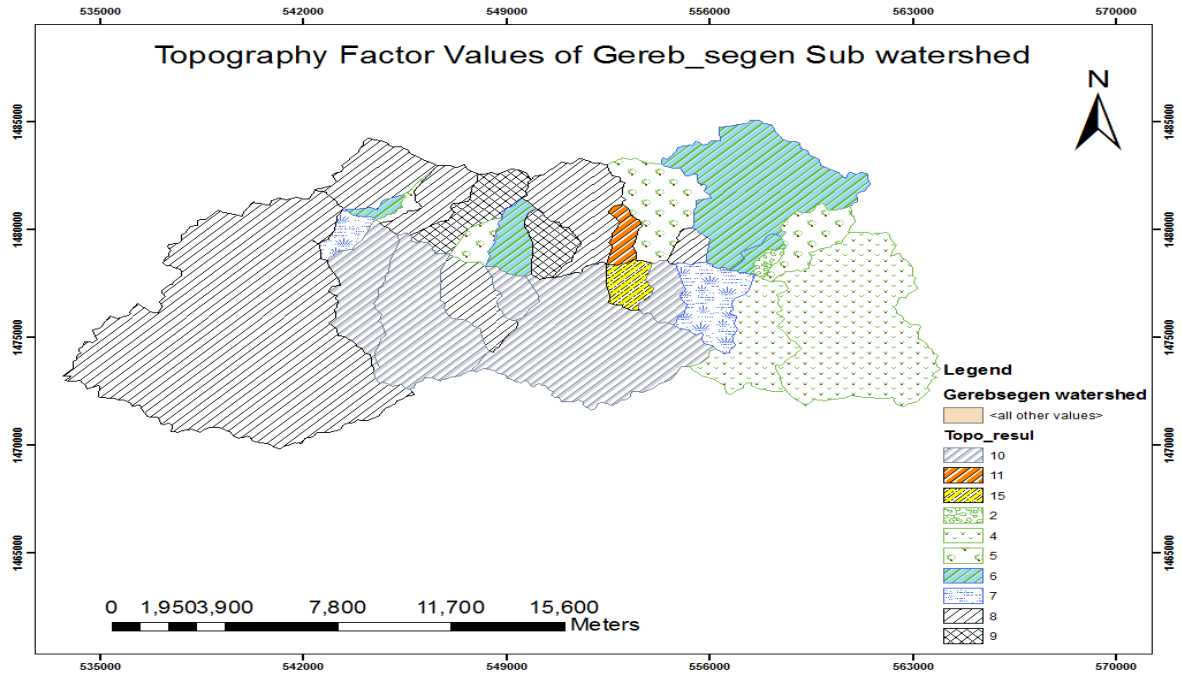


Table 4.15 : Topography factor values of Gereb-segen sub watershed

Table 4.19: Slope of Gereb-segen Sub watershed and its topography factor values

Slope of Gereb-segen Sub watershed and its topography factor values								
Ws	Slope %	Topography factor (X5) value	Ws	Slope %	Topography factor (X5) value	Ws	Slope %	Topography factor (X5) value
ws - a3	7.98	2	ws - as	19.1	10	ws - ai	11.297	5
ws - a2	11.98	5	ws - ar	17.17	9	ws - ah	10.964	4
ws - a1	13.90	6	ws - aq	13.04	6	ws - ag	16.36	8
ws - az	12.33	6	ws - ap	15.5	8	ws - af	19.8	10
ws - ay	15.07	8	ws - ao	11.69	5	ws - ae	12.31	6
ws - ax	20.52	11	ws - an	17.265	9	ws - ad	18.26	10
ws - aw	11.56	5	ws - am	16.54	8	ws - ac	9.31	4
ws - av	14.92	7	ws - al	14.82	7	ws - ab	16.19	8
ws - au	20.2	10	ws - ak	16.56	8			
ws - at	24.78	15	ws - aj	19.45	10			

### 4.3.6 Land cover factor

The percentage of bare land without any cover were determined using the remote sensing satellite data with Image at 2017 CNES/Atrium similar manner with the MUSLE model and the results are presented in table 4.16 and figure 4.20.

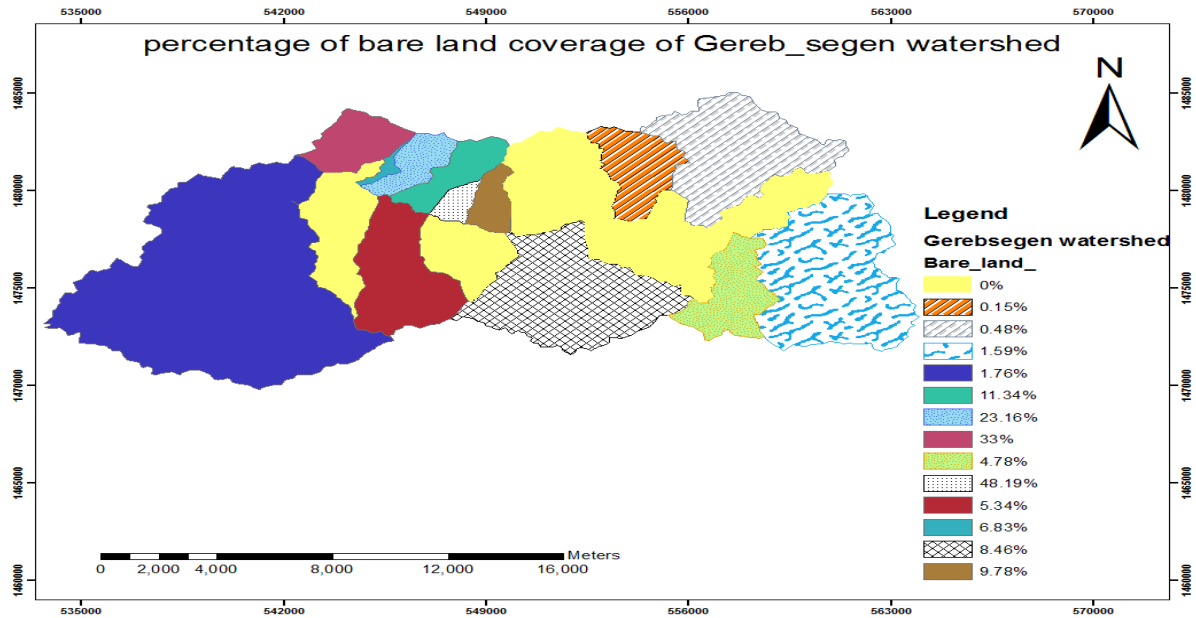


Figure 4.16: percentage of bare land of Gereb-segen Watershed

Table 4.20: Land covers factor values of Gereb-segen sub-watershed

Land cover factor =0.2*bare land coverage in percent									
Ws	Total Area(ha)	Bare land(ha)	% bare land	land cover factor	Ws	Total Area(ha)	Bare land(ha)	% bare land	land cover factor
ws - a3	78.82	0	0	0	ws - ao	526.04	0	0	0
ws - a2	84.22	5.75	6.83	1.37	ws - an	623.3	70.67	11.34	2.27
ws - a1	95.26	0	0	0	ws - am	631.62	0	0	0
ws - az	121.72	0	0	0	ws - al	714.26	0	0	0
ws - ay	173.24	0	0	0	ws - ak	742.59	245.07	33.00	6.60
ws - ax	210.52	0	0	0	ws - aj	888.27	0	0	0
ws - aw	212.61	102.45	48.19	9.64	ws - ai	965.49	1.45	0.15	0.030
ws - av	222.09	0	0	0	ws - ah	1012.65	48.38	4.78	0.96
ws - au	259.34	0	0	0	ws - ag	1058.11	0	0	0
ws - at	290.53	0	0	0	ws - af	1703.01	90.9874	5.34	1.07
ws - as	319.04	0	0	0	ws - ae	2388.24	11.5	0.48	0.096
ws - ar	383.43	0	0	0	ws - ad	2886.14	244.24	8.46	1.69
ws - aq	388.28	37.98	9.78	1.96	ws - ac	3477.28	55.44	1.59	0.32
ws - ap	496.27	114.92	23.16	4.63	ws - ab	7812.6	137.34	1.76	0.35

### 4.3.7 Land use factor

The result of the land use factor were determined by subtracting the bare land and water bodies coverage from the total area land use of the sub watershed and the results were shown below

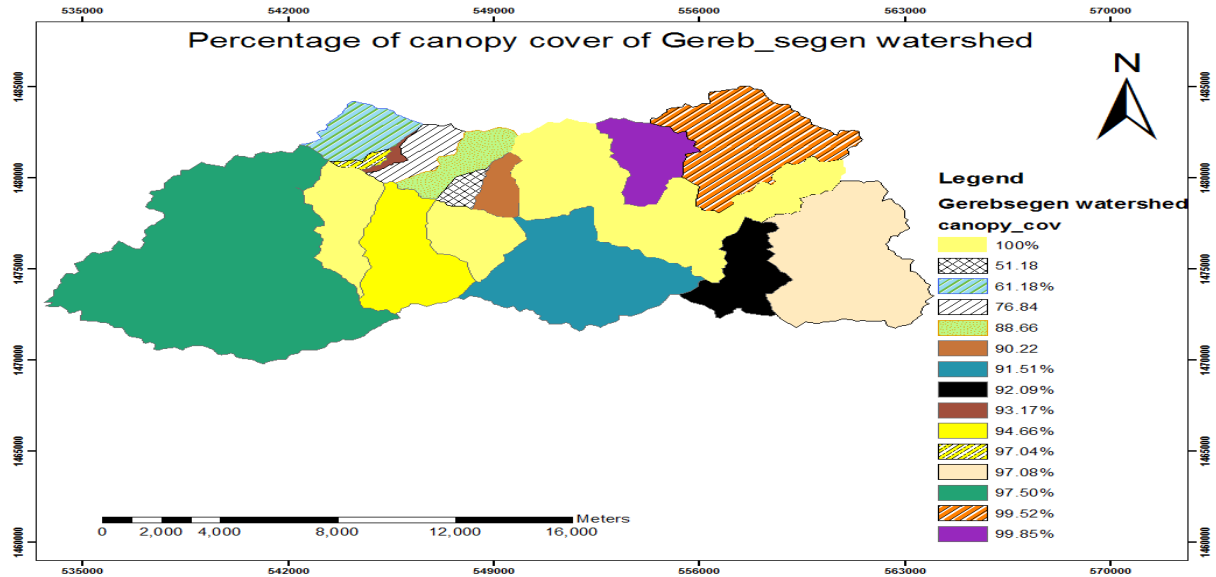


Figure 4.17 : Percentage of canopy cover of Gereb-segen Watershed

Table 4.21: Land use factor (canopy cover) values of Gereb-segen sub-watershed

Land use factor = (20 - (0.2 * Land use coverage in percent))									
Ws	Total Area(ha)	land use(ha)	% land use	land use factor	Ws	Total Area(ha)	land use(ha)	% land use	land use factor
ws - a3	78.82	78.82	100	0	ws - ao	526.04	526.04	100	0
ws - a2	84.22	78.47	93.17	1.37	ws - an	623.3	552.63	88.66	2.27
ws - a1	95.26	92.44	97.04	0.59	ws - am	631.62	631.62	100	0
ws - az	121.72	121.72	100	0	ws - al	714.26	714.26	100	0
ws - ay	173.24	173.24	100	0	ws - ak	742.59	454.3	61.18	7.76
ws - ax	210.52	210.52	100	0	ws - aj	888.27	888.27	100	0
ws - aw	212.61	110.15	51.81	9.64	ws - ai	965.49	964.04	99.85	0.030
ws - av	222.09	222.09	100	0	ws - ah	1012.65	932.52	92.09	1.58
ws - au	259.34	259.34	100	0	ws - ag	1058.11	1058.11	100	0
ws - at	290.53	290.53	100	0	ws - af	1703.01	1612.02	94.66	1.07
ws - as	319.04	319.04	100	0	ws - ae	2388.24	2376.8	99.52	0.096
ws - ar	383.43	383.43	100	0	ws - ad	2886.14	2641.19	91.51	1.70
ws - aq	388.28	350.3	90.22	1.96	ws - ac	3477.28	3378.63	97.08	0.58
ws - ap	496.27	381.35	76.84	4.63	ws - ab	7812.6	7617.5	97.50	0.50

