ESTIMATION OF SOIL EROSION AND SEDIMENT YIELD OF GEFFERSA

RESERVOIR WATERSHED

M.Sc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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A THESIS SUBMITTED TO THE

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ADVISORS' APPROVAL SHEET

This is to certify that the thesis entitled **Estimation of Soil Erosion and Sediment Yield of Geffersa Reservoir Watershed** submitted in partial fulfilment of the requirements for the degree of **Master's** in **Hydraulic Engineering,** the Graduate Program of the **Department of Hydraulic and Water Resources Engineering,** and has been carried out by **Kanaol Merera Abdisa** ID. No **GPHyd R013/11**, under our supervision. Therefore we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defence by **Kanaol Merera Abdisa** have read and evaluated his thesis entitled **Estimation of Soil Erosion And Sediment Yield of Geffersa Reservoir Watershed,** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfilment of the requirements for the masters of Science degree.

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DECLARATION

I hereby declare that this MSc. thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: ____

Signature: _____________________________________

This MSc. thesis has been submitted for examination with my approval as Thesis advisor.

Name: _________________________________

Signature: ________________________________

Place and Date of Submission: ___________________________

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LIST OF ACRONYMS AND ABBREVIATION

AAWSA	Addis Ababa Water and Sewerage Authority
AHP	Analytical Hierarchy Process
CR	Consistency Ratio
CW	Criteria Weight
DEM	Digital Elevation Model
EHRS	Ethiopian Highland Reclamation Study
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization
GIS	Geographic Information System
LS	Slope Length and Slope Steepness
LULC	Land Use/Land Cover
MAP	Mean Annual Precipitation
MUSLE	Modified Universal Soil Loss Equation
MWIE	Ministry of Water, Irrigation and Energy
NDVI	Normalized Difference Vegetation Index
NMA	National Meteorological Agency
OMC	Organic Matter Content
RI	Rainstorm Intensity
RS	Remote Sensing

RUSLE	Revised Universal Soil Loss Equation
SDR	Sediment Delivery Ratio
SE	Soil Erosion
SWAT	Soil and Water Assessment Tool
SY	Sediment Yield
Te	Trapping Efficiency
UBNRB	Upper Blue Nile River Basin
USDA	United State Department of Agriculture
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator

ABSTRACT

Sedimentation is an important parameter to measure the life of a reservoir. It depends on sediment yield and sediment yield depends on soil erosion. This study has been conducted in Geffersa reservoir watershed in the upper Awash River basin of Ethiopia. The objective of the study is to estimate potential soil erosion, sediment yield from the watershed and identify hotspot areas for proper planning using Arc GIS and RUSLE adopted to Ethiopian condition. The revised universal soil loss equation (RUSLE) was integrated with Geographic Information System (GIS) to model the spatial patterns in soil erosion in the watershed. All the parameters of the model (erosivity, erodibility, steepness, land use land cover, and supportive practice factors) were used in ArcGIS to create a soil erosion map. The annual soil loss of the watershed range from 0 to 728.48 ton/ha/year. The average annual soil loss value was found to be 23.6 ton/ha/year and has been classified into five erosion severities classes as very slight, slight, moderate, severe, and very severe to identify erosion hotspot area. Based on those results, 772.73 ha & 606.34 ha of the watershed were felt under severe and very severely vulnerable to soil erosion. The estimated Sediment yield delivered to the outlet was found ranges 0 to 78 ton/ha/year. The average annual sediment yield from the entire watershed is 5.3 ton/ha/year. If the same rate of sedimentation continues, the total storage volume will be filled up in 394 years. Out of the available reservoir sedimentation management strategies, watershed management is the best technique to minimize the sediment yield and its flow into the reservoir.

Key words: - *Soil Loss, Sediment Delivery Ratio, Sediment Yield, Sedimentation, RUSLE, Geffersa Watershed.*

1. INTRODUCTION

1.1. Background of the Study

Soil erosion and sedimentation are among the greatest of the world's modern environmental concerns (Xiaoqing, 2003). Sedimentation of the world's reservoirs represents a serious hazard to the sustainability of hydropower, there is limited guidance on how best to address the problem. Also, affects the safety of dams and reduces energy production, storage, discharge capacity and flood attenuation capabilities (Sumi & Kantoush, 2011).

On the worldwide more than 40,000 large reservoirs suffer from sedimentation and, it is estimate that between 0.5% and 1% of the total storage capacity is lost per year. The annual sediment load of the entire world's Rivers together varies among 24 and 30 billion tons for a water inflow of 40,000 km^3, (i.e. an average sediment content of 0.6 to 0.75 T/1000 m^3) of water, but it varies enormously according to the River and the discharge. The accumulated sediment storage in world reservoirs has been evaluated as 2000 million m^3 for dams 35 years old on average, (i.e. in the range of 57 billion m^3 per year, i.e. 0.8 % of the total storage per year) (ICOLD, 2009; Xiaoqing, 2003). At a global scale, water erosion is the main cause of soil degradation and about 80 % of the world's agricultural land suffers from moderate to severe erosion (Dutta, 2016). It also delivers millions of tons of sediment into reservoirs and lakes, causes damages to the dams facilities, and results in high economic costs by affecting the water quality (Noori et al., 2016).

Soil erosion is being considered as one of the major threats to global economic and environmental problem especially in developing countries like Ethiopia. The recorded annual soil erosion in Ethiopia ranges from 16 to 300 ton/ha/year depending on mainly on the slope, land cover, and rainfall intensities (Hellden, 1987). Similarly, the problems is more severe in the countries related with steep topography, overgrazing and long cultivation history to outdated technology.

Despite the severity of soil erosion and its consequences, many of Ethiopia’s hydroelectric power and irrigation reservoirs such as Aba-Samuel, Koka, Angerib, Melka Wokana, Geffersa, Legedadi and Dire dam have been threatened by the heavy sedimentation. Thus, those dams have suffered from reduction in their capacity and life span, quality of water and require costly operation for removal and operation, and these dams lose their intended services (Gelagay, 2016; Haregeweyn et al., 2013). Geffersa reservoir is one of the surface water sources providing clean drinking water to residents of Addis Ababa in addition to Legedadi and Dire reservoirs. The reservoir supply an average of 30,000m^3 of treated water per day to Addis Ababa city (MPR, 2011).

Geffersa dam is initially built in 1943 as a 10 m high masonry dam (Geffersa I), it was first modified in 1955 by raising its height by 6 m (Geffersa II) and it has a storage capacity of 7.39 MCM. In 1966 a smaller dam (Geffersa III) was built about 800 m upstream from the main dam to serve as a silt trap and additionally for the water storage. The capacity of the Geffersa III reservoir is 1.17MCM. Lately, in 2009, a major rehabilitation project was finished which renovated the dam body and the hydraulic works and the height was increased by about 1.4 meters (MPR, 2011).

Based on the bathymetric surveys in 1955 to 1966 that were conducted prior to the construction of Geffersa III dam, average siltation rate of 46,400 m^3/year and since 1966 and after Geffersa III dam was built, between 1979 to 1998 the average annual siltation rate fell more than 50% to 22,105m^3/year. These results indicate that Geffersa reservoir had lost 0.51 MCM. Since the Geffersa III dam was built, the reservoir in 1998 had lost another 0.71 MCM of its capacity. Therefore, the total volume loss in 1998 compared to 1955 was 16.5% of the 1955 capacity, representing an average annual volume reduction rate of 0.38%/yr. The calculated sediment yield for the period up to 1966 is 1198 t/km^2/yr. and since 1966, 574 ton/km^2/yr. The sediment density that was assumed for these figures seems to be 1.45ton/m^3 (MPR, 2011).

1.2. Statement of the Problem

Still today, Ethiopia is investing billions of birr for construction of a dam and hydropower structure including reservoir in order to balance water demands and supply activity of the country. In other way silting of dam reservoirs is still the most challenging problem in the country. As a result, the country loses a huge amount of money per year expected to be gained from constructed infrastructure. On the other hand, removal of top fertile soil, increase soil erosion rate, eutrophication of freshwater, dropping storage capacity of reservoir, and reduction of quality as well as quantity of water supply are the major threat found in the study area. Especially, sedimentation of the reservoirs is a major problem found around the reservoirs due to their small storage capacities.

To address these problems, a few researchers carried out their study on Geffersa watershed. For instance, on sediment problem of Geffersa reservoirs and prediction of sediment inflow to Geffersa Reservoir were carried out by Daba (2017) and Tarekegn, (2012), respectively. Catchment Rehabilitation and awareness creation for Geffersa, Legedadi, and Dire Catchment Areas have also been studied in master plan review (MPR, 2011). However, those studies did not consider the spatial patterns of soil erosion, sediment yield and sediment delivery ratio of the Geffersa reservoir and no one of the previous studies estimated sediment yield using GIS and remote sensing techniques with geospatial processing capabilities.

Therefore, this study has attempted to estimate and map the spatial distribution of soil loss, sediment yield using Revised Universal Soil Loss Equation (RUSLE) and Sediment delivery ratio (SDR) model for Geffersa watershed in Arc GIS and remote sensing environment.

1.3. Objective of Study

1.3.1. General Objectives

The general objective of this study is to estimate soil erosion and sediment yield of Geffersa reservoir watershed by RUSLE and SDR model using GIS and remote Sensing.

1.3.2. Specific Objectives

The specific objectives of the study are;

- To determine the amount of soil loss in the watershed with help of RUSLE.
- To estimate annual sediment yield of Geffersa reservoir watershed.
- To estimate the useful life span of the reservoir.

1.4. Research Questions

How much of soil is lost annually per unit area in Geffersa watershed?

How much sediment yield produced from the watershed?

Which methods are effective to preserve the reservoir capacity?

1.5. Significance of the Study

If soil erosion will be minimized in the watershed, sediment enter into reservoir will be minimized, and the sedimentation rates will also be minimized. That means, the quality of the reservoir water will be improved, treatment plant costs will be reduced and the live storage capacity of the reservoir will be maintained (Dutta, 2016). Therefore, estimation of soil loss, sediment yield of the reservoir and quantifying the range, magnitude and rate of erosion as well as identifying its consequences are very essential for the study area.

In this study, the catchment erosion rate of the basin and the sediment yield of the reservoir have been estimated and recommended for the concerned body to handle the sediment problem of the basin. Therefore, Development planners, policy makers, operators, and researchers will benefit from the study result in designing and implementing appropriate policy and effective sediment mitigation measures. In addition to this, engineering analysis that can be used as a guide in planning the water resources for future purposes in watershed study will be forwarded.

2. LITERATURE REVIEW

2.1. Soil Erosion

Since 1930s, several questions were raised with regarding to the soil erosion from the watershed, Eighty-one years ago Bennet was the first to defined soil erosion. Bennet (1939), suggests that soil erosion vastly accelerated process of soil removal brought about by human interferences with the normal equilibrium between soil building and soil removal. Mitchell and Bubnezer (1980), also defined soil erosion in the following way: Soil erosion is the gross amount of soil moved by drop detachment or runoff. Similarly, Han Hurni (1983), defined it is a process induced by man's impact on a landscape, whether he acts to remove the forest cover, to cultivate, or to introduce his own structure. A recent review of the literatures on this topic found that Soil erosion is a naturally occurring process and it is a normal geological phenomenon associated with the hydrologic cycle. It is a gradual increase which occurs when the influence of water detaches and removes soil particles causing the soil to deteriorate (Jazouli et al., 2017).

The major erosion problem around the world are mostly reduces soil productivity, nutrient loss, siltation in water bodies, and degradation of water quality (Benavidez et al., 2018). Crozeir (1986), study on global soil loss has indicated that soil loss rate in the United States is 16 t/ha/yr; in Europe it ranges between 10 to 20 t/ha/year, while in Asia, Africa and South America between 20 and 40 tons/ha/year. As mentioned by Helldan (1987), the annual soil erosion in Ethiopia ranges from 16-300 tons/ha/year depending mainly on the slope steepness, agricultural practices, land cover, and high rainfall erosivity. According to the Ethiopian highland reclamation study FAO (1986), in mid-1980’s 27 million hectares or almost 50% of the highland area was significantly eroded, 14 million hectare seriously eroded and over 2 million hectares beyond reclamation.

In generally, Soil erosion is a growing problem in Ethiopia especially in areas of agricultural activity and water availability. Which in turn is threatening the survival of the Overwhelming majority of the rural population not only that its consequences affect the survival of the urban population.

2.2. Process of Soil Erosion

As several investigators clarified that Soil erosion encompasses the process of detachment, transport and deposition of soil particles (including plant nutrients and organic matter) by water or wind. This process is a complex process that is related to the soil property, climate (rainfall and intensity), topography, land use land cover pattern and human influence. The rainfall drop and the surface runoff that is generated from the rainfall events are the main mechanisms of soil detachment and transport process respectively. This process may be accelerated by either natural or human interference in the environment (Geleta, 2010; Kim, 2006; Osore, 2019; Wischmeier & Smith, 1978). More recent review Kim (2006), suggests that major force influence soil erosion is originate from either raindrop impact or shearing force of flowing water. The detached sediment is transported down slope primarily by surface runoff /flowing water (Walling, 1999). The main types of water erosion comprise Rain splash, sheet, rill, and gully and stream channel erosion.

2.3. Surface Erosion

In order to identify erosion of soil from surface areas and deposition of sediment in low land and River banks is primarily governed by the hydrology and geomorphology of a watershed. The spatial variability of the topographic and the geomorphologic characteristics of watershed attributes to the variability of soil loss in the upland areas, and of sediment yield at the outlets of watersheds. Understanding the way in which topographic and geomorphologic factors, as well as hydrologic factors influence sediment yield is helpful in orchestrating the wise handling of sediment models and watershed management activities. Due to that, each watershed has its own distinct characteristics, the geomorphology and hydrology of one watershed varies from the other (Daba, 2017; Geleta, 2010).

2.3.1. Rain Splash Erosion

Rain splash erosion formed when the water falling directly on to the ground during rainstorms or when it is intercepted by the canopy and finds its way through the ground. In the same way, it happens when rain droplets fall on soil or shallow water causing soil loss by splash directly or by increasing water turbulence. The splash tends to move further downhill than uphill due to the larger traveling distance of soil particles and the favourable angle of impact (Jaramillo, 2014; Morgan et al., 1998).