### 4.3.8 Upland erosion factor

The result of upland erosion factor were done based on drainage density of the area and the PSIAC rating values determined according to the table 3.16 above mention in the PSIAC model descriptions . The result of upland erosion factor described briefly in figure 4.18 and table 4.22 below

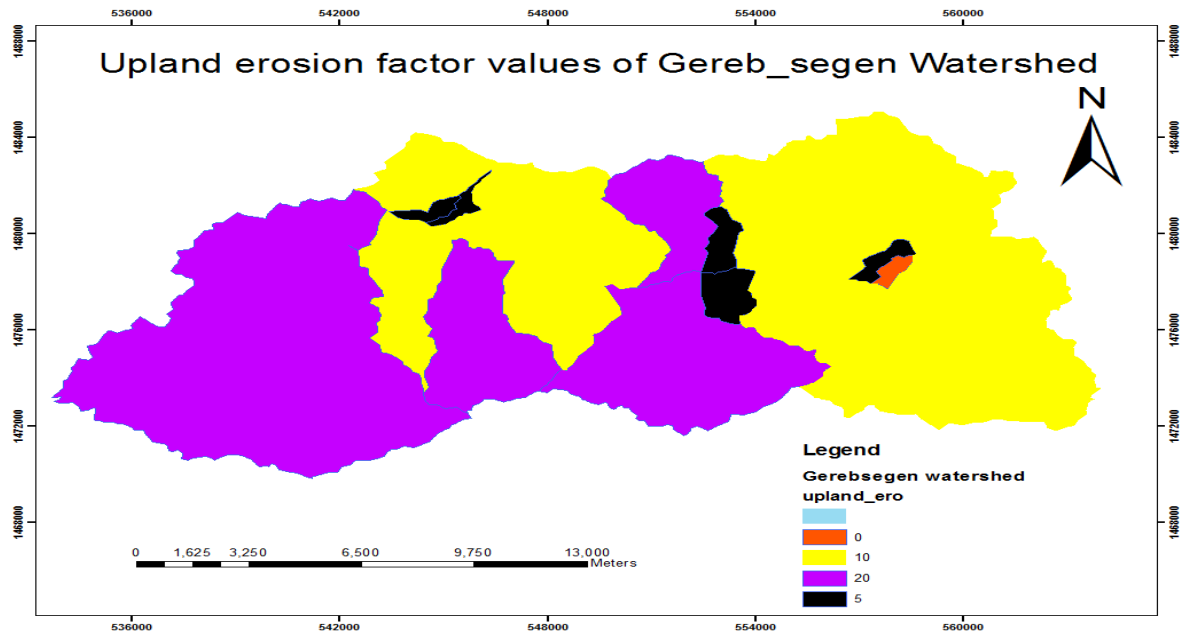


Figure 4.18 : Result Upland erosion factor of Gereb-segen watershed

Table 4.22: The erosion hazard classification and PSIAC rating values

Ws	Hazard Classification	PSIAC rating value	Ws	Hazard Classification	PSIAC rating value
ws - a3	Low	0	ws – ao	Moderate	10
ws - a2	Slight	5	ws – an	Moderate	10
ws - a1	Slight	5	ws – am	Moderate	10
ws – az	Slight	5	ws – al	Moderate	10
ws – ay	Moderate	10	ws – ak	Moderate	10
ws – ax	Slight	5	ws – aj	Moderate	10
ws – aw	Moderate	10	ws – ai	Moderate	10
ws – av	Moderate	10	ws – ah	Moderate	10
ws – au	Moderate	10	ws – ag	Sever	20
ws – at	Slight	5	ws – af	Sever	20
ws – as	Moderate	10	ws – ae	Moderate	10
ws – ar	Moderate	10	ws – ad	Sever	20
ws – aq	Moderate	10	ws – ac	Moderate	10
ws – ap	Moderate	10	ws – ab	Sever	20

### 4.3.9 Channel erosion factor

The channel erosion factor was rated based on the drainage density of the watershed. The watershed has a drainage network of twenty eight numbers, for each drainage density the cumulative drainage tributaries length were summed and then divided to their specific area coverage's. The watershed with the drainage pattern condition according the drainage density classification suited 21-drainage area from high to sever condition and 7-drainage area from slight to moderate and high conditions. This indicates as there is high soil erosion and sediment deposition in reservoir. The result of drainage density for each sub-watershed was mention below in figure 4.19 and table 4.23 below.

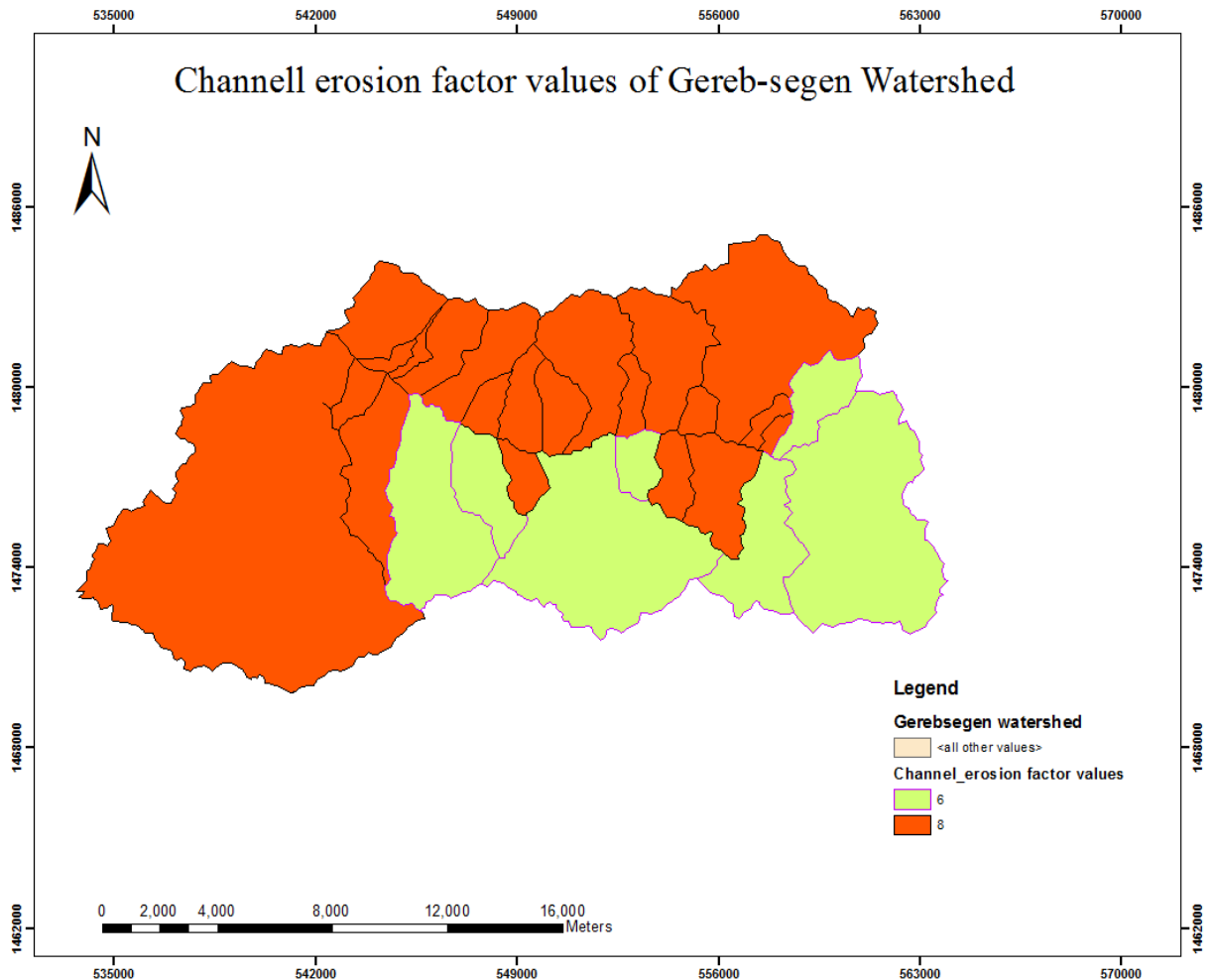


Figure 4.19 : Result of Drainage density factor of Gereb-segen watershed

Table 4.23: Drainage density values of Gereb-segen sub watershed

Gereb segen watershed Drainage density =L (Km)/A(KM <sup>2</sup> )									
Ws	area_s qKm	Stream_ L_Km	Drainage density (Km/Km <sup>2</sup> )	PSIAC rating value	Ws	area_s qKm	Stream L_Km	Drainage density (Km/Km <sup>2</sup> )	PSIAC rating value
ws - a3	0.788	1.003	1.273	8	ws - ao	5.26	5.176	0.984	6
ws - a2	0.84	1.116	1.324	8	ws - an	6.23	6.501	1.043	8
ws - a1	0.95	1.489	1.563	8	ws - am	6.32	5.624	0.890	6
ws - az	1.22	2.264	1.860	8	ws - al	7.14	7.728	1.082	8
ws - ay	1.73	2.461	1.420	8	ws - ak	7.43	7.898	1.064	8
ws - ax	2.11	2.843	1.351	8	ws - aj	8.88	9.203	1.036	8
ws - aw	2.13	2.471	1.162	8	ws - ai	9.65	10.323	1.069	8
ws - av	2.22	2.501	1.126	8	ws - ah	10.13	10.201	1.007	6
ws - au	2.59	3.250	1.253	8	ws - ag	10.58	13.378	1.264	8
ws - at	2.91	2.712	0.933	6	ws - af	17.03	16.997	0.998	6
ws - as	3.19	3.270	1.025	8	ws - ae	23.88	25.325	1.060	8
ws - ar	3.83	5.323	1.388	8	ws - ad	28.86	28.906	1.002	6
ws - aq	3.88	5.634	1.451	8	ws - ac	32.60	32.707	1.003	6
ws - ap	4.96	6.047	1.219	8	ws - ab	78.13	82.137	1.051	8

#### 4.3.10 PSIAC Model sediment yield

The results of PSIAC Model sediment yield of Gereb-segen Watershed is presented in figure 4.20 and table 4.24 below.

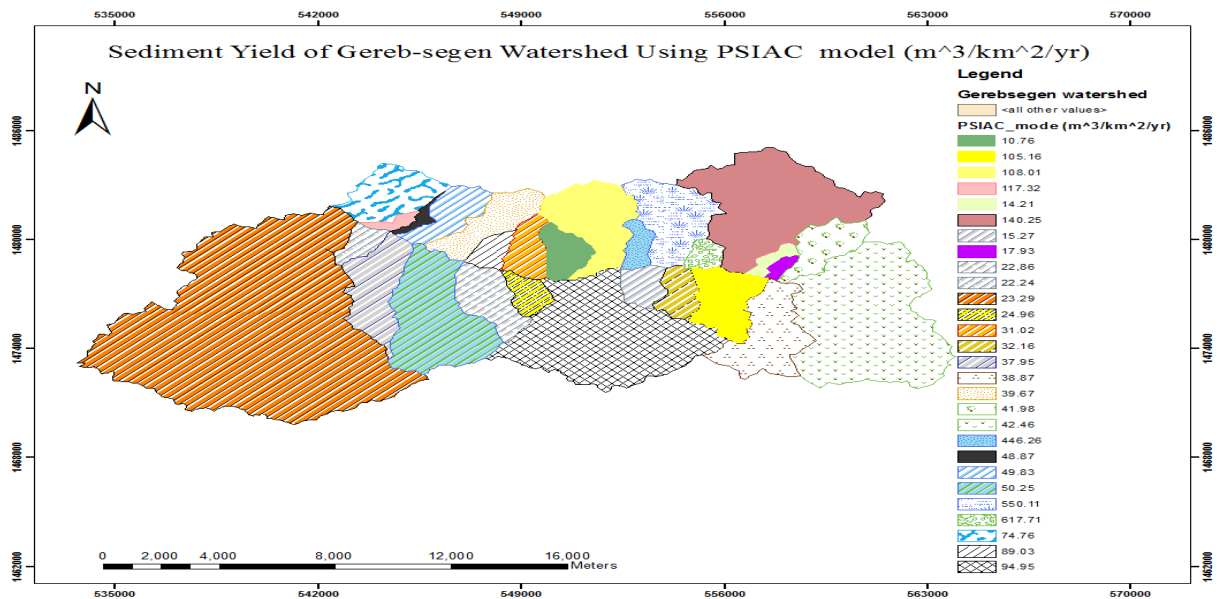


Table 4.20: Annual Sediment Yield of Gereb-segen watershed using PSIAC mode

Table 4.24: Sediment Yield estimation using PSIAC model of Gereb-segen watershed

sediment yield estimation using PSIAC model of Gereb segen watershed											
Ws	X <sub>1</sub> - Value	16.67 X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub> - value	X <sub>5</sub>	0.2X <sub>6</sub>	20 - 0.2X <sub>7</sub>	X <sub>8</sub>	X <sub>9</sub>	R	QS=0.253 e <sup>0.036R</sup>
ws - a3	5.68	94.69	1	7	2	0	0	0	8	118.37	17.93
ws - a2	6.479	108.00	7	4	5	1.37	1.37	5	8	146.22	48.87
ws - a1	7.921	132.04	7	4	6	0	0.59	5	8	170.55	117.32
ws - az	4.805	80.10	1	7	6	0	0	5	8	111.90	14.21
ws - ay	10	166.7	7	7	8	0	0	10	8	216.7	617.71
ws - ax	9.709	161.85	7	5.11	11	0	0	5	8	207.67	446.26
ws - aw	6.203	103.404	7	4	5	9.64	9.64	10	8	162.89	89.03
ws - av	5	83.35	7	4	7	0	0	10	8	124.35	22.24
ws - au	5.012	83.55	7	4	10	0	0	10	8	127.56	24.96
ws - at	4.352	72.55	7	4	15	0	0	5	6	113.90	15.27
ws - as	5.37	89.52	7	4.71	10	0	0	10	8	134.60	32.16
ws - ar	3.746	62.45	7	4	9	0	0	10	8	104.19	10.76
ws - aq	5.358	89.32	7	4	6	1.96	1.96	10	8	133.60	31.02
ws - ap	5.688	94.82	7	4	8	4.63	4.63	10	8	146.77	49.83
ws - ao	6.395	106.60	1	7	5	0	0	10	6	142.00	41.98
ws - an	5.54	92.35	7	4	9	2.27	2.27	10	8	140.43	39.67
ws - am	5.1	85.02	7	4	8	0	0	10	6	125.12	22.86
ws - al	7.616	126.96	1	6.94	7	0	0	10	8	167.51	105.16
ws - ak	6.037	100.64	7	4	8	6.6	7.76	10	8	158.03	74.76
ws - aj	5.658	94.32	7	4.22	10	0	0	10	8	139.20	37.95
ws - ai	10	166.7	7	6.72	5	0.03	0.03	10	8	213.48	550.11
ws - ah	6.187	103.14	1	7	4	0.96	1.58	10	6	139.86	38.87
ws - ag	6.766	112.79	7	5.7	8	0	0	20	8	168.25	108.01
ws - af	5.538	92.32	7	4	10	1.07	1.07	20	6	147.00	50.25
ws - ae	8.111	135.21	1	7	6	0.096	0.096	10	8	175.51	140.25
ws - ad	6.409	106.84	7	5.04	10	1.69	1.7	20	6	164.68	94.95
ws - ac	7.616	126.96	1	6.94	7	0	0	10	6	142.32	42.46
ws - ab	6.037	100.64	7	4	8	6.6	7.76	20	8	125.64	23.29
Sum											2908.15
Mean annual sediment yield (m <sup>3</sup> /Km <sup>2</sup> /yr)											103.86

According to the PSIAC model sediment classification the watershed of Gereb\_segen suited at High potential 1,138.73 ha (3.96%), Moderate potential 210.52 ha (0.73%), Low potential 1,856.60 ha (6.45 %) and Very low potential 25,559.15 (88.86%). From the above description, the researcher can concluded that the watershed majority suited from low to very low potential.

Table 4.25: Percentage of each potential class

Sediment class	Qualitative Categories	PSIAC Value	Qs(sediment yield=total volume sediment/Sediment production area) ( $m^3/Km^2/yr$ )	watershed area covered (ha)	% of the watershed area covered
5	Very high potential	>100	>1450	0	0
4	High potential	75 -100	450 – 1450	1,138.73	3.96
3	Moderate potential	50 – 75	250- 450	210.52	0.73
2	Low potential	25 – 50	95- 250	1,856.60	6.45
1	Very low potential	<25	<95	25,559.15	88.86

## 4.4 Discussion

### 4.4.1 Comparison of Sediment Yield of the MUSLE, EPM and PSIAC Models with the observed data

The comparison of the three sediment estimation models it considers only their sediment yield with the observation data of Gereb-segen watershed, which studied by Haregeweyni et al., (2008) using reservoir sediment survey methods measured mean annual sediment yield of 11.82 ton/ha/yr.

Table 4.26: Estimation of mean annual sediment yield using the three models

Type of model	Unit	Estimated mean annual sediment yield
MUSLE	ton/ha/yr	13.94
EPM	M <sup>3</sup> /km <sup>2</sup> /yr	13,476.22
PSIAC	M <sup>3</sup> /km <sup>2</sup> /yr	103.86

Before comparison, the sediment yield estimated using EPM and PSIAC model should have to be change to similar measurement values of ton/ha/yr. Using the United Kingdom weight conservation (Appendex Table 14), the sedimentation yield estimated using both models of EPM and PSIAC have been converted from cubic meter to ton. Since the soil erodibility and sedimentation had been mostly takes place when there is rainfall, the rain changed into runoff, and the soil is transported with some moisture, the value of conversion from cubic meter to ton 1.44 used in the study area. Using the conversion factor from cubic meter to ton = 1.44 and from km<sup>2</sup> to hectare = 100, the conversion factor from m<sup>3</sup>/km<sup>2</sup> to ton/ha = 1.44/100 = 0.0144 was used in the study area.

Table 4.27: Comparison of sediment yield using the three models and observed data

Type of model	Unit	Sediment yield	Difference from observed data	% of different from observed data
MUSLE	ton/ha/yr	13.94	-2.12	17.94%
EPM	ton/ha/yr	194.06	-182.24	1541.79%
PSIAC	ton/ha/yr	1.496	10.324	87.34%
Observed data	ton/ha/yr	11.82		

As of the aforementioned table 4.30 the sediment yield with the observed data the MUSLE model differed by 17.94%. The PSIAC model differ 87.34 % while the EMP model it is more

different from the observed data. According to Ramin et al., (2006) and sadeghi, (1993) description, the suitability of sediment estimating models for specific area depends on the climate conditions of the area. Therefore, from the above description, the researcher can concluded that the difference sediment yield estimate among the MUSLE, EPM and PSIAC models is due to the climate conditions, If one model adapted to specific area it only works with sister watershed (similar climate conditions ) only according the above definition.

As the three models yield compared with the observed data the MUSLE was the nearest values with a difference of 17.94% than the rest two models due to:

- ❖ The sediment yield estimation factors (soil erodibility, land use, land cover, support practices (conservation) factor of the MUSLE model adapted to Ethiopia conditions by Hurni (1985), Bewket, and Teferi, (2009).

Therefore, it is possible to suggest the reason why the PSIAC and EPM models could not estimate similar sediment yield with observed data in the Gereb-segen watershed context, and the reasons are list as flows:

- ❖ The PSIAC model adapted to south western USA climate condition and it is believed to estimate sediment yield appropriate for the same environmental conditions sadeghi, (1993)
- ❖ The southwestern USA it covers predominantly low- and high-elevation desert and semi desert and includes the great basin desert, Mojave desert, Sonoran desert, and the Chihuahuan desert. The minimum temperature  $-45^{\circ}\text{C}$  ( $-50^{\circ}\text{F}$ ), Maximum temperature of  $53^{\circ}\text{C}$  ( $128^{\circ}\text{F}$ ) and mean annual temperature of  $14^{\circ}\text{C}$  (Sheppard et al., 2002). This indicates there is too hot and cool climate condition in area of southwest USA. Therefore, the minimum and maximum temperature value of Southwest USA largely differed from the Gereb-segen watershed (minimum temperature of  $9.03^{\circ}\text{C}$  and maximum temperature of  $27.22^{\circ}\text{C}$ ). The thermal brake down of rocks mostly occurred in southwest of USA while in the case of Gereb-segen watershed it is less effect.
- ❖ Mean annual rainfall measurements across climatic divisions of the Southwest range from 127 mm to about 500 mm. In high elevation portions of the Colorado Plateau in Arizona and New Mexico, more than 75% of winter precipitation falls as snow, with annual total ranging from 2.4 to 3.3 m (96 to 132 inch). During extremely cold and wet periods, over 2.5 m (100 inch) can fall in a single month. Southwest mountain ranges

with elevations above 2100 m (7000 ft) typically receive as much as 1.5 m (60 inch) of snow annually. High deserts (e.g. southeastern Arizona) record between 25 and 150 mm (1 and 6 inch) of snow annually (Sheppard et al., 2002). The rainfall amount of southwest USA significantly differed from Gereb-segen watershed (mean annual precipitation 497.38 – 660.45 mm) and there is no snowfall in the Gereb-segen watershed.

- ❖ The EPM model is more applicable in arid and semi arid areas of Iran climate conditions (Yousefi et al., 2014).
- ❖ The annual mean temperature of Iran differs is greater from 22°C to 28°C. Cold winter in January mean annual temperature 2°C & minimum temperature -25°C. In summer, hot weather generally daily maximum temperature of more than 55°C has been recorded (Ardalan, 2008). The mean annual, minimum and maximum temperature value in the Iran condition largely differed from the Gereb-segen water shad, ( mean annual temperature of 17.82°C, minimum temperature of 9.03°C and maximum temperature of 27.22°C).
- ❖ The mean annual rainfall of Iran is about 240 mm. Maximum amounts fall on the Alborz and Zagros slopes facing north and west respectively, where the mean annual rainfall is more than 1,200 mm. Going inland, the ranges of precipitation decreases to less than 100 or 50 mm annually. In the northern and western mountains the annual mean precipitation is more than 480 mm, snow forms most of the precipitation (Ardalan, 2008). The mean annual rainfall amount of Iran is lower than the Gereb-segen water shad (mean annual precipitation 497.38 – 660.45 mm) and there is no snowfall in the Gereb- segen watershed.