2.3.2. Sheet Erosion

The removal of a uniform thin layer of soil by raindrop splash or water runoff is sheet erosion. This layer of topsoil often removes gradually, making it difficult to monitor because the damage is not immediately perceptible. Soil particles may be dissolved or suspended in the overland flow, beginning the process of sediment transport (Tessema, 2011).

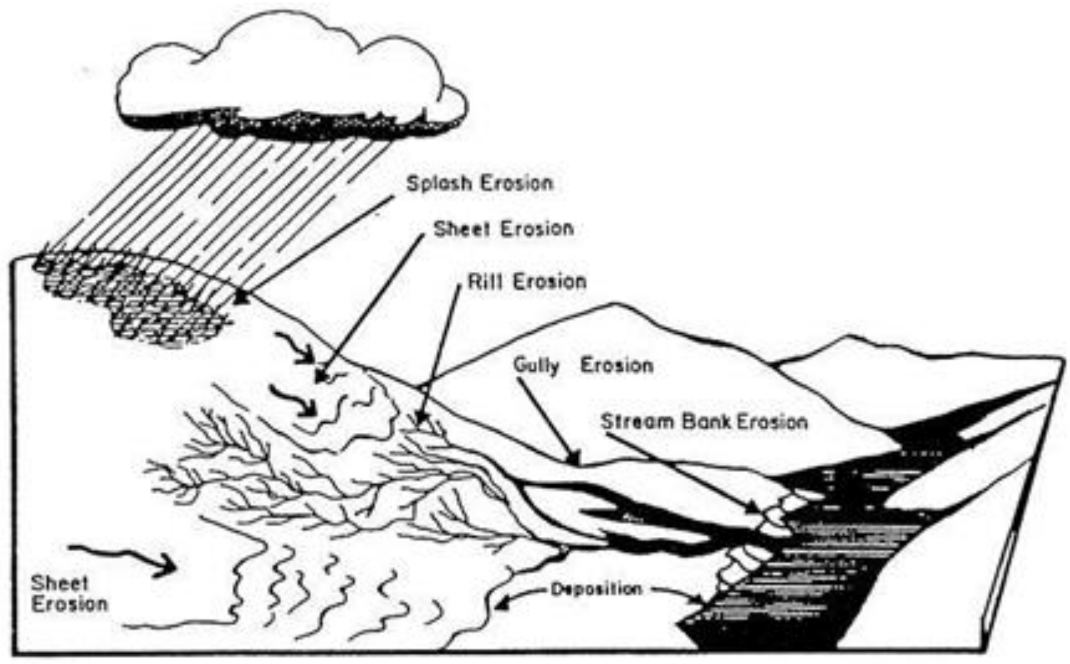

Figure 2:1 The mechanisms of soil erosion (USACE, 1985)

According to Tessema (2011), conducted that it occurs as a shallow sheet of water flowing over the ground surface, resulting in the removal of a uniform layer of soil from the soil surface. Although mostly difficult to identify, sheet erosion is responsible for wide soil loss in both cultivated and non-cultivated environments. Raindrops detach the soil particles, and the detached sediment can reduce the infiltration rate by sealing the soil pores (Cooper, 2011). The eroding and transporting capability of surface flow depends on the rainfall intensity, slope steepness, soil properties, and vegetative cover (Tessema, 2011).

2.3.3. Rill Erosion

Rill erosion starts simultaneously with the initial removal and transport of soil particles when raindrop impact and surface flow are combined. Similarly, It Is the detachment and transport of soil by concentrated flow of water and derived from the small scale rilling as a concentration of overland flow develops small and well-defined channels. Rill initiated at a critical distance down slope where surface runoff concentrates and becomes channelled. This is the form of erosion where the greatest soil loss occurs. The water in a rill has adequate depth for turbulence to develop in it and Thus, entrain large particles (Jaramillo, 2014; R.Williams, 1965).

2.3.4. Gully Erosion

Gully erosion produces channels larger than rills and it is formed when runoff water accumulates and often recurs in narrow channels and removes the soil from this narrow area to considerable deeper than 50 cm and that formed from rill erosion (Habtegebreal, 2014).

These formed channels carry water while and immediately after rains. The amount of sediment from gully erosion is usually less than from upland areas (Tessema, 2011; Williams & Berndt, 1977). Consequently, it has been widely neglect in erosion modelling (Sidorchuk et al., 2003), as most of the researchers found that soil erosion has concentrated on sheet and rill erosion. Relatively, few studies have taken gully influence into account when evaluating soil losses in upland areas or when quantifying sediment production. For example, Haregawyan (2017), has been estimated less than 10 percent of gross soil erosion from the watershed. According to Tesfaye (2014), has been done he predict gully erosion based on the stream power index (SPI) by digitizing area from google earth. However, the estimation with google earth is mostly not recommended due to its low in accuracy.

2.4. Factors Affect Soil Erosion

The major factors affecting soil erosion are rainfall intensity, soil properties, vegetation characteristics, and topography. These factors are totally dependent, as geology affects topography, which can influence climate and the like. Human disturbances and natural disturbances are dramatically increase erosion (Tessema, 2011).

2.4.1. Rainfall Intensity Factor

The basic energy input required to drive erosion processes is provided by rainfall and runoff. Therefore, rainfall is identified as the main cause of water erosion. The ability of the rain to cause erosion is defined as erosivity (Lenjiso, 2019). The rainfall erosivity (R) factor is a function of the falling raindrop and the rainfall intensity, and is the product of kinetic energy of the raindrop and the 30-minute maximum rainfall intensity (Mishra et al., 2015; Wischmeier & Smith, 1978).

2.4.2. Soil Factor

The soil erodibility factor refers to the influence of soil properties on soil loss during storm events on highland areas. It is a quantitative description of the inherent erodibility of a particular soil type; it measures the sensitivity of the soil to erosion, easy removal of the silt, and the amount of runoff assumed in an individual rainfall contribution (Wang et al., 2016). It is the K-factor implies the properties of the soil and vulnerability of soil particles to be detached and transported by rainfall-runoff. The K-factor is strongly related with the R-factor through the soil erosion rate per kinematic energy of rainfall erosivity index. The main soil properties influencing the k factor are soil texture, soil type, organic matter, soil structure and permeability of the soil profile (Wischmeier & Smith, 1978).

2.4.3. Topographic Factor

Topographic Factor has been considered as one of the most significant model parameters in RUSLE analysis. The slope length & steepness factor mainly reflect the effect of Topography on erosion. Slope length is defined as the horizontal distance from the point of source of overland flow to the point where either the slope gradient decreases that deposition begins, or runoff is concentrated in a defined channel (Wischmeier & Smith, 1978). If the slope length increases, the soil erosion by water also increases as due to the greater accumulation of surface runoff. The soil loss per unit area increases as the slope length increases. Soil loss increases dramatically with slope steepness than it does with slope length.

2.4.4. Vegetation Cover Factor

Vegetation cover is the second most vital factor next to topography that controls soil erosion risk because the land cover intercepts rainfall, increases infiltration, and reduces rainfall energy (Koirala et al., 2019). According to different researchers agreed to that this method requires extensive knowledge of the area's cover characteristics including agricultural management and may be suitable at the field or farm scale, but monitoring all these characteristics at the watershed scale may not be feasible. Uninterrupted soils and soils that exist under a dense cover of vegetation are rich in organic content. Such soils have high infiltration rates and as a result of this, the rain drop that falls from the plant canopy after dissipating its potential energy has less capability to detach and transport the soil particles. Moreover, the presence of high organic matter in soils decreases soil erodibility factor because the organic content facilitates soil infiltration rate (Geleta, 2010).

Several studies was carried out to determine C-factor value, which related to land use/cover factors (Esa et al., 2018; Hurni, 1985a; Wischmeier & Smith, 1978). However, some of those studies provided different value to C-factors. When using C factors from the literature, it is important to note that the definition of land cover type between two countries may vary. For example, land classified as forest in one country may be different in terms of the vegetation cover or type compared to forest in another country for instance differences in forests and tropical forests. Therefore, it is crucial to understand the differences between land use/cover classifications before applying C-factor values from the literature (Bewket & Teferi, 2009; Gelagay&Minale, 2016; Hurni, 1985b; Wischmeier & Smith, 1978).

2.4.5. Conservation Practice Factor

Contour farming means that farmers apply certain field practices (ploughing, planting) along contours, perpendicular to the normal flow direction of runoff. Contour cultivation reduces runoff velocity by increasing up and downslope surface roughness. The increased surface roughness reduces water velocity providing more time for infiltration (Parveen & Kumar, 2012). The effectiveness of contour farming in reducing soil erosion depends on the slope gradient. Stone walls are mainly built on hilly land and reduce the velocity of overland flow and as a consequence reduce soil erosion rates (Morgan et al., 1998). The other method has considered grass margins as one of the most effective measure for reducing sediment delivery. The grass margins obstruct runoff, induce infiltration, trap sediments and reduce sediment transport (Panagos et al., 2015).

2.5. Sediment Yield

There is increasing interest in improving water resources development, watershed management, land use and productivity. Sediment store in River reduces channel capacity and result in flooding problems. The water storage capacity of a reservoirs can be depleted by sediment deposition. Sediment yield is a critical factor in identifying non-point source pollution as well as in the design of the construction such as dams and reservoirs (Geleta, 2010).

Several investigators developed different empirical equations to estimate sediment yield at the outlet of watershed. For example, Khosla (1953) developed the equation to predict the volume of sediment yield, but the disadvantage of that equation is underestimates the rate of sedimentation. FAO (1986) developed traditional catchment experiments to measure the sediment yield at the outlet of a watershed. One of the major drawbacks to using this method is the traditional models are not encouraged to estimate the sediment yield precisely due to their inabilities to simulate accurately runoff rates and amounts. Duta (2016) conducted his study there are three common methods to estimate the sediment yield from a watershed these are, simultaneous flow duration curve or sediment rating curve, reservoir sedimentation survey data, and estimates of soil erosion and sediment delivery ratio. However, some of these methods are limited to certain boundary conditions and cannot be widely applied because they were developed based on data driven parameters of a specific area.

Several researchers were tried to improve Sediment Delivery Ratio equations. For example (Ferro & Minacapilli, 2009; Kusimi et al., 2015; Vanoni, 1975; Williams & Berndt, 1977). A recent review of the literature on this area found that SDR is the ratio of sediment delivered at a given area in a stream system (sediment yield) to the gross erosion or the fraction of gross erosion that is transported from a given catchment in a given time interval (Kusimi et al., 2015; Yujra, 2010). Similarly, Kim (2006) defined that the ratio of the sediment yield at a given River cross section to the gross erosion from the watershed upstream from the measuring point. SDR depends upon drainage area and other physical characteristics of the watershed including surface roughness, land slope, soil hydrologic conditions, and length of the travel path (flow length) to the stream and vegetative cover (Ferro & Minacapilli, 2009; Kusimi et al., 2015)

Soil erosion and sedimentation investigations have been developed to better understand the relation of soil loss within a drainage basin to the sediment yield (SY) at the basin outlet. It is still difficult to predict the SY, however SDR can help to better understand the sediment delivery process at basin scale (VENTE et al., 2007). The sediment delivery ratio (SDR) has been one of main method used to quantify the sediment delivery process. In order to investigate sediment yield, estimation of soil erosion and sediment delivery ratio is advisable than the other remain methods.

2.1. Relationship of the Soil Erosion and Sediment Yield

Sediment yield from a watershed is an integrated result of all water erosion and transport processes occurring in the entire contributing area. The relationships between erosion and sediment yield include the sediment delivery ration. Sediment delivery ratio denotes the ratio of the sediment yield (SY) at a given stream cross section to the gross erosion from the watershed upstream from the measuring point (Lenjiso, 2019)

2.1. Reservoir trap efficiency

Trap efficiency is influenced by many factors of which primary factors are: the sediment fall velocity, velocity field through the reservoir and reservoir operation rules (Ahmed, 2008). The main factors influencing trap efficiency can be categorized as hydraulic characteristics of the reservoir and sediment characteristics. Hydraulic characteristics of the reservoir such as the capacity inflow ratio, reservoir shape, type of outlet and reservoir operation affect trap efficiency of a reservoir. Sediment characteristics include particle size, particle shape and behaviour of fine sediment under varying fluid and hydraulic properties (USACE, 1989).

Historically, the two most common approaches are first the relationship developed by Brune, (1953) and second the sedimentation index curve of Churchill, (1948). The Brune (1953) curve, which equates capacity to inflow ratio requires little input data, simple to apply, and has been widely adopted to estimate reservoir TE. In Other ways, the Churchill (1948) curve incorporates both water retention period and flow velocity to calculate a sedimentation index for the reservoir. The Churchill (1948) index produces two curves that describe trap efficiency for locally derived sediment upstream of the reservoir and for overflow sediments that have passed through other upstream reservoirs.

Trap efficiency estimates are empirically based up on measurements of deposited sediment in a large number of reservoirs mainly in the USA. Brune’s and Churchil’s empirical relationships have been widely used and found to provide reasonable estimates for long term release and trapping efficiency (Morris and Fan, 1998). Both methods are based on reservoir capacity to inflow ratio referred to as capacity inflow ratio and neither method specifically considers effect of sediment characteristics.

2.1. Useful life of the reservoir

The period up to which the reservoir can serve the defined purpose is called usable life, the period after which the cost of operating the reservoir exceeds the additional benefits expected from its continuation is called economic life, design life is generally the useful life, full life period is that when no capacity is available in the reservoir for useful purpose (Kulkarni et al. 1994). Useful life is the period during which the sediment collected does not affect the intended primary use of the reservoir (Agrawal and Singh, 1994). In most of the developed countries full life said to be arrived, when half of the total capacity of reservoir is depleted. While in case of Trinity River basin reservoirs (Texas), it was considered as the period when the useful storage would be completely destroyed (Arora and Goel, 1994). Useful life is an important design parameter of a reservoir which may affect the economic feasibility and sustainability of a water resources project (Gill, 1979).

2.2. Reservoir Sedimentation

Sedimentation of reservoirs built for purposes including hydroelectric generation, irrigation, and water supply for domestic and industrial needs has been a topic of concern all over the world (Randle et al., 2019). In reservoir, sedimentation is a phenomenon due to which the sediment particles get deposited in the form of bed load and suspended load after separating from their origin. In fluvial hydraulics, sedimentation is an important parameter as it provides a probability of being used as a capacity predicting device in all storage zones due to which life of a reservoir can be predicted; as there is a unique relationship between capacity and life of a reservoir (Dutta, 2016).