### **Life Span of the dam**

Dams built to serve for a long time of reliable and safe operation, which monitored for many dams since a long time. The life span of any dam is as long as it is technically safe and operable and it affects by Structural (geologic, hydraulic, and seismic design criteria), monitoring, operational and sedimentation affect (Wieland, 2010). Using the sedimentation affect (considering the rest as negligible) with the MUSLE model estimated sediment yield the life span of Gereb-segen dam is except to be 16.8 years.

Table 4.28: The amount of sediment entering to Gereb-segen dam reservoir

sub watershed	Sediment yield (ton/ha/yr)	Area(ha)	Total sediment yield(ton/yr)
ws - a3	3.891025	78.82	306.6905805
ws - a2	6.162694	84.22	519.0220928
ws - a1	7.179167	95.26	683.8874739
ws - az	8.429676	121.72	1026.060169
ws - ay	9.168809	173.24	1588.404479
ws - ax	6.400817	210.52	1347.499891
ws - aw	13.57161	212.61	2885.459679
ws - av	10.89868	222.1	2420.597221
ws - au	8.525858	259.34	2211.096123
ws - at	7.227639	290.53	2099.845918
ws - as	14.11944	319.04	4504.666729
ws - ar	15.59756	383.43	5980.570803
ws - aq	17.66007	388.29	6857.227201
ws - ap	10.25926	496.27	5091.364309
ws - ao	15.37988	526.04	8090.432574
ws - an	10.83055	623.3	6750.68319
ws - am	13.76585	631.62	8694.788257
ws - al	18.45398	714.27	13181.12572
ws - ak	16.53682	742.59	12280.07896
ws - aj	10.56638	888.29	9386.00965
ws - ai	14.7925	965.49	14282.00993
ws - ah	20.35989	1,012.65	20617.44715
ws - ag	22.37741	1,058.11	23677.76605
ws - af	23.00486	1,703.01	39177.51462
ws - ae	17.48372	2,388.24	41755.31193
ws - ad	22.16453	2,886.14	63969.92571
ws - ac	19.16688	3,477.28	66648.59947
ws - ab	26.44956	7,812.60	206639.841
Total sediment yield (ton/yr)			572,673.9269

Table 4.29: The Life span of Gereb-segen dam

Total volume of sediment per year (ton/yr) entering	Total volume of sediment per year (m <sup>3</sup> /yr) entering ,(a)	Design of dead storage of the dam (m <sup>3</sup> ),(b)	Life span of the dam (year)=b/a
572,673.9269	397,690.227	6,680,000	16.80

## 5 Conclusion and Recommendation

### 5.1 Conclusion

Sedimentation is a serious problem in Ethiopia especially in Tigray region and attempting different methods to evaluate sediment yield. The sedimentation study at the watershed scale is necessary for planning of sedimentation protection and conservation measures, which are necessary for sustainable utilization water and development. The MUSLE, EPM and PSIAC were an empirical models used to estimate mean annual sediment yield at Gereb-segen dam reservoir. MUSLE, EPM and PASIC model in GIS environment were a relatively simple sediment yield estimation methods. GIS With proper selection of digital elevation models satellite imagery indices and appropriate methodology very objective results been achieved. GIS-based sediment yield estimation, minimizes subjective errors of the traditional (classical) estimations, and maximizes the possibilities for different uses and spatial computation. To adopt the MUSLE, EPM and PSIAC models large sets of data starting from rainfall, soil type, slope, land use and land management, soil erosion type, Surface geology, temperature, channel erosion and gully erosion are needed in detail. This paper attempts to estimate sediment yield in Gereb-segen dam reservoir watershed by means of satellite images and geographic information system tools. The mean annual sediment yield of Gereb-segen dam reservoir watershed computed using MUSLE, EPM and PSIAC models. The sediment yield estimated, by MUSLE ranged between 3.89 & 26.45 ton/ha/yr with mean annual sedimentation value of 13.94 ton/ha/yr and EPM estimate sediment yield in the ranged of 5847.39 to 23,895.28 m<sup>3</sup>/km<sup>2</sup>/yr (84.20 to 344.09 ton/ha/yr), with mean annual sedimentation value of 13,476.22 m<sup>3</sup>/km<sup>2</sup>/yr (194.06 ton/ha/yr). PSIAC also estimate the sediment yield from 10.76 to 617.71 m<sup>3</sup>/km<sup>2</sup>/yr (0.16 to 8.90 ton/ha/yr) with the mean annual sedimentation value of 103.86 m<sup>3</sup>/km<sup>2</sup>/yr (1.50 ton/ha/yr).

As they were, compared the three models used to estimate sediment yield of the target area with the observed data, the MUSLE model, is more appropriate sediment yield estimating method, due to 82.06% nearly similar yield estimations with the observed data. However, the EPM and PSIAC models are not appropriate sediment estimation models in the study area.

## 5.2 Recommendation

The finding of the study indicates that the study area is suffer to sedimentation of the dam reservoirs and there is change on the land use land cover trend of the area due to the road construction from Mekelle to Samre and quarry site in the areas. The unsustainable use of resources and the disposal of surface soil from the construction roads around the tributaries' (Appendix figure 7) that facilitates the sedimentation of dam reservoir and influence the life span of the dam and the water supply of the city of Mekelle. The following recommendations forwarded on the finding of the study areas.

- ❖ The MUSLE model was more appropriate sediment estimation model in the target area where as, the EMP and PSIAC models are not appropriate sediment estimation models. Therefore, the EPM and PSIAC sediment estimation models are not advisable estimation models in the target areas and sister watersheds with target area.
- ❖ Based on the results of the study, the areas that have fallen under very high and high sedimentation classes need immediate attention in their order of sediment yield potentials.
- ❖ The physical and biological soil conservation of the watershed should been improved to reduce the reservoir sedimentation problem.
- ❖ Creating awareness, at regional, Woreda, Kebele, and community group leaders concerning sustainable use of natural resources and conservation methods.
- ❖ When there is any, infra structures constructed around the catchment area it should be participate the multi disciplinary, environmentally screened and mitigation majors included. The surface soil excavated from the road construction should be disposed outside the watershed areas or possible mitigation majors should been taken, unless otherwise it continues to influence the reservoir sedimentation.
- ❖ The responsible bodies including the regional administration, Woreda administration, Kebele manager, and the community leaders should incorporate during the soil and water resource conservation and management practices.
- ❖ In order to get accurate sediment yield result gauged station that record sediment yield at the outlet level is important.

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## Appendix

Appendix Table. 1: Gereb-segen watershed area of sub watershed and drainage area

Gereb-segen watershed area and drainage density						
FID	Shape	ID	area_km2	Stream lengt(km)	drainage density= length(km)/Area(km <sup>2</sup> )	Code
0	Polygon	1	34.7728	34.88616	1.003261	ws_ac
1	Polygon	1	7.425907	7.898316	1.063616	ws_ak
2	Polygon	1	0.9526359	1.489465	1.56352	ws_al
3	Polygon	1	2.220919	2.500582	1.125922	ws_av
4	Polygon	1	8.882868	9.202546	1.035988	ws_aj
5	Polygon	1	0.8421696	1.115557	1.324623	ws_a2
6	Polygon	1	4.962665	6.047361	1.218571	ws_ap
7	Polygon	1	6.233034	6.5008	1.042959	ws_an
8	Polygon	1	17.03007	16.996676	0.998039	ws_af
9	Polygon	1	6.316243	5.623807	0.890372	ws_am
10	Polygon	1	2.126067	2.470972	1.162227	ws_aw
11	Polygon	1	3.882857	5.634001	1.450994	ws_aq
12	Polygon	1	2.593401	3.250381	1.253328	ws_au
13	Polygon	1	3.834317	5.323858	1.388476	ws_ar
14	Polygon	1	10.58107	13.377908	1.264324	ws_ag
15	Polygon	1	28.86141	28.906164	1.001551	ws_ad
16	Polygon	1	2.105179	2.843526	1.350729	ws_ax
17	Polygon	1	9.654941	10.323234	1.069218	ws_ai
18	Polygon	1	2.905296	2.711674	0.933356	ws_at
19	Polygon	1	3.190395	3.269674	1.024849	ws_as
20	Polygon	1	1.732401	2.46086	1.420491	ws_ay
21	Polygon	1	23.88237	25.324812	1.060398	ws_ae
22	Polygon	1	7.142657	7.727919	1.081939	ws_al
23	Polygon	1	1.217242	2.264483	1.86034	ws_az
24	Polygon	1	0.7881908	1.00312	1.272687	ws_a3
25	Polygon	1	5.260424	5.175593	0.983874	ws_ao
26	Polygon	1	10.12647	10.200726	1.007333	ws_ah
27	Polygon	0	78.12602	82.136968	1.051339	ws_ab

Appendix Table. 2 : Time of concentration, time to peak and rain fall excess duration of  
Gereb-segen watershed

Gereb segen watershed peak rate discharge													
Sb-Ws	x <sub>1</sub> (m)	X <sub>2</sub> (m)	y <sub>1</sub> (m)	y <sub>2</sub> (m)	z <sub>1</sub> (m)	z <sub>2</sub> (m)	Distance (m)	slope	slope %	L(m)	Tc	D= Tc/6	Tp
ws - a3	557673	558324	1478086	1478845	2195.3	2202.1	999.94	0.007	0.7	399.28	0.039	0.006	0.027
ws - a2	544578	545424	1480415	1480885	1892.8	1926.9	967.79	0.035	3.5	1048.5	0.043	0.007	0.030
ws - a1	543733	544672	1480697	1480885	1888.2	1894.4	957.63	0.007	0.70	921.34	0.076	0.013	0.052
ws - az	557239	557456	1478195	1479062	2196.2	2211.3	893.74	0.017	1.70	1331.04	0.069	0.012	0.047
ws - ay	555612	555504	1478520	1479822	2173.3	2196.9	1306.47	0.018	1.81	908.59	0.050	0.008	0.034
ws - ax	552900	554186	1478629	1480147	2042.4	2215.3	1989.50	0.087	8.70	1824.76	0.047	0.009	0.032
ws - aw	547802	548836	1478629	1479605	1948.3	2019.1	1421.88	0.05	5.00	1025.96	0.037	0.006	0.026
ws - av	544897	543246	1480364	1479713	1893.4	1995.5	1774.71	0.058	5.80	1442.26	0.046	0.008	0.031
ws - au	548778	549912	1477978	1477110	1979.5	2060	1428.07	0.056	5.60	1483.37	0.047	0.008	0.032
ws - at	553009	554334	1478520	1477435	2059.9	2177.3	1712.56	0.068	6.80	1293.9	0.040	0.007	0.027
ws - as	553311	554928	1478412	1476568	2134.5	2259.3	2452.55	0.051	5.10	2289.11	0.069	0.011	0.047
ws - ar	550997	550080	1478056	1479713	1986.3	2066.7	1893.82	0.042	4.20	2630.66	0.082	0.014	0.056
ws - aq	548670	550321	1478415	1480581	1959.7	2083.6	2723.48	0.045	4.50	2767.35	0.083	0.014	0.057
ws - ap	545416	547260	1480147	1481991	1901.6	2068.4	2607.81	0.064	6.40	3687.78	0.091	0.015	0.062
ws - ao	558216	560060	1478195	1480798	2201.8	2316.3	3189.98	0.036	3.60	4172.05	0.125	0.021	0.085
ws - an	546222	548806	1479382	1482294	1916.8	2098.6	3893.17	0.047	4.70	4065.35	0.111	0.018	0.076
ws - am	547368	548344	1478303	1476134	1942.5	2153.2	2378.47	0.089	8.90	3499.56	0.077	0.013	0.053
ws - al	555938	556263	1478195	1476025	2174.2	2277.4	2194.20	0.047	4.70	3472.27	0.098	0.016	0.067
ws - ak	543029	545199	1481991	1482534	1823.2	1961.9	2236.91	0.062	6.20	2786.47	0.074	0.012	0.051
ws - aj	544982	544222	1479822	1475591	1900	2207	4298.72	0.071	7.10	5194.86	0.113	0.019	0.078
ws - ai	553500	553637	1478730	1482765	2060.4	2264.4	4037.32	0.050	5.0	5308.38	0.132	0.022	0.090
ws - ah	558107	557890	1477544	1473205	2209.9	2310.8	4344.42	0.023	2.30	5256.61	0.177	0.029	0.121
ws - ag	550948	551382	1478086	1482859	1983.3	2266.6	4792.69	0.059	5.90	5425.28	0.126	0.021	0.086
ws - af	544524	541260	1479279	1474398	1919.1	2193.6	5871.78	0.047	4.70	6369.15	0.156	0.026	0.107
ws - ae	555133	540766	1478491	1483278	2175.5	2257.7	15143.51	0.005	0.54	8486.53	0.447	0.074	0.305
ws - ad	550839	554033	1481761	1472771	2011.8	2132.8	9540.53	0.013	1.30	8650.64	0.327	0.055	0.223
ws - ac	558324	560006	1478652	1472771	2199.8	2206.2	6116.80	0.001	0.10	7412.79	0.759	0.126	0.519
ws - ab	540944	545439	1482232	1471295	1832.4	2026	11824.68	0.016	1.60	16356.38	0.484	0.081	0.331