Sedimentation reduces the capacity of the reservoir progressively which is the great concern for water management. During heavy rains the whole River basin transfers certain amount of sediment eroded from the catchment area. In this principal sedimentation processes in reservoirs fall into three basic categories. Deltaic deposition of primarily coarse materials, Deposition of fine sediments from homogeneous flow and Transport and deposition of usually fine sediment from stratified flow (Palinkas & Russ, 2019).

Delta deposits are formed where streams enter the reservoir pool and coarse materials are deposited from a homogeneous (non-stratified) flow as velocity and transport capacity diminishes. The delta may be divided into two zones, the topset bed and the foreset bed (Elliott, 2005). The topset bed has a milder slope than the now-submerged River. Particles of bed material size predominate in delta topset deposits, but finer particles also can be present. Wash load particles begin to predominate downstream of the topset deposits. The transition from topset to foreset beds in the delta typically coincides with the plunge point of the density current (Yang et al., 1998).

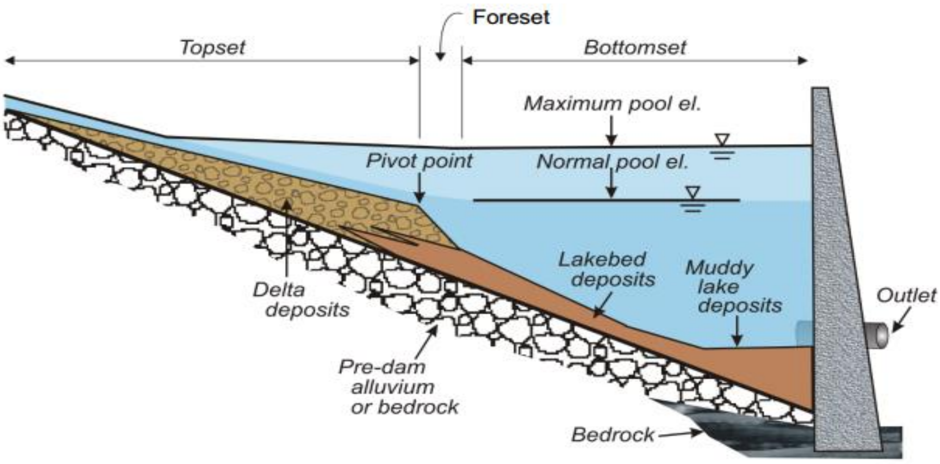

Figure 2:2 Reservoir sediment profile (source; Randle and Bountry, 2017)

Smaller particles may be settled near the base of the dam. Some of the intensity currents and deposit sediments near the base of the dam can possibly be flushed out by operating the sluice gates. The modern multipurpose reservoirs are operated at various water levels, which are significant in the deposition and movement of silt in the reservoir (Tolosa, 2015).

2.3. Sediment Management Options

As mentioned by (Sumi & Kantoush, 2011), There are two techniques to reduce the amount of transported sediment, countermeasure to control sediment discharge which covers entire basin including the construction of erosion control dams; and countermeasure to forcibly trap sediment by constructing check dams at the end of reservoirs. In the technique with sediment trap, a low dam is constructed at the end of reservoir as to deposit transported sediment, mainly bed load of relatively coarse grain size (Haregeweyn et al., 2012), employed multi-criteria decision analysis approach for dam catchment. The selection and evaluation options are; Dry excavation (machinery or manual), Sediment flushing, Watershed management, Replacing lost storage by either raising the dam height or construction new dam.

2.3.1. Sediment routing

Sediment routing includes all methods to manipulate reservoir hydraulics, geometry, or both, to pass sediment through or around reservoir or intake areas while reducing objectionable deposition. Routing is the most environmentally benign sediment management strategy. Sediment routing techniques include sediment passing through and sediment by pass (Kondolf et al., 2014; Randle et al., 2019)

2.3.2. Sediment Passing Through

It may be by seasonal drawdown, by drawdown adapted to floods or by turbidity currents. This requires initial implementation of the necessary bottom gates to be designed with great care. A reservoir operated under seasonal drawdown is either partially or completely emptied during the beginning of flood season (Randle et al., 2019). Seasonal drawdown is conducted during a predetermined period each year, as opposed to flood routing, which requires that the reservoir level be drawn down for individual flood events when they occur. At some sites routing can be implemented at very low cost. Sediment routing is most applicable at hydrologically small reservoirs where the water discharged by large sediment-transporting floods exceeds the reservoir capacity, making water available for sediment release without infringing on beneficial uses. Analysis of this intervention showed that the reservoir could last 20 to 50 years longer (Tolosa, 2015).

2.3.3. By Pass

By pass depend on topographic conditions, if topography are favourable a large-capacity channel or tunnel can be constructed to bypass sediment-laden flow around the reservoir or part of it. It may be built initially and possibly used for flood control during construction. Most may also be built according to precise needs after years or decades of operation. Such tunnel may be associated with a low dam in the upstream part of the reservoir. It may bypass some hundred m^3/s or even thousand m^3/s of water (Haregeweyn et al., 2012).

2.3.4. Sediment Flushing

Hydraulic flushing involves reservoir drawdown by opening a low-level outlet to temporarily establish Riverine flow along the impounded reach, eroding a channel through the deposits and flushing the eroded sediment through the outlet. Unlike sediment routing, which attempts to prevent deposition during flood events, flushing uses drawdown and emptying to scour and release sediment after it has been deposited. Usually flushing is less efficient if the sediment is coarse or is consolidated clay materials (Cheng et al., 2017).

2.3.5. Managing the Silted Storage

It is usually difficult to drawdown completely the large hydropower reservoirs but it is usually possible to drawdown the reservoir by 20 % or 30 % at the flood time in order to store the sediment in the dead storage and to pass through most sediment when the dead storage is full. Corresponding gates may be 20 to 50 m under the dam crest. Turbines abrasion may be a key problem for high head hydropower and many de-silting underground chambers along head race tunnels designed for avoiding it proofed costly and poorly efficient (Haregeweyn et al., 2012).

2.3.6. Removing Stored Sediment

Sediment deposits may be mechanically removed from reservoirs by dry excavation or hydraulic dredging and hydro-suction (Chekol, 2006). For instance In Japan, it is common practice to remove accumulated coarse sediment by excavation and dredging, and to make effective use of the removed sediment. Sediment replenishment method is one of the new measures of sediment management (Sumi & Kantoush, 2011).

2.4. Soil Erosion and Sediment Yield Models

Data collection can be expensive, tedious and time consuming, so in such situations using modelling approach makes valuable, particularly in the developing countries where institutions and organizations charged with the monitoring and collection of data are limited in terms of personnel, materials and money (Kusimi et al., 2015). Models for sediment yield, when applied to those areas lacking data, provide invaluable information for predicting future impacts of agricultural activities, land use, stream stabilization and sediment storage in reservoirs (Khanchoul et al., 2010).

Soil erosion and sediment yield can be modelled on an upland catchment scale to predict the sediment supply to the River and in channel networks that to estimate amount of sediment that can be transported within River system. In the both case, the sediment estimation and transport capacity are different. To estimate soil erosion and sediment yield different physical and empirical models were developed based on watershed hydrologic and geomorphologic parameters (Abera, 2014; Geleta, 2010; Williams & Berndt, 1977).

Physically based models are other helpful tools to analyze watershed sediment yield at different spatial scales. According to Bennet (1974), the models based on the knowledge of the fundamental erosion processes; and incorporate the law of conservation of mass and energy. Model calibration and validation is a required procedure when using physically based models for a watershed sediment yield analysis. Consequently, the reliability of the results of physically based models depends on the quality of the hydro-climatic and hydraulic input data. Therefore, the calibration and validation work of physically based models demands a wide range of professional expertise and reliable data sources (Geleta, 2010). In spite of this, the available data in Ethiopia are not only limited in number but they are also unreliable (Haregeweyn et al., 2013). Physically based models are intensively data dependent, need reliable and representative data sets. Additionally, the demerit of physically based models are the requirement of large amount of data (Dutta, 2016).

Conceptual models play an intermediary role between empirical and physical based models. While they tend to be aggregated, they still reflect the hypotheses about the process governing system behaviour. According to Renschler (1996), conceptual models tend to include a general description of catchment processes, without including the specific details of process interactions, which would require detailed catchment information (Tessema, 2011).

Empirical models are generally the simplest of the three model types. Empirical models are those that are based entirely on data not derived from relationship between variables and they are not based on physical parameters. They are based primarily on defining important factors through field measurement, experimentation and statistical analysis relating erosion factors to soil loss (Petter, 1992). The computational and data requirements for such models are usually less than for conceptual and physically based models (Li et al., 1996). Therefore, such models are frequently used on the worldwide in preference to more complex models. As identified by several researchers, Especially empirical models used as a first step in identifying the sources of sediments (Abera, 2014; Dutta, 2016; Tessema, 2011).

In general due to consideration of hydro-climatic and geomorphologic watershed parameters governing most likely sediment yield, empirical models are preferable, especially for data scarce areas like Ethiopia, where water resources development is at a beginning stage, it is an essential to have alternative solutions where physically based models cannot be applied.

2.5. Revised Universal Soil Loss Equation (RUSLE)

Several empirical models of soil erosion due to water induced erosion were reported by the investigators. As most of the studies concluded that the methods based on erosion plots have drawbacks in respect of cost, representativeness and reliability of the resulting data. Hence, some of these methods cannot provide spatial distribution of soil erosion loss in complex environments. The hydrological models are used incorporating the topographical features of terrain, land use and soil characteristics from remote sensing satellites and GIS (Star et al. 1997). When comparing the RUSLE model with the other soil erosion modelling methods for example, LISEM (De Roo et al., 1996) model is a physically based hydrological and soil erosion model that is completely incorporated in a raster GIS. But LISEM used during single rainfall events on a catchment scale. There are also another integrated soil erosion models have been developed such as ANSWERS (Beasley et al., 1980), SEMMED, SWAT (Neitsch et al., 2002) WEPP, CREAMS, EUROSEM, MODSIM, WRAP, Hydro-BEAM but only a few have been really integrated in a raster GIS.

RUSLE model enables prediction of an average annual rate of soil erosion for a catchment of interest for any number of scenarios involving cropping systems, management techniques, and erosion control practices, and it has been found to produce realistic estimates of surface erosion over small area (Wischmeier & Smith, 1978). The RUSLE is also the most popular model for estimating average soil erosion in water and it is simple to integrate with GIS and remote sensing. Furthermore, RUSLE can provide global applicability and comparability for the results and methods.

In recent years such model has been considerable interest in soil erosion. To improve that many of researchers were carried out their studies by USLE model and it's revised version. Specially, RUSLE was widely adaptable with soil erosion condition in Ethiopia (Belayneh et al., 2019;

Gelagay, 2016; Haregeweyn et al., 2013). Because it is one of the most feasible model within the relatively limited data required. This model is often uses secondary data freely available with a Geographic Information System as an alternative approach because the measurement of soil erosion is expensive and time-consuming. Therefore, RUSLE model is more valuable than another empirical models.

2.6. Geographic Information System and Remote Sensing

The use of GIS and remote sensing techniques makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas. A combination of remote sensing, GIS and RUSLE provide high potential to estimate soil erosion loss on a cell-by-cell basis. Additionally, in the GIS and RS technology provide an effective analytical tool in the modelling of soil erosion. Soil erosion is spatial phenomena, thus geo information techniques play an important role in erosion modelling (Yazidhi, 2003).

2.6.1. Geographic Information System

A Geographic Information System (GIS) is an arrangement of computer hardware, software, and geographic data that people interact with to integrate, analysed, and visualize data; identify relationships: patterns and trends, and find solutions to problems. The system is designed to capture, store, and update, manipulate, analyse, and display studied data and used to perform analyses ESRI, (2005).

In General, GIS is a very valuable tool to deal with the large number of spatial data and the relationship from different sources in the erosion modelling process. In order to that, soil erosion prediction with GIS application is increasing from time to time. USLE and RUSLE are an example of empirical equation were developed to integration of GIS application.

2.6.2. Remote Sensing

The basic fundamentals in remote sensing are the properties of electromagnetic radiation and their interaction with matter. Remote sensing has opened a new era in the planning and development of watershed management, as satellites imagery provides a fast and economic way to analyze large watersheds by virtue of their synoptic and repetitive coverage (Jain and Goel, 2002). It is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. Now a days different studies utilize Satellite imagery for the characterization of watershed and management aims (Saxena et al., 2000).

2.1. Previous Studies

The useful life of a storage reservoir depends upon the rate of sediment deposition in the reservoir. Geffersa main dam is the result of successive modifications. Originally built in 1943 as a 10 m high masonry dam (Geffersa I), it was first modified in 1955 by raising its height by 6 m (Geffersa II). The original live storage capacity of the reservoir in 1955 was 7.45MCM. The capacity of the reservoir from the 1979 surveys is found to be 6.55MCM and as indicated by the findings of the 1998 bathymetric survey the capacity of the reservoir was reduced to 6.23MCM. The loss of capacity till 1998 is found to be 1.22 MCM. As the remedial measures were taken in 1966 by construction of Geffersa III silt trap dam. As bathymetric survey showed that between 1979 and 1998, the average annual siltation rate dropped more than 50% as a result of sediment trapping in the upstream Geffersa III reservoir. The Geffersa I/II main dam was renovated and commissioned again in 2009. The dam height was increased by 1.4 m. There has been no new bathymetry conducted after the renovation of the dam, however, the design study by Tractebel & others (2002) states that the intended capacity of the reservoir according to the design finally chosen is 7.39 MCM.

Fasil Gebremeskel and Tesfaye Daba also done their study on Geffersa reservoir with the title called Prediction of Sediment Inflow to Geffersa Reservoir (by using SWAT Model) and Assessing Sediment Reduction Methods and Sediment Problem of Geffersa Reservoirs and the Appropriate Mitigation, the average sediment load of 32063.7 tons/year for the period of 1979 to 1992 and 27,288.75 ton/year for the period of 1979 to 1992, respectively. However, sustaining the positive achievements in managing sediment yield is still a major problem in the area. Those researches have tend to focus on sediment yield at the outlet of watershed rather than originate of sediment from watershed. Additionally, soil loss from watershed is main source of sediment in watershed that significantly affect the reservoirs storage capacity.

3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1. Geographical Location

Geffersa watershed is located in the upper Awash River basin. The Awash River is one of the Rivers in the eastern part of Africa, in the central part of Ethiopia. The administrative location of Geffersa watershed is in West Shewa Zone, within Oromiya National Regional State, 18 km west of Addis Ababa.

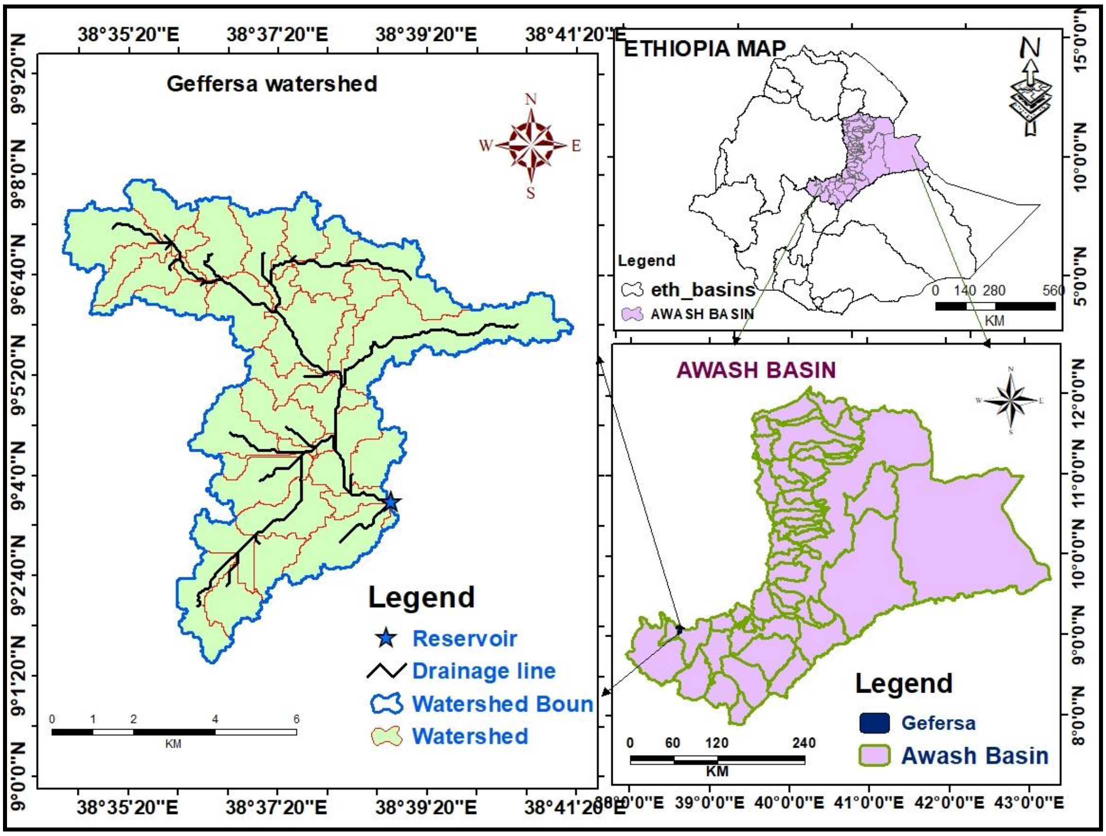

Figure 3:1 Location of study area map

The geographic coordinate of the catchment lies within 9°1'30 to 9°8'0N in latitude and 38°34'30 to 38°41'30E in longitude with an average altitude of 2600ma.s.l.

Addis Ababa Water and Sewage Authority (AAWSA) have administrative control of the area. The reservoir is in a shallow basin about 10 km wide, stretching between the Wechacha and Entoto Mountain and the catchment covers an area of 5451.64 hectares in the Awash River basin. The altitude of the catchment area ranges from 2580 to 2940 m.a.s.l. The major physiographic units in this area are undulating plains, steep stream banks, hills, and mountains.

3.1.1. Climate

The Geffersa catchment is located in a relatively high rainfall area with an average annual rainfall is around 1200mm/year.

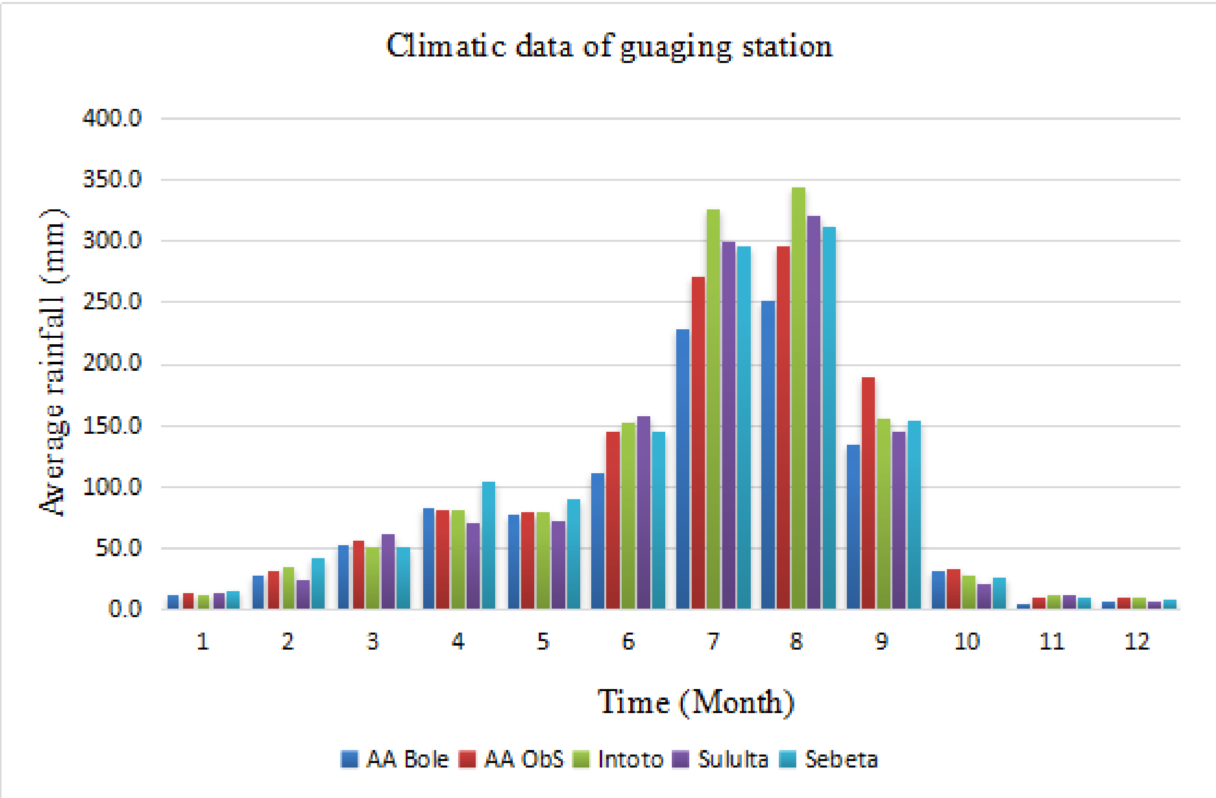

Figure 3:2 Average monthly rainfall of around selected area

The seasonal patterns of the Geffersa watershed are relatively cold in the wet ('kiremt') season of July to September when the main rainfalls are, while the dry season extending from October to June has warmer temperatures. Normally, about 70% of the rainfall has been got in the ‘kiremt’ (AAWSA, 1995). The rainfall is bimodal type, which is distributed into the first and shorter rainy season occurring in the months between February and May, and a second longer rainy season occurring between June and September. The mean monthly rainfall of the study watershed is shown in (Figure 3:2). Mean annually minimum and maximum temperatures are 14°C and 23.3°C respectively. The monthly mean relative humidity and rainfall are 50.4% and 43.4mm respectively (CSA, 2014).

Table 3:1 Metrological station of the watershed

No	Station	Location		Altitude	Mean annual rainfall(mm)
		Latitude	Longitude		
1	Addis Ababa Bole	8.981	38.798	2354	1023.322
2	Addis Ababa Obs	9.018	38.747	2386	1215.522
3	Entoto	9.083	38.721	2903	1282.081
4	Sululta	9.1833	38.733	2610	1200.135
5	Sebeta	8.93	38.63	2240	1250.793

3.1.2. Hydrology

The Geffersa River and its feeder streams are part of the Akaki River catchment. Most parts of the Akaki River basin are characterized by undulating topography steeper in the North, moderate in the middle and West, and relatively gentle and flat-lying in the South. In South West, a flat grassland plain covered with thick black cotton soil covers the East of Addis Ababa to Jimma road and it is swampy and extends in the Southeast direction. The catchment has been highly eroded by the little Akaki River and its tributaries but in the Northern and Western parts, the removal of topsoil is reduced due to the Eculpatus tree that covers the area. Groundwater in this basin occurs in the confined, unconfined, and or semi-confined condition (Daba, 2017).

3.1.3. Land Use Land Cover

The land use and land cover types that were found in the catchment area are cultivated fields, tropical plantation, cropland with shrub land, secondary semi deciduous forest/wood, grassland with cropland, grassland (wet and dry) bare soil, built-up areas (paved road, dam concrete buildings) and a water body. Grasses and eucalyptus woodland cover the area surrounding the reservoir. The dominant land cover types found in the catchment area are grassland, forest land around Entoto Mountain which are important for environmental protection.

The cultivated fields situated on the steep and undulating slopes are not protected from water erosion by any soil and water conservation measures. The farming system of the watershed is mixed farming with dominantly oxen plough crop production and livestock rearing. Barley is the main crop alongside with teff and wheat. Around the household, potato and cabbage are the most common cultivated plants.

3.1.4. Soil

According to the data obtained from MWIE soil of the study area is classified, four soil types namely, chromic camisols, Eutric nitosols, Vertic luvisols, and chromic luvisols are common soil types in the catchment. Luvisols are soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an argic subsoil horizon.

Most Luvisols are fertile soils and suitable for a wide range of agricultural uses. Luvisols on steep slopes require erosion control measures (Tessema, 2011). The soil in the cultivated fields is intensively cultivated. No same continuous cropping is practiced on the same land because soil fertility is poor (according to the farmers of the area). Thus, nearly half of the land cropped each year (Tessema, 2011).

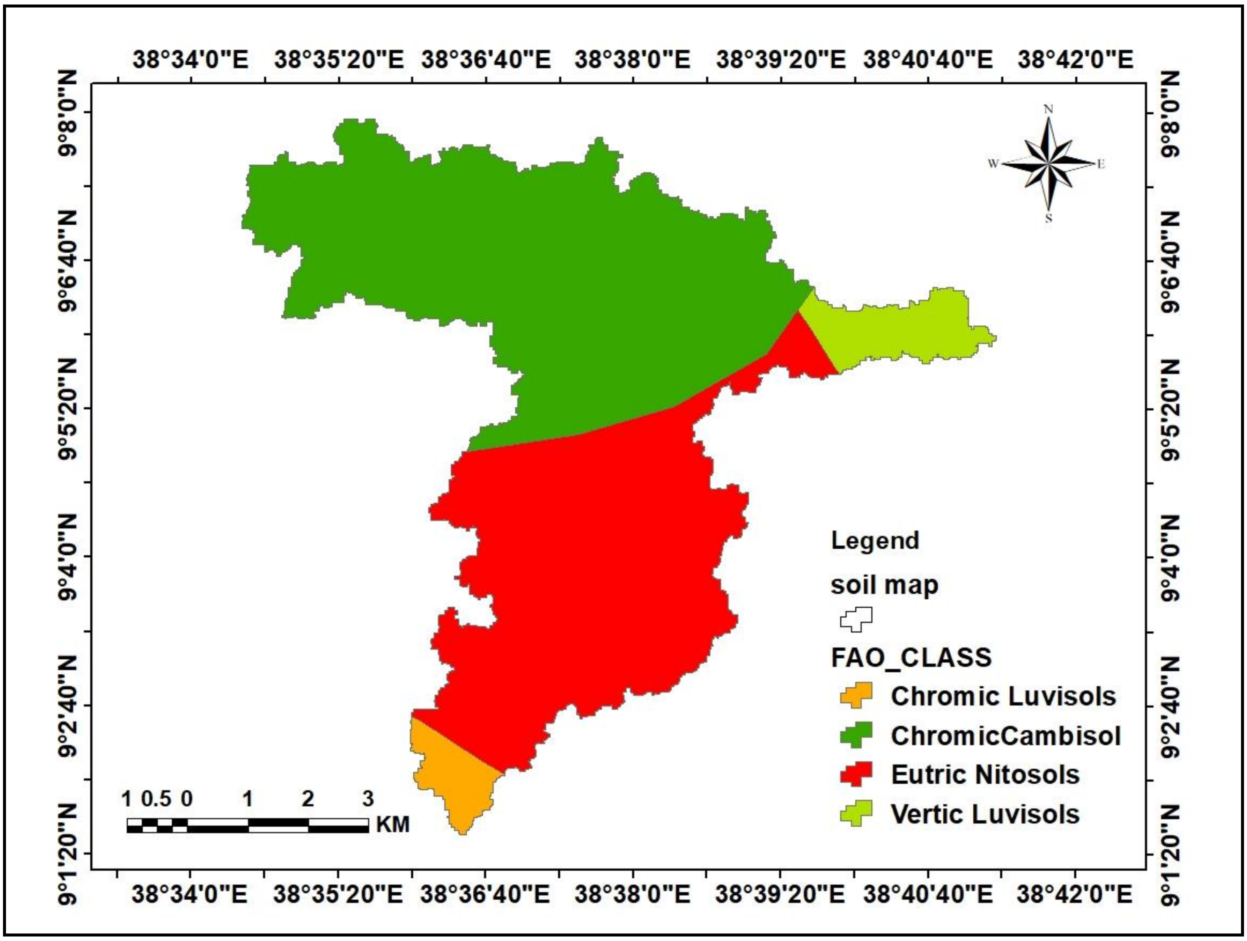

Figure 3:3 Soil classification map

Table 3:2 Soil type and coverage area

No	Soil type	Area (ha)	Coverage area in (%)
1	Chromic cambisols	2793.03	51.23
2	Eutric Nitosols	2243.98	41.16
3	Vertic luvisols	269.447	4.94
4	Chromic Luvisol	144.54	2.66

3.1. Data collection and analysis

It is very important to collect adequate and quality data to do successful research work in any field of study. Primary data were generated from satellite image, and ground truth data were collected from the field. A field observation was concurrently conducted to assess the state of the watershed and to identify where and what kind of support practice had been constructed in the watershed (Appendix Figure 3).