Appendix Table. 3: Gereb-segen watershed slope length

Greb-segen Watershed slope length												
Su_Ws	x <sub>1</sub>	x <sub>2</sub>	y <sub>1</sub>	y <sub>2</sub>	z <sub>1</sub>	z <sub>2</sub>	slope length(m)	Distance (m)	slope	Θ	L-factor	S-factor
ws - a3	558054	558113	1478969	1478973	2219	2248.1	66.13	59.14	0.501	0.463	1.7287	6.9966
ws - a2	545787	545846	1481100	1481108	1953	1991	70.52	59.54	0.635	0.561	1.7852	8.4438
ws - a1	544660	544722	1481039	1481045	1913	1975.8	88.45	62.29	1.008	0.765	1.9992	11.135
ws - az	557209	557210	1478461	1478514	2199	2225	59.04	53.01	0.49	0.455	1.6334	6.8769
ws - ay	554714	554778	1478483	1478487	2133	2182.2	80.82	64.12	0.767	0.645	1.6789	6.5258
ws - ax	552839	552846	1478677	1478763	2035	2075.7	95.40	86.28	0.472	0.44	2.0763	6.6492
ws - aw	547700	547761	1478569	1478571	1938	1963.4	66.11	61.03	0.416	0.394	1.7284	5.9446
ws - av	543362	543429	1479590	1479639	1981	2005	86.32	83.01	0.286	0.278	1.975	4.1106
ws - au	549450	549545	1476663	1476676	2098	2135	102.78	95.88	0.386	0.368	2.155	5.5407
ws - at	553190	553276	1477564	1477617	2167	2182	102.11	101.02	0.147	0.146	2.1481	1.9513
ws - as	554560	554652	1477154	1477171	2220	2254.2	99.61	93.56	0.366	0.35	2.1216	5.2622
ws - ar	550168	550180	1479508	1479587	2023	2055.8	86.38	79.91	0.41	0.389	1.9756	5.8698
ws - aq	549176	549267	1479933	1479936	2035	2074	98.89	91.05	0.424	0.4	2.1139	6.0461
ws - ap	547177	547243	1481963	1482072	2066	2091.8	129.93	127.42	0.199	0.197	2.4231	2.7839
ws - ao	560212	560224	1480382	1480445	2344	2359.5	65.98	64.13	0.242	0.237	1.7267	3.4459
ws - an	548654	548753	1480625	1480704	2116	2154	132.15	126.66	0.298	0.289	2.4437	4.2905
ws - am	547753	547757	1476885	1476940	2060	2072	56.54	55.14	0.227	0.223	1.5985	3.2133
ws - al	555580	555624	1476072	1476136	2246	2260.5	79.01	77.67	0.187	0.185	1.8895	2.583
ws - ak	545396	545482	1482330	1482337	1961	1972.4	87.03	86.28	0.132	0.131	1.9831	1.7005
ws - aj	544182	544222	1474786	1474859	2341	2353	84.09	83.24	0.143	0.142	1.9493	1.8775
ws - ai	553832	553887	1482008	1482012	2277	2284	55.64	55.14	0.134	0.133	1.5856	1.7343
ws - ah	557452	557456	1473935	1473986	2291	2303.1	52.57	51.16	0.237	0.232	1.5412	3.3662
ws - ag	552480	552487	1481466	1481549	2264	2275.4	84.07	83.29	0.137	0.136	1.9491	1.778
ws - af	547382	547395	1473843	1473900	2368	2378.3	59.36	58.46	0.176	0.174	1.6378	2.4147
ws - ae	556801	556865	1482013	1482077	2269	2277.6	90.92	90.51	0.095	0.095	2.0269	1.0891
ws - ad	554017	554031	1473521	1473614	2212	2224.7	94.90	94.05	0.135	0.134	2.0708	1.7482
ws - ac	561293	561266	1473655	1473668	2262	2268.4	30.64	29.97	0.214	0.21	1.1767	3.0084
ws - ab	541045	541188	1476418	1476465	2119	2122	150.56	150.53	0.023	0.023	2.6084	0.2739

$$\text{Slope length} = ((x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2)^{0.5}$$

$$\text{Slope} = (z_2-z_1)/((x_2-x_1)^2+(y_2-y_1)^2)^{0.5}$$

$$\text{L-factor} = (\lambda/22.13)^m$$

m = 0.5 for slope >5%, 0.4 for slope 3-4%, 0.3 for slope 1-3%, 0.2 for < slope

S=10.8sinθ +0.03 for slope <0.09

S =16.8sinθ-0.5 for slope >0.09

Appendix Table. 4: Land use and its curve number values of Gereb-segen Sub watershed

land use ws ay hydrologic soil group –C			
Land use type	Area-ha	CN	CN*Land-use
Cultivated_Land	9.193215	83	763.036845
wood-land	4.144229	73	302.528717
bush-land	159.902	70	11193.14
Total	173.240068		12258.70556
	CN		70.76163072

land use ws a2 hydrologic soil group -B			
Land use type	Area- ha	CN	CN*Land-use
Cultivated_Land	54.70213	75	4102.65975
Bare Land	5.749918	69	396.744342
Bush_Land	23.764913	56	1330.835128
Total	84.216961		5830.23922
	CN		69.22880084

land use ws az hydrologic soil group –C			
Land use type	Area-ha	CN	CN*Land-use
Cultivated_Land	103.356253	83	8578.568999
Bush_Land	18.367924	70	1285.75468
Total	121.724177		9864.323679
	CN		81.03832716

land use ws ax hydrologic soil group –B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	149.519	56	8373.064
Cultivated_Land	61.00008	75	4575.006
Total	210.517937		12948.07
	CN		61.50544644

land use ws as hydrologic soil group –B			
Land use type	Area-ha	CN	CN*Land-use
Cultivated_Land	222.24184	75	16668.138
wood-land	18.439499	60	1106.36994
Bush_Land	78.358123	56	4388.054888
Total	319.039462		22162.56283
	CN		69.4665252

land use ws a1 hydrologic soil group –B			
Land use type	Area-ha	CN	CN*Land-use
Cultivated_Land	90.491324	75	6786.8493
Bush_Land	1.946433	56	109.000248
Water-body	2.825832	100	282.5832
Total	95.263589		7178.432748
	CN		75.35337292

land use ws ad hydrologic soil group –B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	954.578841	56	53456.4151
wood-land	105.8152	60	6348.912
Bare_Land	244.2409	69	16852.6221
Cultivated_Land	1581.506	75	118612.95
Total	2886.140941		195270.8992
	CN		67.65813007

land use ws aq hydrologic soil group -B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	135.809978	56	7605.358768
wood-land	24.5761	60	1474.566
Bare_Land	37.9816	69	2620.7304
Cultivated_Land	189.918	75	14243.85
Total	388.285678		25944.50517
	CN		66.81808431

land use ws at hydrologic soil group –B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	38.4806	56	2154.9136
Cultivated_Land	252.049	75	18903.675
Total	290.5296		21058.5886
	CN		72.48345298

land use ws ag hydrologic soil group –C			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	400.3954	70	28027.678
Cultivated_Land	657.7119	83	54590.0877
Total	1058.1073		82617.7657
	CN		78.08070665

land use_ws_aw hydrologic soil group -B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	12.4724	56	698.4544
wood-land	48.1002	60	2886.012
Bare_Land	102.4512	69	7069.1328
Cultivated_Land	49.5829	75	3718.7175
Total	212.6067		14372.3167
	CN		67.60048813

land use_ws_an hydrologic soil group -B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	286.0236261	56	16017.32306
Wood-land	127.3158401	60	7638.950406
Bare_Land	70.67272022	69	4876.417695
Cultivated_Land	139.2912016	75	10446.84012
Total	623.303388		38979.53128
	CN		62.53701172

land use_ws_af hydrologic soil group -C			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	336.235011	56	18829.16062
wood-land	64.5936	60	3875.616
bare-land	90.9874	69	6278.1306
Cultivated_Land	1211.1914	75	90839.355
Total	1703.007411		119822.2622
	CN		70.35921361

land use_ws_ah hydrologic soil group -C			
Land use type	Area-ha	CN	CN*Land-use
Wood-land	95.6109525	73	6979.599533
Bare_Land	48.37937443	79	3821.97058
Cultivated_Land	836.909685	83	69463.50385
Water body	31.74726893	100	3174.726893
Total	1012.647281		83439.80086
	CN		82.39769408

land use_ws_ar hydrologic soil group -B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	151.345317	56	8475.337752
Cultivated_Land	232.0864	75	17406.48
Total	383.431717		25881.81775
	CN		67.50046124

land use_ws_av hydrologic soil group -B			
Land use type	Area-ha	CN	CN*Land-use
Cultivated_Land	180.6658622	75	13549.93966
Bush_Land	41.42605046	69	2858.397482
Total	222.0919126		16408.33714
	CN		73.88084037

land use_ws_au hydrologic soil group -B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	172.1613	56	9641.0328
Cultivated_Land	87.1788	75	6538.41
Total	259.3401		16179.4428
	CN		62.38696908

land use_ws_a3 hydrologic soil group -C			
Land use type	Area-ha	CN	CN*Land-use
Cultivated_Land	78.819075	83	6541.983225
	CN		83

land use_ws_am hydrologic soil group -B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	164.24383	56	9197.65448
wood-land	12.7533	60	765.198
Cultivated_Land	454.6272	75	34097.04
Total	631.62433		44059.89248
	CN		69.75648402