Likewise, secondary data such as Digital Elevation Model (DEM), metrological (rainfall) data, Soil map, and Land use/land cover map were collected from various sources. To get a better result, it is critical to use all relevant and good quality data required. The outcome depends on the quality and quantity of data used. The spatial and temporal resolution of data used in modelling will greatly influence the model performance.

Table 3:3 Software employed in the study

No	Software	Version	Description and sources
1	Arc GIS	10.3	Analyzing, Displaying and viewing Spatial data https://getintopc.com/softwares/maps-creation/esri-arcgis-desktop-10-5-0-6491-addons-download/
2	ERDAS EMAGIN	2015	For image processing classifying and supervising Downloaded from https://getintopc.com/softwares/development/hexagon-erdas-imagine-foundation-2015-free-download/
3	Hec- GeoHMS (Arc GIS extensio	10.2	For main stream channel processing and estimating chai slope
4	Arc SWAT tools (Arc GIS extensio	2012	For watershed delineation and sub watershed Generation https://swat.en.softonic.com
5	GPS points		For field data collection

After collecting all the required data from various sources the data processing and analysis of the available data with the support of software and tools were conducted. The important software and tools used in the study are explained here in (Table 3:3)

3.1.1. Precipitation Data

There is no any metrological station within the watershed. As a result, five stations were used in this study, which are located around the study watershed. The daily amounts of precipitation for these stations were collected over years by the National Metrological Agency. The majority of these daily precipitations were derived from more than 30 years of precipitation data.

The annual rainfall surface was interpolated from these five point observations in ArcGIS by the spatial analyst tool.

3.1.2. Soil Data

The soil data for the study was obtained from digital soil map of FAO (2010) and used to develop the soil map for soil erosion risk analysis. The soil map has a polygon shape format. The soil feature map of the study area is obtained by clipping the FAO soil map of Ethiopia with the study watershed in the GIS environment. Then, erodibility value (K factor) is assigned for each of the four soil types based on their OMC as indicated by (Hilborn et al., 2012).

3.1.3. Digital Elevation Model (DEM)

The digital elevation model (DEM) data was used to delineate the watersheds in the arc SWAT interface. The DEM data with a resolution of 30x30m was downloaded from https://earthexplorer.usgs.gov/. Topographic information was obtained from DEM which has projection. Before it was loaded in to Arc SWAT version of Arc GIS, it was projected into projected coordinate system. The projection of the DEM data was done using the Arc tool box operation in ArcGIS 10.3. The projected coordinate system parameters of Ethiopia are:

WGS_1984_UTM_ZONE 37N. The extraction by masking was done to focus catchment area because DEM covers more area than the watershed to be modelled.

3.1.4. Land Use Land Cover (LU/LC)

The 2020 Landsat 8 satellite image, Path 169 and Row-54, acquired on 11, February 2020 was used to classify the current land use and land cover map of the study watershed.

Table 3:4 Satellite image used in the study

Year	Date of Acquisition	Path	Raw	Resolution	Level of processing
Land Sat	02/11/2020	169	54	30m	LC08-L1TP

The material and the data that are collected from different agencies are prepared as in the (Table 3:5).

Table 3:5 Summary of datasets and their respective sources

No	Data sets	Data Sources
1	DEM	https://earthexplorer.usgs.gov/
2	Rainfall data	National metrology agency of Ethiopia 30 years(1988-2017) rainfall records from five Rain gauge stations
3	Soil map	Ministry of water, irrigation and energy of Ethiopia FAO soil downloaded from ISRIC- word soil database https://www.data.ISRIC.org/geonetwork/srv/catalog/
4	Land use land cover map	Land use land cover map from Ethiopia mapping agency Satellite image with Spatial resolution of 30 meter of 2020 year

3.1.5. Data Quality Control

The precipitation data has been checked for continuity and consistency before is used for further analysis. The quality control can be done by visual inspection, filling of missing data if there is any. This was help to identify if there are any gaps or unphysical peaks in data series and correct them before the data is used or input to the model. Otherwise, using the uncorrected data as input to the model will give inaccurate output from the model.

3.1.6. Filling of Missing Data

Measured precipitation data are important to many problems in hydrologic analysis and design. Because of the cost associated with data collection, it is very important to have complete records at every station. Though, conditions sometimes prevent this. For gages that require periodic observation, the failure of the observer to make the necessary visit to the gage may result in missing data. It is often necessary to estimate or fill in this missing record. Vandalism of recording gages is another problem that results in incomplete data records, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the precipitation record. The missing precipitation of a station was estimated from the observations of precipitation at some other stations as close to and as evenly spaced around the station with the missing record as possible. Various methods are available to estimate missing rainfall records of station data. These are: arithmetic mean method, normal ratio method and inverse distance weighting method. The Arithmetic mean method can be used to fill in missing data when normal annual precipitation is within 10% of the gauge/station for which data are being reconstructed. The normal ratio method is used when the normal annual precipitation at any of the index station differs from that of the precipitation station by more than 10%. In the absence of normal annual rainfall for the stations inverse distance weighing method employed to fill the missing data. The gaps should estimate first before this study use the rainfall data for any analysis. In this study by using Microsoft excel normal ratio method is used to calculate the missing data of stations before the data is used by the model.

3.2. Methods of Data Processing

3.2.1. Application of GIS Tools

This study was carried out using Geographic Information System (GIS) software. GIS have been used in various environmental applications since the 1970s; although as different studies were stated that, extensive application of GIS to hydrologic and hydraulic modelling and flood mapping and management did not begin until the early 1990s (Huisman & By, 2001). The ability to represent elevation in terms of topographic surfaces is central to geomorphological analyses and thus to the importance of representing topography using DEM. It is through the distribution of soil that the land surface changes over the long terms (Schmidt et al., 2000).

GIS-based soil erosion models are important means for erosion assessment and prioritization to initiate possible land management measures. The use of GIS and remote sensing techniques makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas. A combination of remote sensing, GIS and RUSLE provide high potential to estimate soil erosion loss on a cell-by-cell basis.

3.2.2. Applicability of the RUSLE Model

Several models exist to predict the amount of water induced erosion. The revised universal soil loss equation RUSLE is among widely applied empirical models for assessment of sheet, inter-rill and rill erosion (Foster et al., 2008). The models range from empirical to physical or process-based EUROSEM (Morgan et al., 1998), GUEST, LISEM (De Roo et al., 1996), WEPP (D. C. Flanagan et al., 2007) and varies considerably in ramification and data input.

RUSLE model enables prediction of an average annual rate of soil erosion for a catchment of interest for any number of scenarios involving cropping systems, management techniques, and erosion control practices, and it has been found to produce realistic estimates of surface erosion over small area (Wischmeier & Smith, 1978). The RUSLE is also the most popular model for estimating average soil erosion in water and it is simple to integrate with GIS and remote sensing. Furthermore, RUSLE can provide international applicability and comparability for the results and methods, as the model can be adapted and applied in many regions globally.

3.2.3. Descriptive Statistics in the RUSLE Model

Statistical significance was performed by through the use of RUSLE model. It is an updated version of the USLE was designed by the United States Department of agriculture (USDA) in 1978 to predict long time-average inter-rill and rill cropland soil losses by water under various effects such as land use, relief, soil and climate, and guide development of conservation plans to control erosion (Karamage et al., 2017). In 1996, U.S. Department of Agriculture (USDA) developed a method for calculating the amount of soil erosion under soil conditions besides pilot sites such as pastures and forests, RUSLE was announced to add many factors such as the revision of the weather factor, the development of the soil erosion factor depending on seasonal changes, the development of a new estimate to calculate the land use land cover factor, and the revision of the length and gradient of slope (Tarekegn, 2012).

To estimate soil loss in developing countries, such like Ethiopia and many other countries where basic necessary data for erosion assessment is not sufficiently available (Hurni, 1985b; McCool et al., 2000; Wischmeier & Smith, 1978). However, a number of parametric models like USLE and its revised forms are the most widely used empirical equations to estimate annual soil loss with a limited data.

3.3. Methods of Soil Loss and Sediment Yield Analysis

The overall methodology has much interesting applications. The methods involved the use of the RUSLE in a GIS techniques, with the input data obtained from rainfall data, topographic maps, satellite images, Digital Elevation Model, soil surveys, and all other relevant data were used in ArcGIS 10.3. Individual GIS files applicable for the RUSLE were built for each factor and combined on a cell-by-cell grid modelling technique in ArcGIS 10.3 environment to predict soil loss in a spatial domain (Tessema, 2011). Each factors in the grid had a cell size of 30 m. All layers were projected with WGS_1984_UTM_Zone_37N using the datum. These correspond to the standards used by the Ethiopia Mapping Agency. Details of the technique used to generate each of the input parameters in GIS are explained in the following section.

The amount of soil loss was determined using the RUSLE model in ArcGIS environment (McCool et al., 2000). The equation is a function of five input RUSLE input factors. These input factors are: rainfall erosivity, soil erodibility, slope length and steepness, cover management and support practice (P) (Figure 3:6). Therefore, the RUSLE model is expressed as

$$SE = RxKxLSxCxP \qquad (1)$$

Where SE is the mean annual soil loss (metric tons/ha/year); R is the rainfall erosivity factor (MJ mm h^{-1} ha $^{-1}$ $year^{-1}$); K is the soil erodibility factor (metric tons $ha^{-1}MJ^{-1}mm^{-1}$); LS is the slope length steepness factor (dimensionless); C is the cover and management factor (dimensionless, ranges from zero to one); and P is the erosion support practice or land management factor (dimensionless and ranges from zero to one). The following methodological framework have been show how to RUSLE model employed to estimate soil loss of Geffersa watershed.

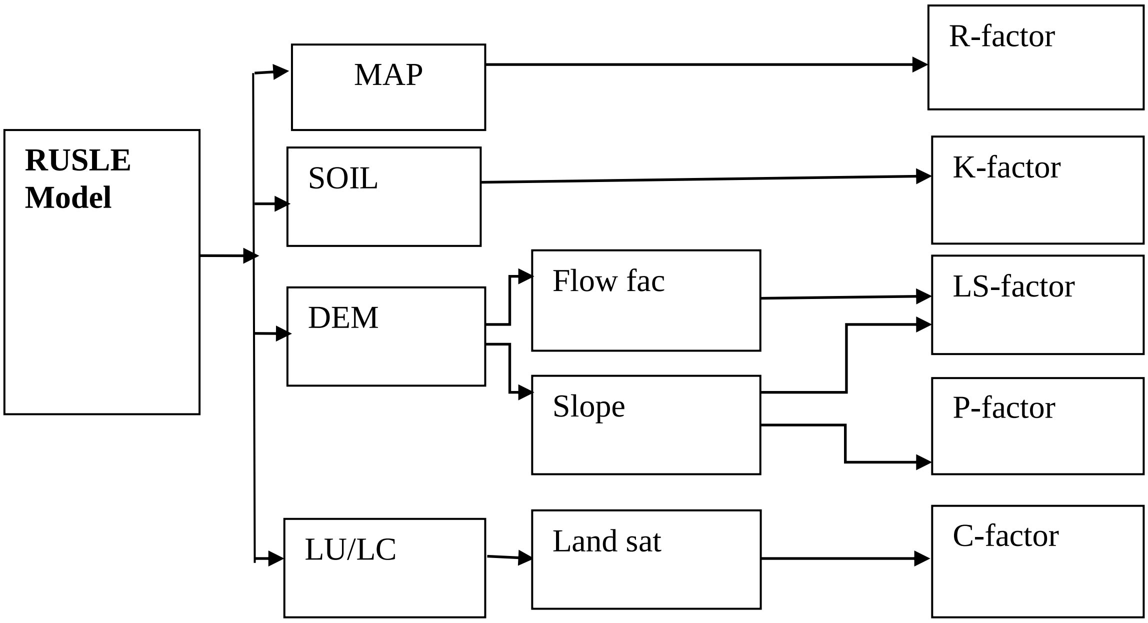

Figure 3:4 Conceptual frame work of Soil loss factor analysis to RUSLE model

3.4. RULSE and GIS Parameterization

To identify the contribution of parameter in RUSLE model, each factor was calculated as a specific thematic layer on the cell by cell bases (Millward and Mersey 1999). RUSLE is simple and easy to parameterize, with great acceptance and broadly routine, requires less data and time to run than most other models dealing with rill and inter rill erosion (Jones et al., 1996).

3.4.1. Rainfall Erosivity (R) Factor

Rainfall plays an important role in the process of soil erosion and sedimentation and leads to water erosion, such as splash erosion, sheet erosion, rill erosion and gully erosion, caused by water flow. Soil particles, which are transported away from a site by the flow water, are those detached by rainfall influence. Therefore, potential erosion can be determined by rainfall intensity and storm duration. Generally, the relationship between total storm energy (E) and maximum 30 min intensity (I30) can be regarded as the R factor. Realistic estimation of monthly or annual rainfall erosivity EI30 values requires long term pluviometry data at 30 min intervals or less (Wischmeier & Smith, 1978).

$$R = \frac{1}{n}\sum_{j=1}^{n}\sum_{k=1}^{m}(E)(I30)\text{...}(2)$$

Where: R = rainfall erosivity factor (100ft x tonft x acre-1 x yr-1); E = the total storm kinetic energy in hundreds of ft-to acre; I30 = the maximum 30-minute rainfall intensity; j= the counter for each year used to produce the average k= the counter for the number of storms in a year.

In many parts of the world a limited detailed rainfall intensity data were available. Especially in developing countries, spatial coverage of pluviographic data is frequently difficult to obtain (Shamshad et al. 2008). Due to this reason, the various studies have been performed based on available rainfall data such monthly, seasonal and annual rainfall data are frequently available for longer periods and are mostly used to calculate R-factor. In this study, due to the absence of rainfall kinetic energy and intensity data that erosivity factor was computed by analysing the rainfall data available at five rain-gauge stations (Addis Ababa Bole, Addis Ababa Obs, Entoto, Sululta and Sebeta) located near Geffersa watershed. Therefore, the empirical equation developed by Hurni (1985), to estimate R- values for the Ethiopian soil context has been used for this study as following (Equation 3).

$$R = 0.562xMAP - 8.12\text{...}(3)$$

Where R Rainfall Erosivity Factors MAP Mean Annual Precipitation

The rainfall data was obtained from National metrology agency (NMA). The average annual rainfall data of those stations are used in parameter of R- factor to the RUSLE model.

Table 3:6 Average annual Rainfall and the corresponding R- factor value

Station	Precipitation(mm)	R-factor @gauge station
AA Bole	1023.322	566.9871
AA Obs	1215.522	675.0036
Entoto	1282.082	712.41
Sululta	1200.135	666.356
Sebeta	1250.793	694.8257

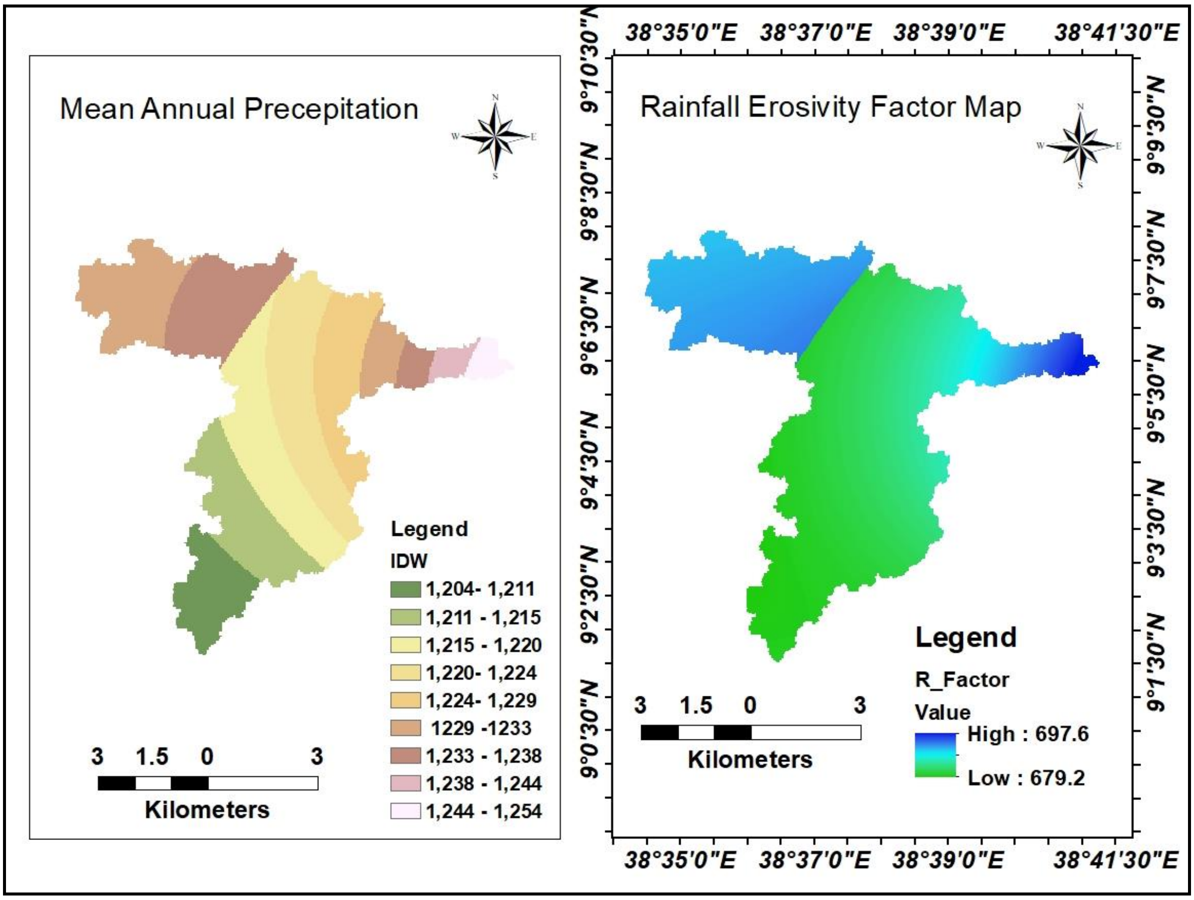

Figure 3:5 Precipitation data (left) Soil erosivity (right) map - RUSLE approach

The rainfall data for stations was available from 1988 to 2017 years. Hence, as showed in (Figure 3:6) annual precipitation of surround watershed (left) ranges from 1204 mm to 1254 mm and the rainfall erosivity (right) ranges from 679.2 to 697.6 MJ mm /ha/year.

Spatial distribution of R Factors data in the watershed area is estimated using inverse distance weighting (IDW) method of interpolation. Inverse distance weighted method was used to produce uninterrupted rainfall data from point mean annual rainfall data of 30 years obtained from five rain gauge stations near and around area considered for each grid cell in Arc GIS10.3 version. From this continuous rainfall data, the R-factor of each grid cell was calculated using Equation (3) and raster calculator geo processing tools.

3.4.2. Soil Erodibility (K) Factor

Different soil types have variable susceptibility to erosion. The fine textured clay and coarse textured sandy soils have low K values; medium textured silt and loam soils have moderate K values, while soils with high silt content have high K values due to their inherent physical property of soils. Similarly, the soil organic matter reduces erodibility values because it produces mixtures that bind soil particles together and increases aggregation by decreasing detaching effect of raindrop, increasing infiltration and reducing surface runoff (Esa et al., 2018; Foster et al., 2008; Wischmeier & Smith, 1978).

To direct measurement of K-value on a standard plot is costly and unsustainable at this scale. However, K-factor estimation methods have been widely developed in many developed countries to modelling soil erosion and water quality. Those different methods of soil edibility estimations were suggested on soil type, organic matter and soil colour are the common methods. Unfortunately, the K-factor determined by soil colour is often not very precise given the fact that soils of the same colour have quite different K values (Esa et al., 2018). Most of these methods are developed for data rich area that pose a challenge for areas with limited soils data. The effect of soil and soil properties on soil erosion can be represented by the soil erodibility factor, because that factor shows the physical and chemical properties of the soil (soil texture, soil organic matter and percentages of sand, silt, and clay). Some of the most important soil properties that affect soil erodibility are soil texture, drainage condition, soil depth, structure stability, cohesiveness and organic matter content (Prasannakumar et al. 2012). The method to estimate soil erodibility factors developed by Wischmeier & smith (1978) has become the most popular and well accepted to erodibility calculation method. As the Wischmeier & smith (1978), theory the equation can be applied to areas where there is a complete soil profile parameters like soil texture, soil organic matter content (OM), soil structure classes and soil permeability. The K-value based on basic soil property variables may expressed in mathematical terms as follows. However, to calculate k factor value for the soil with silt fraction does not exceed 70%.

$$K = \frac{0.00021 * (M^{1.14})(12 - OM) + 3.25(S - 2) + 2.5(P - 3)}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where K is the soil erodibility factor, M is the product of percent of silt plus very fine sand and the percent of all soil fractions other than clay, OM is soil organic matter content (%), S is the soil structure code used in soil classification and P is the soil permeability class. Though in realism, especially at local level, these data are frequently difficult to find and may not be suitable for extrapolation from one area to another.

Unlike the Wischmeier & smith (1978) method, only two soil properties are needed in EPIC to calculate the soil erodibility K-value, soil organic carbon content and soil particle size distribution (Sharpley & Williams, 1990). In other ways the required soil parameters to calculate K factor, in the Erosion Productivity Impact Calculator model can be extracted from the Food and Agricultural Organization (FAO) world database (Osore, 2019). Similarly, the method of (Sharpley & Williams, 1990) applied in areas where there are sufficient data sets related to soil particle size distribution and soil organic carbon content. Furthermore, to calculate soil erodibility values the following equation that put as erosion productivity impact calculator

$$k = Fcsand * Fsi - cl * Forg * Fhsand * 0.1317 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Fcsand = it gives a low soil erodibility factor for soil with coarse sand and a high value for soil with little sand content.

Fsi-cl = it gives a low soil erodibility factor with high clay to silt ratio.

Forgc = it is the factor that reduces soil erodibility for soil with high organic content.

Fhisand= it is the factor that reduces soil erodibility for soil with extremely high sand content.

An investigation by (Belayneh et al., 2019; Wischmeier & Smith, 1978) conducted that the soil erodibility estimation method developed in soil texture and soil organic matter model is predicting better than others. Moreover, the demand for a many number of soil input parameters remains a major challenge for estimating soil erodibility factor. The different soil texture and organic matter values that were used to determine the K-factor of each soil type as adapted from (Esa et al., 2018; Hilborn et al., 2012).

Table 3:7 Estimation of soil erodibility

Soil type	TSS (%)	TSL (%)	TSC (%)	Particle size	AOMC
Chromic luvisols	64.3	12.2	23.5	loamy sand	0.04
Chromic cambisols	22.4	24.5	53	clay loam	0.3
Eutric nitisols	68.4	10.5	21.2	Silty clay loam	0.32
Vertic luvisols	23.3	26	50.7	silty clay	0.26

The acronyms OMG, TSS, TSL, TSC, and AOMC represents average organic matter content, topsoil sand, topsoil silt, topsoil clay, and average organic matter content.

In the case of k factor all fraction of soil sand, silt, and clay and organic carbon were represented to the top soil cover of the watershed because it has been affected directly by the raindrop energy. According to the MWIE (2010), soil map classification (Vertic luvisols, Eutric nitisols, chromic cambisols, chromic luvisols) were identified in the Geffersa watershed (Figure 3:3).

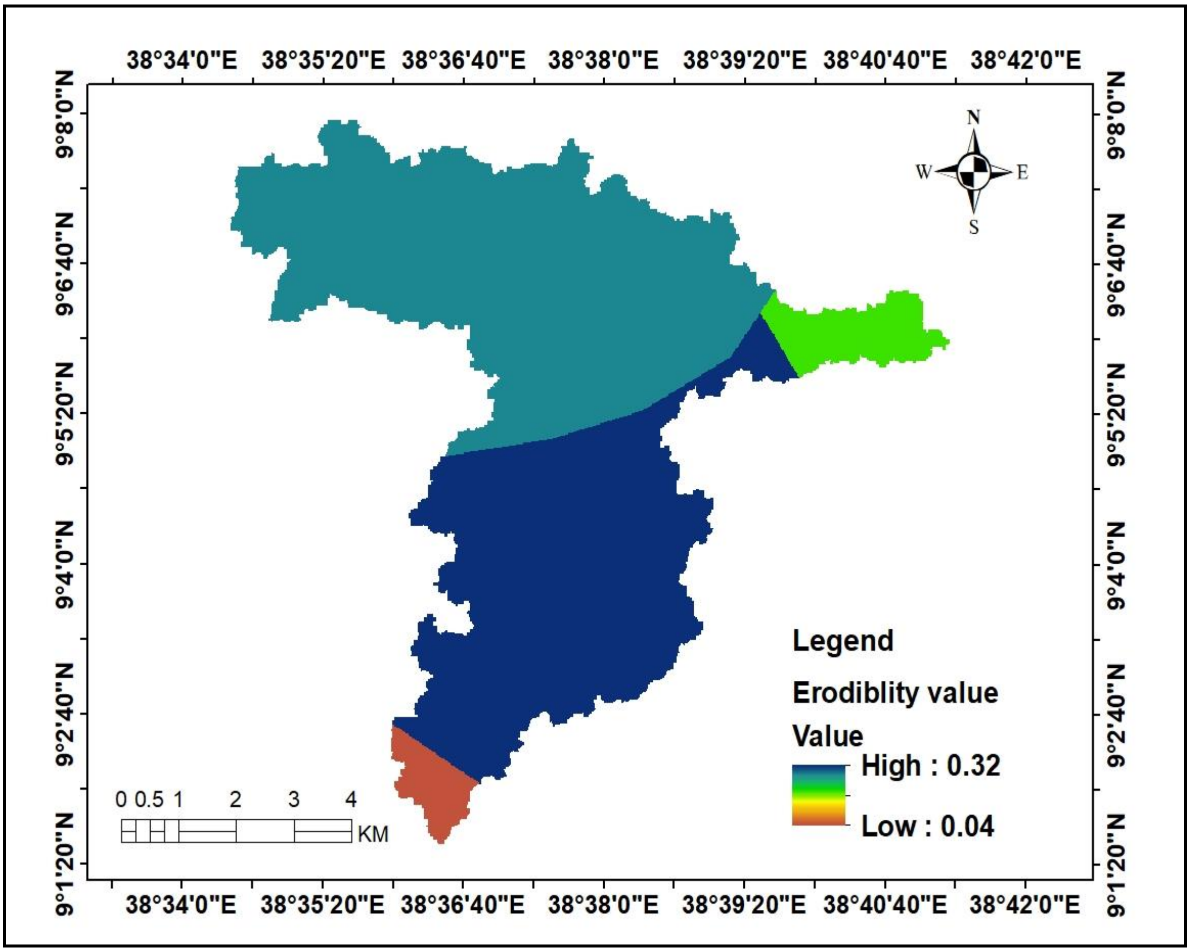

Figure 3:6 Soil erodibility map - RUSLE approach

The soil properties in the Geffersa watershed has lack of information and difficult to access based on limitation of time. However, additional information of the soil data of this study were derived from the Soil Grids map, which is developed and maintained by ISRIC–World Soil

Information and were arranged with obtained data from MWIE. When the K value is high, it implies deterioration in the physical properties of the soil such as low organic matter, coarse soil texture, coarse granular structure etc. Thus, the soil is more prone to erosion.

The vector format soil map was changed into grid and the grid data set was reclassified with a cell size of 30 m x 30 m resolution into the corresponding K values using Spatial Analyst Tool of ArcGIS 10.3 version (Table 3:7). As the results of analysis indicated that K-factor values of the study area were ranges from 0.040 to 0.32 with the mean value of 0.29 (Figure 3:7).

3.4.3. Topographic (LS) Factors

Slope-length and gradient are the important parameters in the soil erosion modelling. Both slope length and gradient can be determined from the DEM. The LS factor represents soil erodibility due to combinations of slope length and steepness relative to a standard unit plot.