land use_ws_ao hydrologic soil group -C			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	40.5863203	70	2841.042421
wood-land	125.8653976	73	9188.174022
Cultivated_Land	359.5906502	83	29846.02396
Total	526.042368		41875.24041
	CN		79.60431127

land use_ws_ak_hydrologic_soil_group -B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	109.4990365	56	6131.946046
Bare_Land	245.0726035	69	16910.00964
Cultivated_Land	325.7770083	75	24433.27562
Water-bady	62.24210052	100	6224.210052
Total	742.5907488		53699.44136
	CN		72.31364173

land use_ws_ac_hydrologic_soil_group -C			
Land use type	Area-ha	CN	CN*Land-use
wood-land	168.932	73	12332.03239
Bare_Land	55.44131	79	4379.863639
Cultivated_Land	3209.69	83	266453.1815
Water-bady	43.21351	100	4321.351
Total	3477.276		287486.4287
	CN		82.67574613

land use_ws_ai_hydrologic_soil_group -C			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	319.0213462	70	22331.49423
wood-land	130.2694327	73	9509.668587
Bare_Land	1.45039699	79	114.5813622
Cultivated_Land	514.7528762	83	42724.48872
Total	965.4940521		74680.23291
	CN		77.34924182

land use_ws_ae_hydrologic_soil_group -C			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	162.1418054	70	11349.92638
wood-land	90.54290189	73	6609.631838
Bare-land	11.49770359	79	908.3185836
Cultivated_Land	2018.610174	83	167544.6444
Grazing -land	105.5002759	79	8334.521796
Total	2388.237495		194747.043
	CN		81.54236285

land use_ws_ab_hydrologic_soil_group -C			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	1575.018209	70	110251.2746
wood-land	495.3992445	73	36164.14485
Bare_Land	137.3391503	79	10849.79287
Cultivated_Land	5244.141774	83	435263.7672
Water-body	57.76453881	100	5776.453881
Grazing-land	302.9391964	79	23932.19651
Total	7812.602113		622237.63
	CN		79.64537564

land use_ws_ap_hydrologic_soil_group -B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	189.6118941	56	10618.26607
Wood-land	30.52314062	60	1831.388437
Bare_Land	114.9204595	69	7929.511706
Cultivated_Land	161.2110392	75	12090.82794
Total	496.2665334		32469.99415
	CN		65.42853883

land use_ws_al_hydrologic_soil_group -C			
Land use type	Area-ha	CN	CN*Land-use
wood-land	90.64313291	73	6616.948702
bush-land	4.1262042	70	288.834294
Cultivated_Land	619.4963249	83	51418.19497
Total	714.265662		58323.97796
	CN		81.65586149

land use_ws_aj_hydrologic_soil_group -B			
Land use type	Area-ha	CN	CN*Land-use
Bush_Land	358.3642556	56	20068.39831
Wood-land	0.43325482	60	25.9952892
Cultivated_Land	529.4893239	75	39711.69929
Total	888.2868344		59806.0929
	CN		67.32745616

Appendix Table. 5: Soil type and soil erodibility (K) factor values of Gereb-segen Sub watershed

soil_ws_aj			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Lithosols	539.149	0.22	118.6128
Eutric Cambisols	283.715	0.25	70.92875
Vertic Cambisols	65.367	0.225	14.70758
Total	888.231		204.2491
	k-factor		0.22995

soil_ws_ab			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Lithosols	2379.61	0.22	523.5142
Eutric Cambisols	290.308	0.25	72.577
Vertic Cambisols	5142.19	0.225	1156.993
Total	7812.602		1753.084
	k-factor		0.224406

soil_ws_av			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Lithosols	29.528	0.22	6.49616
Eutric Cambisols	192.55	0.25	48.1375
Total	222.09		54.63366
	k-factor		0.246011

soil_ws_a2			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Calcic Cambisols	15.202	0.2	3.0404
Eutric Cambisols	69.009	0.25	17.25225
Total	84.211		20.29265
	k-factor		0.240974

soil_ws_ap			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Calcic Cambisols	280.61	0.2	56.122
Eutric Cambisols	215.626	0.25	53.9065
Total	496.266		110.0285
	k-factor		0.221726

soil_ws_af			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Lithosols	1293.06	0.22	284.4732
Eutric Cambisols	409.844	0.25	102.461
Total	1703.007		386.9342
	k-factor		0.22722

soil_ws_aq			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Calcic Cambisols	81.77	0.2	16.354
Eutric Cambisols	306.492	0.25	76.623
Tota	388.28		92.977
	k-factor		0.23947

soil_ws_au			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Lithosols	152.568	0.22	33.56496
Eutric Cambisols	106.756	0.25	26.689
Total	259.34		60.25396
	k-factor		0.23235

soil_ws_am			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Lithosols	359.366	0.22	79.06052
Eutric Cambisols	272.218	0.25	68.0545
Total	631.624		147.115
	k-factor		0.23293

soil_ws_aw			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Calcic Cambisols	1.293	0.2	0.258
Eutric Cambisols	211.314	0.25	52.826
Total	212.607		53.084
	k-factor		0.249697

soil_ws_ay		
MAJOR_SOIL	Area-ha	k-factor
Vertic Cambisols	173.24	0.225

soil_ws_ae		
MAJOR_SOIL	Area-ha	k-factor
Vertic Cambisols	2388.24	0.225

soil_ws_ax			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Vertic Cambisols	78.223	0.225	17.60018
Lithosols	132.282	0.22	29.10204
Total	210.51		46.70222
	k-factor		0.221858

soil_ws_ai			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Vertic Cambisols	874.968	0.225	196.8678
Lithosols	90.465	0.22	19.9023
Total	965.49		216.7701
	k-factor		0.224531

soil_ws_ar			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Lithosols	53.623	0.22	11.79706
Calcic Cambisols	82.419	0.2	16.4838
Eutric Cambisols	247.365	0.25	61.84125
Tota	383.43		90.12211
	k-factor		0.235056

soil_ws_ad			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Vertic Cambisols	1005.33	0.225	226.1993
Lithosols	1816.24	0.22	399.5728
Eutric Cambisols	64.388	0.25	16.097
Total	2886.14		641.8691
	k-factor		0.222411

soil_ws_as			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Vertic Cambisols	75.262	0.225	16.93395
Lithosols	243.758	0.22	53.62676
Total	319.04		70.56071
	k-factor		0.22118

soil_ws_al			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Vertic Cambisols	698.98	0.225	157.2705
Lithosols	15.241	0.22	3.35302
Total	714.27		160.6235
	k-factor		0.224893

soil_ws_ak			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Calcic Cambisols	466.616	0.2	93.3232
Eutric Cambisols	275.928	0.25	68.982
Total	742.59		162.3052
	k-factor		0.21858

soil_ws_ac			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Vertic Cambisols	3308.8796	0.225	744.498
Rendzinas	168.3969	0.3	50.5191
Total	3477.2765		795.017
	k-factor		0.22863

soil_ws_at		
MAJOR_SOIL	Area-ha	k-factor
Lithosols	290.53	0.22

soil_ws_al		
MAJOR_SOIL	Area-ha	k-factor
Eutric Cambisols	95.26	0.25

soil_ws_az		
MAJOR_SOIL	Area-ha	k-factor
Vertic Cambisols	121.72	0.225

soil_ws_a3		
MAJOR_SOIL	Area-ha	k-factor
Vertic Cambisols	78.82	0.225

soil_ws_ao		
MAJOR_SOIL	Area-ha	k-factor
Vertic Cambisols	526.04	0.225

soil_ws_an			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Calcic Cambisols	354	0.2	70.8
Eutric Cambisols	269.264	0.25	67.316
Total	623.30		138.116
	k-factor		0.221601

soil_ws_ag			
MAJOR_SOIL	Area-ha	k-factor	K*A(ha)
Vertic Cambisols	600.964	0.225	135.2169
Lithosols	178.439	0.22	39.25658
Calcic Cambisols	210.523	0.2	42.1046
Eutric Cambisols	68.115	0.25	17.02875
Total	1058.107		233.6068
	k-factor		0.220792

soil_ws_ah		
MAJOR_SOIL	Area-ha	k-factor
Vertic Cambisols	1012.65	0.225

Appendix Table. 6 :Surface geology of Gereb-segen sub watershed

sub watrshed of _ac Geological rock type			
FID	Shape *	Rock_type	Area__ha
0	Polygon	Andesine dolerite(Mekele dolerite)	1166.993694
1	Polygon	Marl intebeded withcoquina	4.773842
2	Polygon	Marl and shale (Agula shale )	2088.34817
		Total	3260.115706

sub watrshed of _a1 Geological rock type			
FID	Shape *	Rock_type	Area__ha
0	Polygon	Finely crystalline limestone	0.92256
1	Polygon	Marl intebeded withcoquina	38.681896
2	Polygon	coquina,Oolitic limestone and Marl	55.659133
		Total	95.263589

sub watrshed of _ai Geological rock type			
FID	Shape *	Rock_type	Area__ha
0	Polygon	Marl and shale (Agula shale )	965.494052

sub watrshed of _ab Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	3032.792411
1	Polygon	Marl intebeded withcoquina	2325.494117
2	Polygon	Marl and shale (Agula shale )	2454.315586
		Total	7812.602114

sub watrshed of _ag Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	276.333663
1	Polygon	Finely crystalline limestone	25.729962
2	Polygon	Marl intebeded withcoquina	106.07067
3	Polygon	Marl and shale (Agula shale )	649.973048
		Total	1058.107343

sub watrshed of _ah Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	147.587399
1	Polygon	Finely crystalline limestone	51.58916
2	Polygon	Marl intebeded withcoquina	425.411589
3	Polygon	Marl and shale (Agula shale )	388.059133
		Total	1012.647281

sub watrshed of _ak Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Finely crystalline	296.098813
1	Polygon	Marl intebeded withcoquina	292.411841
2	Polygon	coquina,Oolitic limestone and Marl	104.269837
3	Polygon	Marl and shale (Agula shale )	49.810258
		Total	742.590749

sub watrshed of _aj Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	46.508864
1	Polygon	Marl intebeded withcoquina	678.433148
2	Polygon	Marl and shale (Agula shale )	163.344822
		Total	888.286834

sub watrshed of _af Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	289.420235
1	Polygon	Marl intebeded withcoquina	940.962972
2	Polygon	Marl and shale (Agula shale )	472.624204
		Total	1703.007411

sub watrshed of _al Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	65.884361
1	Polygon	Marl intebeded withcoquina	208.761154
2	Polygon	Marl and shale (Agula shale )	439.620147
		Total	714.265662

sub watrshed of _au Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Marl intebeded withcoquina	258.710167
1	Polygon	coquina,Oolitic limestone and Marl	0.625602
2	Polygon	Marl and shale (Agula shale )	0.004342
		Total	259.340111

sub watrshed of _av Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Marl intebeded withcoquina	222.091913

sub watrshed of _az Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	63.232626
1	Polygon	Marl and shale (Agula shale )	58.491551
		Total	121.724177

sub watrshed of ar Geological rock type			
FID	Shape *	Rock type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	180.639821
1	Polygon	Finely crystalline limestone	81.625236
2	Polygon	Marl intebeded withcoquina	36.69153
3	Polygon	coquina,Oolitic limestone and Marl	2.091302
4	Polygon	Marl and shale (Agula shale )	82.383828
		Total	383.431717

sub watrshed of ad Geological rock type			
FID	Shape *	Rock type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	7.713626
1	Polygon	coquina,Oolitic limestone and Marl	18.744237
2	Polygon	Finely crystalline limestone	386.702807
3	Polygon	Marl and shale (Agula shale )	802.599466
4	Polygon	Marl intebeded withcoquina	1670.80805
		Total	2886.568186