It expresses the impacts of topography, specifically hill slope length and steepness, on soil erosion. An increase in hill slope results in an increase in the LS factor. The input requirement for the generation of the topographic grid is a filled DEM. Filling a DEM can be described as identifying any sinks or cells that have a lower elevation value than the surrounding cells and giving them a higher elevation value. The slopes gradient and slope length factors were calculated from the DEM and combined to result in the topographical factor grid as the following relation. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard unit plot of 22.13m long slope length with 9% of slope gradient (Wischmeier & Smith, 1978). With the incorporation of Digital Elevation Models into GIS, the slope gradient (S) and slope length (L) may be determined accurately.

The precision with which it can be estimated depends on the resolution of the Digital Elevation Model (DEM) (Parveen & Kumar, 2012).

LS = pow{fac x cell/22.13,0.6} x pow{sin(slope x 0.01745)/0.09,1.3}…………………………(7)

There are many relationships available for estimation LS factor. Among these the best suited relation for integration with GIS is the theoretical relationship proposed by (Parveen & Kumar, 2012) based on unit stream power theory given below.

LS= $(\mathbf{A}/22.13)^{0.6}$ $(\sin \mathbf{B}/0.0896)^{1.3}$……………………………..…….…….……………….(6)

LS = (pow (flow length, 0.3)/22.1) * pow (slope/9, 1.3)

Where **A** is the upslope contributing factor, **B** is the slope angle. In raster calculator two steps was followed:

Determination of $(\lambda^{0.3}) * (S/9)^{1.3}$

Division of the result of step one by 22.1

The LS value is considered to have values between 0.02 - 48 for Ethiopian condition (Habtegebreal, 2014; Hurni, 1985) and the study area are ranging from 0 to 10.5 (Figure 3:8).

Slope length represents the distance between the origin and culmination of inter rill process. The culmination is either the point where slope decreases and the resultant depositional process begins or the point where concentration of flow into rill or other constructed channel such as a terrace or diversion (Gelagay&Minale, 2016).

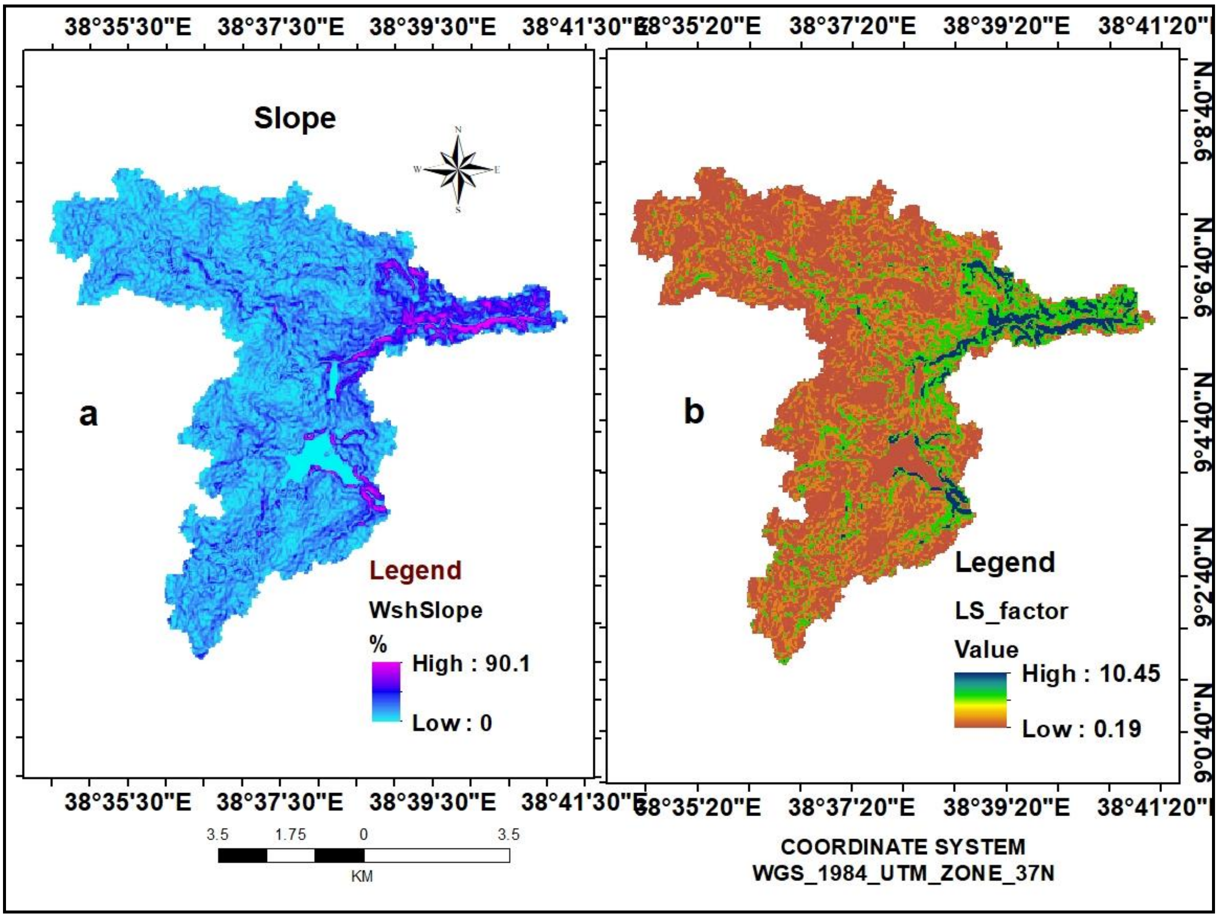

Figure 3:7 Topography map - RUSLE approach

For this study calculating LS factor by using DEM after preparing the flow direction and flow length map of the formula (Equation 6) was used. Slope gradient and slope length factor is calculated from the flow direction and slope values. Topographic Erosivity (LS) Factor map has been derived using the equation (6) in ArcGIS through the process of spatial analysis tools in raster calculator function. In general, an increase in the LS factor produces higher overland flow velocities and correspondingly greater erosion. Finally, the Topographic Erosivity (LS) factor of Geffersa watershed has been calculated by considering the flow accumulation and slope factor extracted from DEM. From the result map, it is observed that the Topographic Erosivity factor of the Geffersa watershed has been found to be in the range of 0 to 10.45 (Figure 3:8).

3.4.4. Cover Management (C) Factors

Cover management factor is used to reflect the effect of cropping and other management practices on erosion rates. The pattern of agricultural practice and the change in land cover conditions play a fundamental role. Consequently, the temporal and spatial variability of land use and land cover is one of the crucial aspects to be considered when analysing the soil erosion and sediment yield. Land use/ cover classification map and normalized difference vegetation index are most commonly used methods for C-value estimation. But land use/cover classification map approach it gives comparatively precise C-value than normalized difference vegetation index (Lin et al. 2017). In order to account for the influence of surface cover on erosion rates and spatial patterns, Landsat8 ETM+ satellite image of 30 m resolution was used to derive land-use and land-cover map of the study area, which were acquired on 11 January 2020 taken from Ethiopia geospatial and mapping agency. Prior to classification image rectification, layer stacking, image enhancement and extraction have been made as image pre-processing by using ERDAS IMAGINE 15 software. The image was classified using supervised digital image classification procedure.

3.4.4.1. Image Classification

Landsat image was used in this study. For each of them digital image processing operations such as image restoration, geo referencing, image enhancement and image classification supervised have been done using ERDAS IMAGINE 15 image processing software. Image classification is required to convert image data to thematic data. According to Lillesand and Kiefer (1994), the overall objective of image classification procedures is to automatically categorize all pixels in an image into land use/land cover classes. That data are transformed into information. Multispectral classification is one of the most frequently used approaches of information extraction (Lillesand & Kiefer, 1994).

Following this, supervised land use and land cover classification has been carried out using ERDAS IMAGINE software from 2020 Land sat Satellite image. The maximum likelihood image classification was employed for the supervised classification. By having applied the techniques of image classification, land use and land cover types have been classified so as to use the classified images as inputs for generating crop management (C) factor of the Revised Universal Soil Loss Equation. The land use land cover of the watershed was classified with eight major types of land use land cover classes.

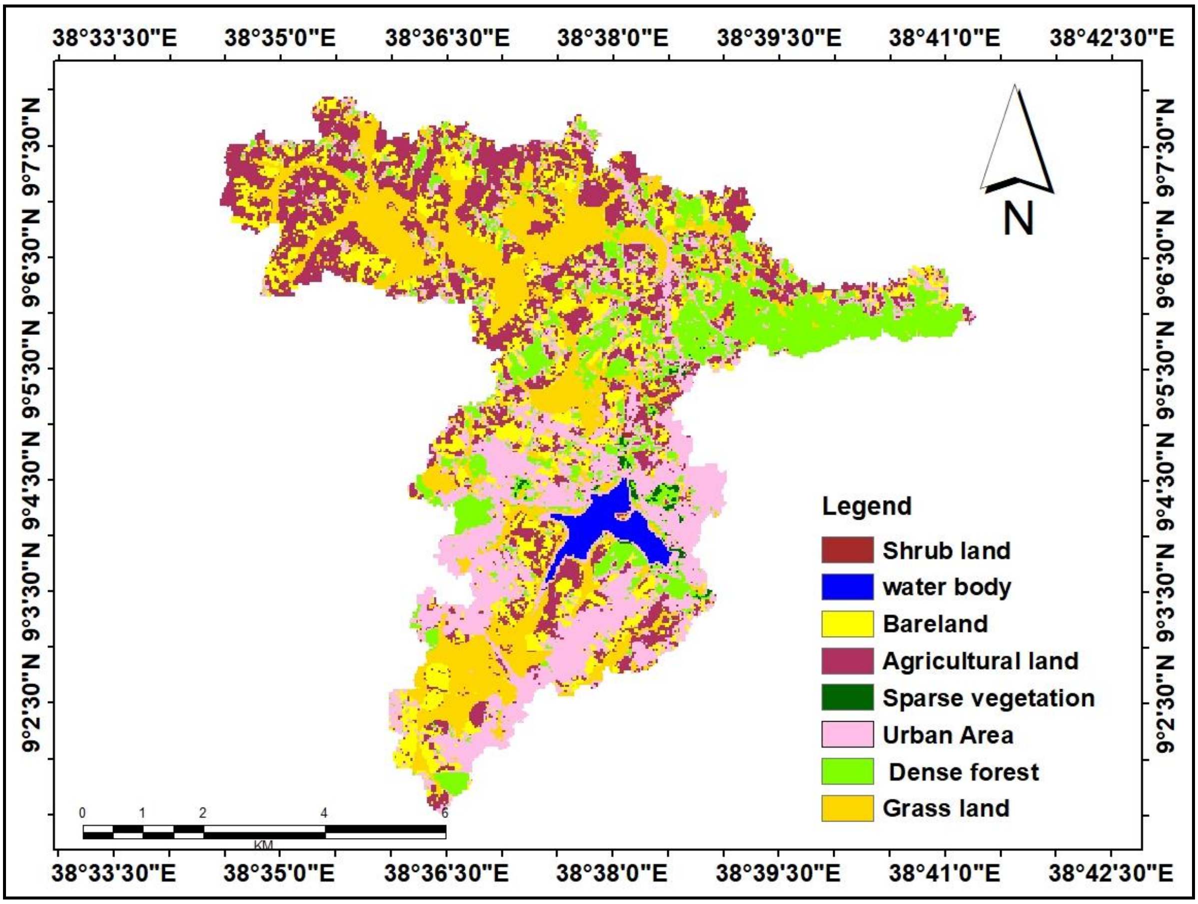

Figure 3:8 Land use land cover map

The classified map, verified with field observations (Appendix Figure 1-3), the study watershed categorized into agricultural area (a land covered by annual and perennial crops, fallow lands), built up area (urban areas, schools and health centre and rural homesteads), bare land (stony or rocky areas and soil exposed without any cover), shrub land(land covered by short trees, shrubs, and scattered trees), water body (area covered by lake, reservoir pond and wetland), dense forest (area covered by dense and tall trees both natural and plantations), sparse Forest and Grassland (an area covered by grasses).

3.4.5. Accuracy assessment

The result of image classification usually has some percentage of misclassification, due to noise and unknown pixels. During classification to what extent the produced classification is compatible with what actually exists in reality is fundamental and should be incorporated as part of the classification process. The study calculated the classification accuracy in terms of producer's and user's accuracy, overall accuracy, and Kappa Statistics. The accuracy assessment was done using 60 reference data from the field using GPS. Ground control points were collected using stratified random sampling method, which is appropriate method for reference data (Congalton and Green, 2009) and accuracy assessment. The accuracy assessment was done through comparing remote-sensing derived classification and reference test data. It was checked for the signature values of classified images calculating the error matrix in ERDAS IMAGE software. The relationship of the sample sets is summarized in an error (confusion) matrix. The confusion matrix is a table with the columns represented the actual (ground truth from field verification) classes, and the rows represent the classified (mapped) classes. The overall accuracy is weighted by the number of sample in each class, i.e. the sum of all samples on the diagonal divided by the total number of cells (7+6+9+5+4+8+5+10)/54 which is equal to 0. 9 or 90 percent (Table 3.8). The kappa statistics calculation was the next steep; Kappa represents the agreement between the classified LULC and the observed land use category. The major cover classes within the study watershed are Shrub land, Waterbody, Bare land Agricultural area, dense forest, urban areas, Sparse Forest and Grassland. For each of the classified cover type's random sample points were established.

Then, each random sample points (60 points) visited in the field for the actual cover type verification (Table 3.8)

Table 3:8 Accuracy assessment

Lu/Lc Accuracy ass	Shrub land	Water body	Bare land	Agricultural area	Dense forest	Urban areas	Spars Forest	Grass land	User
Shrub land	7	1	0	1	0	0	0	0	9
Waterbody	0	6	0	0	0	0	0	0	6
Bare land	0	0	9	1	0	0	0	0	10
Agricultural	0	0	1	5	0	0	0	1	7
Dense forest	0	0	0	0	4	0	1	0	5
Urban areas	0	0	0	0	0	8	0	0	8
Sparse Forest	0	0	0	0	0	0	5	1	6
Grassland	0	0	0	0	0	0		10	10
Procedure sum	7	7	10	7	4	8	6	12	54

The Kappa coefficient lies typically on a scale between 0 and 1, where the 1 indicates complete agreement because it is often multiplied by 100 to give a percentage measure of classification accuracy (100%). Generally, Kappa values characterized into three groups: a value greater than 0.80 (80%) is strong agreement, a value between 0.40 and 0.80 (40 to 80%) be situated moderate agreement, and a value below 0.40 (40%) is poor agreement (Rahman et al., 2006). Therefore, the overall classification of 90% and overall kappa statics of 0.9 was achieved. The reasons for the errors may include the similarity of reflectance between LULC classes and fast land use/land cover dynamic nature of the study area.