sub watrshed of ap Geological rock type			
FID	Shape *	Rock type	Area ha
0	Polygon	Finely crystalline limestone	372.009899
1	Polygon	Marl intebeded withcoquina	55.921261
2	Polygon	coquina,Oolitic limestone and Marl	68.335373
		Total	496.266533

sub watrshed of aq Geological rock type			
FID	Shape *	Rock type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	18.838682
1	Polygon	Finely crystalline limestone	128.639885
2	Polygon	Marl intebeded withcoquina	194.167519
3	Polygon	coquina,Oolitic limestone and Marl	46.639592
		Total	388.285678

sub watrshed of as Geological rock type			
FID	Shape *	Rock type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	0.341197
1	Polygon	Finely crystalline limestone	34.633816
2	Polygon	Marl intebeded withcoquina	260.088744
3	Polygon	Marl and shale (Agula shale )	23.975705
		Total	319.039462

sub watrshed of am Geological rock type			
FID	Shape *	Rock type	Area ha
0	Polygon	Marl intebeded withcoquina	619.003037
1	Polygon	Marl and shale (Agula shale )	12.621293
		Total	631.62433

sub watrshed of at Geological rock type			
FID	Shape *	Rock type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	63.251812
1	Polygon	Finely crystalline limestone	108.698916
2	Polygon	Marl intebeded withcoquina	92.965892
3	Polygon	Marl and shale (Agula shale )	25.612958
		Total	290.529578

sub watrshed of an Geological rock type			
FID	Shape *	Rock type	Area ha
0	Polygon	Finely crystalline limestone	324.980526
1	Polygon	Marl intebeded withcoquina	230.939147
2	Polygon	coquina,Oolitic limestone and Marl	67.383715
		Total	623.303388

sub watrshed of _ao Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	189.62316
1	Polygon	Marl and shale (Agula shale )	336.419208
		Total	526.042368

sub watrshed of _ae Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	451.170036
1	Polygon	Marl and shale (Agula shale )	1937.067459
		Total	2388.237495

sub watrshed of _ax Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	6.134876
1	Polygon	Marl and shale (Agula shale )	204.383061
		Total	210.517937

sub watrshed of _a3 Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Andesine dolerite(Mekele dolerite)	34.048277
1	Polygon	Marl and shale (Agula shale )	44.770798
		Total	78.819075

sub watrshed of _a2 Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Finely crystalline limestone	49.351065
1	Polygon	Marl intebeded withcoquina	9.952255
2	Polygon	coquina,Oolitic limestone and Marl	24.91364
		Total	84.21696

sub watrshed of _ay Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Marl and shale (Agula shale )	173.240068

sub watrshed of _aw Geological rock type			
FID	Shape *	Rock_type	Area ha
0	Polygon	Finely crystalline limestone	104.733824
1	Polygon	Marl intebeded withcoquina	56.698963
2	Polygon	coquina,Oolitic limestone and Marl	51.173955
		Total	212.606742

Appendix Table. 7: Monthly and annual rainfall data of Adigudom station

Station	Adigudom monthly total rain fall (mm)												annual RF	max manthly RF	
	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov			Dec
1997	0	0	18.9	43	0	11	184	107.7	0	48.5	3.2	0	416.3	30.4	
1998	0	0	0	8.4	34.4	10.4	280	674.6	95.7	0	0	0	1103.5	80.5	
1999	0	0	0	0	0	3.4	244	286.5	20.3	0	0	0	553.9	40.8	
2000	0	0	0	19.6	41.5	40.1	167	187.3	0	0	3.2	0	458.6	30.4	
2001	0	0	40.5	31.6	0	36.4	347	169	0	0	0	0	624.1	52.6	
2002	0	0	5.5	0	0	21.8	65.3	134.2	49.7	0	0	10.2	286.7	40.3	
2003	0	16	4.4	17.6	0	11.3	128	230	0	0	0	7.5	415.1	26.2	
2004	3.2	0	7.5	12.5	6.2	27.6	38.3	145.9	0	0	0	0	241.2	22.8	
2005	4.1	0	7.3	16	27.4	23.9	81.6	138.9	42.5	2.1	0	0	343.8	22.9	
2006	0	0	32.6	25.9	26.5	28.4	152	285.6	79.2	0	0	0	630	50.2	
2007	4.2	0	0	9.3	2.5	23.3	275	212.9	57	0	0	0	584.6	40.3	
2008	6.8	0	0	0	6.4	3.2	74.3	98.3	73.8	0	20.4	0	283.2	20.8	
2009	0	0	6.4	8.2	0	9.5	180	160.3	5.4	6.4	3.1	2.4	381.6	40.8	
2010	2.2	0	0	15.9	0	0	101	219.1	61.4	0	0	0	399.5	40.4	
2011	0.0	0.0	8.3	4.2	27.8	27.8	132.5	171.4	41.1	3.1	11.7	0	427.9	30.4	
2012	0.0	0.0	2.1	8.4	6.4	36.8	280.4	292.1	12.5	0.0	0.0	0.0	638.7	64.5	
2013	0.0	0.0	0.0	3.2	0.0	31.5	151.2	301.3	260.4	6.3	5.3	0.0	759.15	46.7	
2014	0.0	5.3	25.0	8.5	26.3	0.0	57.3	158.2	43.3	4.2	0.0	0.0	328.1	43.5	
2015	0.0	0.0	10.2	0.0	35.0	54.6	19.4	323.8	39.5	0.0	0.0	0.0	482.5	33.6	
2016	2.1	0.0	13.6	54.4	38.8	19.8	224.4	219.0	17.1	0.0	0.0	0.0	589.2	45.3	
													Sum	9947.65	80.5
													Men	497.3825	

Appendix Table. 8 :The correction factors for Adigudom rainfall station

correction factors for Adigudom rainfall station taking reading from the old graph station			
Year	M	M	Correction factor (R )
1998	400	600	0.667
2012	400	500	0.80
2013	400	550	0.7273
2014	500	300	1.67

Appendix Table. 9: Monthly and annual rainfall data of Aynalem station

<i>Station</i>	<i>Aynalem monthly total rain fall (mm)</i>												annual RF	max manthly RF
<i>Year</i>	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>		
1997	0	0	24.9	59	25.2	52.2	200	95.3	5.7	32.9	17.3	0	512.8	24.1
1998	7.6	0	0	21.1	24.3	34.7	285	253.7	30.2	13.3	0	0	669.4	35.6
1999	21	0.3	0	0	0	8.2	253	480.7	42.6	0	0	0.6	805.9	61
2000	0	0	9.9	12.7	13.1	24.9	190	175.5	10.4	0	8.8	0.8	446.4	45.4
2001	0	0	24.7	10.7	10.2	34.1	207	246	16.1	4.7	0	3.2	557	21.9
2002	0	4.5	31.5	1.6	7.8	35.7	117	187.4	27.8	0	0	9.3	422.7	32.9
2003	0	35	9.6	6.4	10.1	56.7	134	177.4	15.6	0	0	0.3	445.7	40
2004	6.7	0	24.4	38.7	0	18.9	48.5	208.6	0	0	0	0	345.8	24.6
2005	0	1.8	19.6	46.5	21.7	28.1	155	277.1	26.8	0	2.6	0	579.2	33.2
2006	0	0	30.7	152	35.8	16.3	176	206	21	4.6	0	0	641.6	102.8
2007	0	6	7.7	18.9	10.7	43.7	217	133.5	90.5	0	0	0	528.3	40.1
2008	12	0	0	24.2	6.9	14.5	130	0	52.5	1.3	4.3	0	245.2	33.2
2009	0	0	7.2	4.1	0	8.1	175	196.5	2.6	3.7	1.4	0	398.9	37.5
2010	0	0	12.4	52.4	30.2	14.2	142	305.5	0	0	0	0	556.6	40.1
2011	0	1.4	42.6	0	23.3	37.3	199	139.3	21	0	3.7	0	467.9	52.5
2012	0.0	0.0	2.3	29.9	43.1	52.1	172.7	203.9	37.5	14.5	4.0	0.0	560	39.6
2013	0.0	0.0	30.8	24.3	0.0	15.5	161.4	159.4	0.0	0.0	0.0	0.0	391.4	34.8
2014	0.0	0.0	53.1	42.6	49.3	10.1	163.3	290.5	91.3	8.0	23.1	0.0	731.3	64.1
2015	0.0	0.0	34.0	0.0	36.1	31.0	92.1	160.5	6.5	0.0	0.0	9.3	369.5	28.9
2016	0.0	0.0	35.6	77.9	66.9	39.4	291.4	166.0	0.0	0.0	0.0	0.0	677.2	37.3
												Sum	10352.8	102.8
												Men	517.64	

Appendix Table. 10 : Monthly and annual rainfall data of Dengolat station

Station	<i>DENGOLLAT monthly total rain fall (mm)</i>												annual RF	max manthly RF	
	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov			Dec
1997	0	0	27.6	61.1	27.5	45.6	270	160.1	12.7	42.5	24.9	0	671.5	82.5	
1998	0	0	13	45.9	30	22.5	294	348.1	65.9	0	0	0	819.8	44.5	
1999	19	0	3.4	14.4	0	18.7	312	344.9	15.6	0	0	0	727.7	41.1	
2000	0	0	6.2	16	58.6	33.9	243	235.7	49.2	0	2.7	0	644.8	35.2	
2001	0	0	31	14.5	34.8	96.8	339	258.5	11.6	0	0	0	785.7	61.1	
2002	0	1.3	114	5.9	0	39	153	195.3	29.3	0	0	4.1	542	68.3	
2003	0	14	6.6	51.1	2.9	123.5	104	199.6	65.8	0	0	1.2	568.8	48	
2004	6.6	0	12.1	21.9	6.9	89.2	163	208.6	1.6	6.5	0	0	516.8	46.5	
2005	1.9	14	23.2	54.9	14.1	70.4	235	305.6	13.6	0	0	0	731.9	46.9	
2006	0	0	62.5	57.9	61.8	39.8	118	333.7	75.2	13.4	2.6	0	764.8	63.2	
2007	0	5	19	34.6	14.3	35.6	314	247.5	99.1	0	0	0	769.3	59.6	
2008	18	0	0	19.7	26	31.3	133	201.8	54	2.2	21.6	0	507.4	32	
2009	0	0	19.9	9.6	12.9	31.8	298	238.4	64.3	17.5	0	16.4	708.5	47.4	
2010	0.6	0	11.2	26.1	35.5	105.3	245	395.1	16.2	0	0	0	834.9	45.5	
2011	0	23	55.5	88.3	40.6	33.2	132	190.5	94	10.8	0	0.9	668.8	49.5	
2012	0	0	60.4	66.7	46.7	122.6	299	318.7	67.8	9.9	0	0	991.7	49.5	
2013	0	0	3.8	40.6	0	40.6	126	300.1	81.9	32.3	0	0	625.2	43.6	
2014	0	0	78.1	0	44.8	18.7	211	278.4	125.3	0	9.9	1.4	767.5	34.1	
2015	0	0	49.6	0	25.8	38.6	155	229.7	25.2	0	7	49.8	580.6	54.7	
2016	0	0	0	0	0	61	348	236.8	0	4.6	0	0	650	47.4	
													Sum	13208.9	Mxa = 82.5
													Men	660.445	

Appendix Table. 11 ; Monthly and annual rainfall data of Mekelle station

Station	Mekelle (AP) monthly total rain fall (mm)												Annual RF	max manthly RF
	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov		
1997	0	0	20.4	32.6	29.8	32.4	243.1	100.5	16.3	59.9	15.7	0	550.83	44.4
1998	10	1.2	0	10.6	22.0	48.0	289.0	318.8	31.71	22	0	0	753.43	43
1999	22	0.3	10.9	0.0	0.0	7.5	293.6	359.2	22.82	0.9	0	0	717.22	52.9
2000	0	0	0	10.4	24.6	5.4	201	182	15.8	2.2	10.3	3.5	455.6	59.2
2001	0	0	38.1	18.7	8.7	65.5	268	226.3	9.2	2.9	0	0	637.3	35.7
2002	13	0	35.5	4.2	23	60.8	95.5	208.6	28	0	0	0.3	468.8	41.2
2003	0	26	18.2	8.4	35.2	87.5	126	201.8	23.4	0.7	0	0.1	526.8	41.1
2004	7.4	3.7	35.2	20.5	7.1	25.4	64.3	221.1	1.4	3.1	0.8	0	390	39.8
2005	0	1.4	15.6	48.9	55.1	18.2	111	314	34.3	0	1.3	0	599.3	44.7
2006	0	0	31.3	118	46.3	38.1	187	298.9	23.6	12	0	0.3	755.2	74.9
2007	1.1	2.3	11.2	34.5	22.2	57.1	273	139.7	78.6	0	0	0	619.3	59.6
2008	7.5	0	0	23.9	5.9	13	94.1	103.3	27.4	7.7	4.1	0	286.9	23
2009	0	0	23.6	8.4	0.8	3.9	192	158.8	3.7	17.8	5.6	2.6	416.8	56
2010	0	0	31.3	67.3	13.9	35.1	221	256.3	42.7	2.7	0	0	670.5	37.2
2011	0	2.5	19.3	16.8	32.3	45.1	237	124.3	19.9	0	33.4	0	530.8	58.5
2012.0	0.0	0.0	3.4	17.8	37.4	45.9	166.5	187.1	53.9	0.0	0.0	0.0	512	54.3
2013.0	0.3	0.0	39.1	14.0	0.0	12.7	1.4	151.8	19.2	1.4	6.9	0.0	246.8	26.4
2014.0	0.0	5.0	44.5	61.2	30.9	12.8	198.7	249.0	67.3	0.0	0.0	0.0	669.4	36.8
2015.0	0.0	0.0	23.7	0.0	28.5	12.8	199.7	213.9	7.0	0.0	0.6	13.9	500.1	49.6
2016.0	0.0	0.0	24.2	65.5	41.1	49.1	352.6	175.3	40.1	0.0	0.0	0.3	748.2	69.7
												sum	11055.28	74.90
												men	552.764	74.90

Appendix Table. 12: Maximum and Minimum Mean Monthly Temperature (<sup>0</sup>C)

Maximum and Minimum Mean Monthly Temperature ( <sup>0</sup> C)													
Station	Tempe.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mekelle	Maximum	23.22	24.94	25.41	26.31	23.19	27.23	23.82	22.96	24.17	22.26	23.06	22.20
	Minimum	9.32	10.20	12.14	13.21	13.54	13.22	12.81	12.99	11.44	10.64	10.30	9.03

Appendix Table. 13: Runoff curve number for hydrological soil cover complexes (for catchment condition II and Ia=0.2S )























































Land use	Cover		Hydrological soil groupe			
	Treatment practice	Or hydrological condition	A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row crop	-	Poor	72	81	88	91
		Good	67	78	85	89
	Conture	Poor	70	79	84	88
		Good	65	75	82	86
	Conture and terraced	Poor	66	74	80	82
		Good	62	71	78	81
Small	Straight row	Poor	65	76	84	88
		Good	63	75	84	87
	Conture	Poor	63	74	82	85
		Good	61	73	81	84
	Conture and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded Legumes or Rotation meadow	Straight row	Poor	66	77	85	89
		Good	58	72	81	85
	Conture	Poor	64	75	83	85
		Good	55	69	78	83
	Conture and terraced	Poor	63	73	80	83
		Good	51	67	76	80
Pasture or Range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Conture	Poor	47	67	81	88
		Fair	25	59	75	83
		Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farm steads		-	59	74	82	86
Roads(dirt)		-	72	82	87	89
Roads (hard surface)		-	74	84	90	92

after US soil conservation service,1964 ( Antecedent moisture content II and Ia =0.2S ) in the Federal Democratic Republic of Ethiopia Ministry of Water resources (2002) developed guideline manual.

Appendix Table. 14: Weight conservation using the United Kingdom(wave site  
m.littlerbulkhaulage.co.uk)























































Type of soil	Cubic meter	Ton	Type of soil	Cubic meter	Ton
Dry fine sand	1	1.28	Peat wet	1	0.96
Dry sand coarse	1	1.60	Lump chalk	1	1.2
Top soil(some moisture )	1	1.44	Sandstone	1	2.32
Ballast	1	1.76	Gabion stone(70-160 mm )	1	1.50
Gravel MOT type 1 scalping	1	1.92	Lias	1	2.48
Shingle	1	1.62	Granite	1	2.72
Stiff clay	1	1.6	Slate	1	2.8
Limestone	1	2.1	Flint	1	2.3
Loam	1	1.28	Yorkstone	1	2.5
Peat dry	1	0.8	Brick rubble	1	1.8-2.2

### Soils EURO Style - Fill Symbols

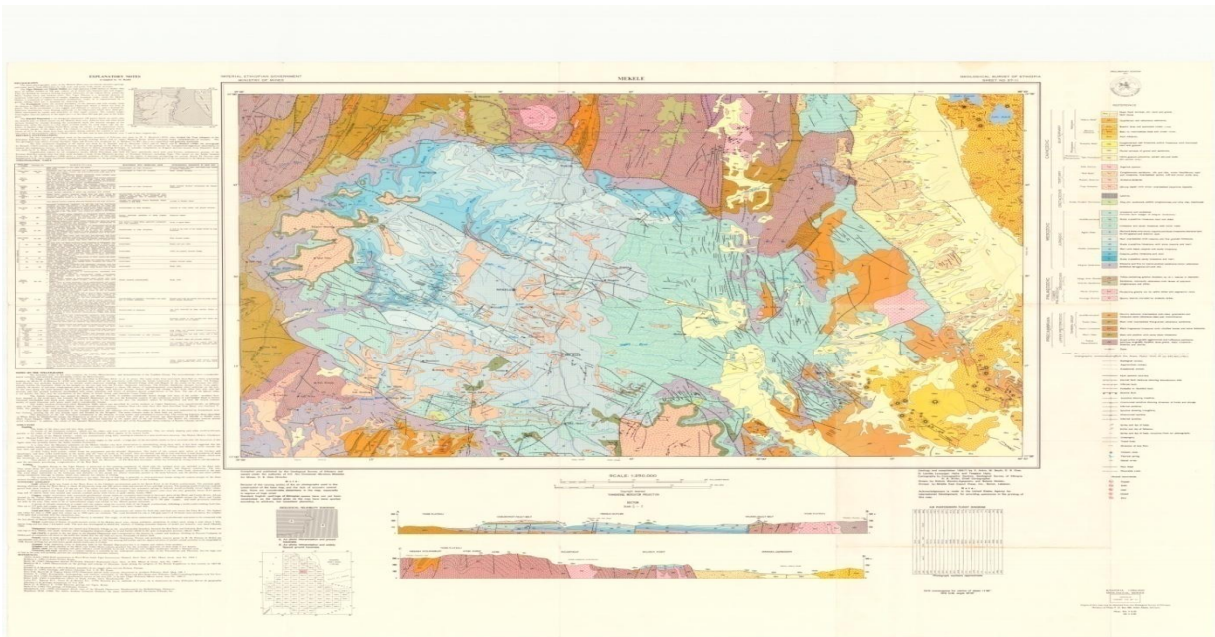
 Luvic Phaeozems	 Albic Luvisols	 Dystric Histosols
 Orthic Phaeozems	 Chromic Luvisols	 Eutric Histosols
 LITHOSOLS	 Dystric Luvisols	 Gelic Histosols
 Calcaric Lithosols	 Ferric Luvisols	 PODZOLS
 Dystric Lithosols	 Gleyic Luvisols	 Ferric Podzols
 Eutric Lithosols	 Humic Luvisols	 Gleyic Podzols
 Fluvic Lithosols	 Calcic Luvisols	 Humic Podzols
 FLUVISOLS	 Orthic Luvisols	 Leptic Podzols
 Calcaric Fluvisols	 Plinthic Luvisols	 Orthic Podzols
 Dystric Fluvisols	 Vertic Luvisols	 Placic Podzols
 Eutric Fluvisols	 GREYZEMS	 ARENOSOLS
 Mollic Fluvisols	 Gleyic Greyzem	 Albic Arenosols
 Thionic Fluvisols	 Orthic Greyzem	 Cambic Arenosols
 KASTANOZEMS	 NITOSOLS	 Ferralic Arenosols
 Haplic Kastanozems	 Dystric Nitosols	 Luvic Arenosols
 Calcic Kastanozems	 Eutric Nitosols	 REGOSOLS
 Luvic Kastanozems	 Humic Nitosols	 Calcaric Regosols
 LUVISOLS	 HISTOSOLS	 Dystric Regosols

Appendix.Figure 1: Guidance of soil colour (Soils EURO style content July 27,2004)

### Soils EURO Style - Fill Symbols

 ACRISOLS	 Glossic Chernozems	 Xanthic Ferrasols
 Ferric Acrisols	 Haplic Chernozems	 GLEYSOLS
 Gleyic Acrisols	 Calcic Chernozems	 Calcaric Gleysols
 Humic Acrisols	 Luvic Chernozems	 Dystric Gleysols
 Orthic Acrisols	 PODZOLUVISOLS	 Eutric Gleysols
 Plinthic Acrisols	 Dystric Podzoluvisols	 Fluvic Gleysols
 CAMBISOLS	 Eutric Podzoluvisols	 Humic Gleysols
 Calcaric Cambisols	 Gleyic Podzoluvisols	 Histic Gleysols
 Chromic Cambisols	 RENDZINAS	 Luvic Gleysols
 Dystric Cambisols	 Cambic Rendzinas	 Mollic Gleysols
 Eutric Cambisols	 Histic Rendzinas	 Plinthic Gleysols
 Ferralic Cambisols	 Orthic Rendzinas	 Stagnic Gleysols
 Gleyic Cambisols	 FERRALSOLS	 Thionic Gleysols
 Humic Cambisols	 Acric Ferrasols	 Gleic Gleysols
 Calcic Cambisols	 Humic Ferrasols	 PHAEZEMS
 Vertic Cambisols	 Orthic Ferrasols	 Calcaric Phaeozems
 Gelic Cambisols	 Plinthic Ferrasols	 Gleyic Phaeozems
 CHERNOZEMS	 Rhodic Ferrasols	 Haplic Phaeozems

Appendix.Figure 2: Guidance of soil colour (Soils EURO style content July 27,2004)



Appendix.Figure 3: Geological map of Tigray and near boundary regions



Appendix.Figure 4: Gereb-segn dam and reservoir bodies



Appendix.Figure 5: At the upper of Gereb-segen the diversion silted at one year after construction



Appendix.Figure 6: Infiltration rate taken site of Gereb-segen watershed



Appendix.Figure 7: Removal of bushes and disposal of soil at the upper Gereb-segen dam reservoir



Appendix.Figure 8 : Some part of the Gereb-segen watershed