Land Use/ cover classification was used for preparing a C-factor map. The raster map was converted to vector and the attributes with same land use type were merged in Arc GIS 10.3 version (Figure 3:9). Since the introduction of the USLE and RUSLE, experimental studies have suggested different values for different cover types and management practices was explained (McCool et al., 2000; Wischmeier & Smith, 1978). It is, however, difficult to apply those values to other environmental settings. In this study, C-factor values suggested by different researchers for different crop and surface cover types in Ethiopia were employed.

Table 3:9 LU/LC and C-factor value of the watershed adopted from (Ethiopian Lu/Lc)

No	Land use	C-factor	Area (ha)
1	Agricultural land	0.17	1256.3
2	Shrub land	0.014	22.3
3	Water body	0.00	113.6
4	Bare land	0.6	756.4
5	Grass land	0.05	1146.5
6	Dense forest	0.01	25.6
7	Sparse vegetation	0.015	830.1
8	Built up area	0.05	1301.0

The C-factor values were assigned to each of these land use–land cover classes (Table 3:8) for the preparation of C-factor map. Thus, based on c-factor the large value shows more vulnerable land use to erosion and on the other hand the lower value shows less vulnerable land use for erosion.

The C-factor values in the watershed vary from 0 for the water body to 0.6 for the bare land of the study areas. From the result bare lands have a large value of c-factor which is highly vulnerable to erosion. Next to bare land agricultural lands (0.17) are more vulnerable than the others. Grass lands, built up, sparse vegetation, shrubs, and dense forest having the c-factor value 0.05, 0.05, 0.015, 0.014, and 0.1 respectively are less vulnerable to erosion.

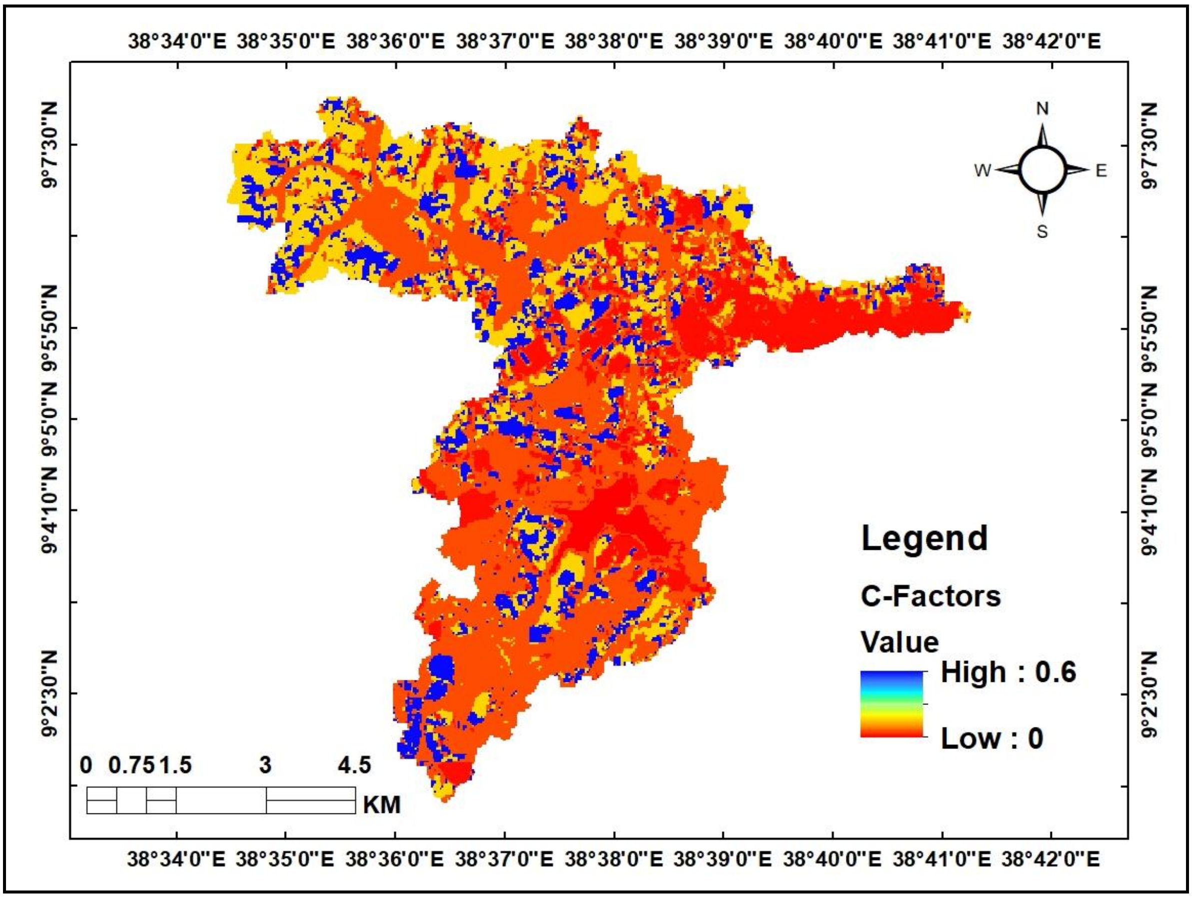

Figure 3:9 Land Use Land Cover factor-RUSLE approach

3.4.6. Supportive Practice (P) Factors

The Support Practice Factor (P) in RUSLE is defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with straight row upslope and downslope tillage. The P factor accounts for control practices that reduces the erosion potential of the runoff by influencing on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. The supporting mechanical practices include the effects of contouring, strip cropping, or terracing (Kim, 2006).

In Geffersa watershed, farming practices in sloppy agriculture land occur through the construction of terraces that closely resembles the contour farmland, which is a mean of the conservation farming. During field visit, it was found that supportive practice are not developed in the watershed except traditional conservation method widely used in the study area as a drainage ditch (Appendix Figure 3), which is used to safely drain excess runoff from croplands during rainstorms (Appendix Figure: 1). However, the available ditches were poorly designed and some of the drain are failed due to poor maintenance. Therefore, the watershed is not treated with improved permanent soil and water conservation measures. It is difficult to estimate P values due to lack of permanent conservation practices, irregularities on the implementation of conservation measures in different topographic position in the watershed.

For the study p factor value has been assigned considering local management practices along with values suggested by (Shin, 1999). Contour slope farm is a widely used method in several areas. The maximum value of the P factor is usually set to one, which means no erosion control solution (Bera, 2017).

Table 3:10 Supportive practice P- factor value

No	Slope (%)	Contouring
1	0-7	0.55
2	7-11.3	0.60
3	11.3-17.6	0.80
4	17.6-26.8	0.9
5	>26.8	1.00

The effect of supportive practice on soil loss was assessed by P-factor estimation taking into account: (a) contour farming, (b) maintenance of stone walls, and (c) grass margins.

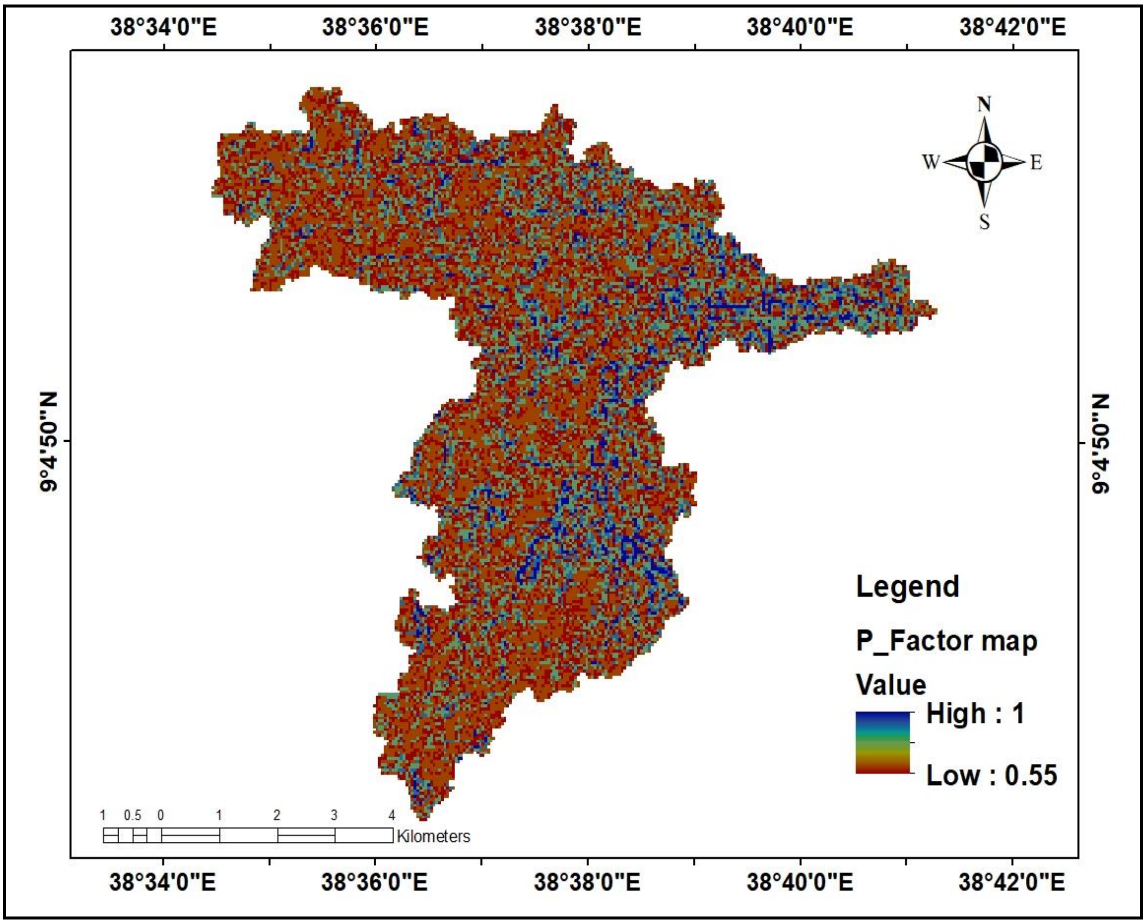

Figure 3:10 Supportive practice map - RUSLE approach

A decreasing value of the P factor means reduced intensity of sediment, deposition on the surface and flowing water is reduced in terms of both volume and velocity. Hence, the support practice factor in the upper part of the watershed where steep slope area dominated, and support practices were not yet constructed has substantial soil erosion. A corresponding P-value was assigned to each contour using the reclassify method in GIS 10.3 (Figure 3:10). Slope map developed from DEM, and the P-value of 0.55, 0.6, 0.8, 0.95 and 1 were given for slope gradient class of 0-7, 7-11.3, 11.3-17.6, 17.6-26.8, and >26.8 percent respectively.

3.5. Methods of Sediment Delivery Ratio (SDR) Estimation

The sediment delivery ratio value in a given watershed indicates the integrated capability of a catchment for storing and transporting the eroded soil (Yang et al., 1998). It compensates for areas of sediment deposition that become increasingly important with increasing catchment area. Therefore, determines the relative significance of sediment sources and their delivery. That may affected by variable of the physical characteristics of a watershed such as drainage area, slope, relief-length ratio, runoff-rainfall factors, land use land cover and sediment particle size (Vanoni, 1975; Wischmeier & Smith, 1978).

The amount of floodplain sedimentation occurring and the presence of hydrologically controlled areas such as small ponds, reservoirs, lakes and wetlands also affect the rate of sediment delivery to the watershed mouth (Gelagay, 2016). According to various previous researchers have been conducted sediment delivery ratio curves include SDR vs. drainage area and SDR vs. distance (Kusimi et al., 2015). The drainage area method is most often and widely used in estimating the sediment delivery ratios rather than distance method.

$SDR = a\ A^{-b}$ ………………………………………..……….…………… (8)

Where A is the drainage basin area; a & b are correction factors related to the physical characteristics of the basin. The adjustment b variable has physical characteristics of sediment transport and is interrelated with the rain-flow phenomenon, and the negative sign signifies that with an area increase SDR decreases, means inverse relationship with area (Ferro & Minacapilli, 2009)

The inverse relationship between SDR and drainage area described by Boyce (1975), the SDR may affected by the topographic features of the watershed, the steepest areas of a basin are the main sediment detached zones, and since average slope decreases with increasing basin size the sediment production per unit area decreases too. Thus, the large catchment have more sediment storage areas located between sediment rise areas and the watershed outlet. (Vanoni, 1975) formulate an equation for estimating SDR, based on data from 300 watersheds throughout the world to develop a model by the power function. This model is considered a more generalized one to estimate sediment delivery ratio.

$SDR = 0.42A^{-0.125}$………………………………………………………………….. (9)

The USDA SCS (1979) developed a comparable equation with similar parameter of SDR model based on the data from the Blackland Prairie. A power function is derived from the graphed data

$SDR = 0.51A^{-0.11}$…………………………….…….………………………………… (10)

Where A = drainage area in square KM.

A watershed with short and steep slopes will deliver more sediment to a channel than a watershed with a long and flat landscape.

For the first time, Williams and Berndt (1972), derived the sediment delivery ratio for the catchment basin of Brushy creek of Texas. That investigation connected SDR to the geomorphological and sediment-logical feature of the catchment. The equation is written as follows

SDR = 0.627*(Msc%)^0.403……………………………………………………………(11)

Where Msc% = percent slope of mainstream channel

The mainstream is defined as the stream of the highest stream order. According to Nguyen & Chen, (2018) suggested that the slope of the mainstream depends on the stream profile, and is defined as the horizontal distance along the mainstream channel divided by the elevation difference between the two end points of the mainstream.

Table 3:11 Different approach to estimate sediment delivery ratio

Models	Area (km^2)	Authors
$SDR = 0.42A^{-0.125}$	2.6-1295	(Vanoni, 1975)
$SDR = 0.51A^{-0.11}$	1.3-388.8	(USDA, 1979)
$SDR = 0.627(Msc\%)^{0.403}$	0.5-180	(Williams & Berndt, 1972)
$\log SDR = 2.9 + 0.869 \log R - 0.854 \log L$	560	(Maner, 1958)

Where Msc = main channel slope in percent L= length of watershed

As the Table 3:10 indicates, various models related to the Sediment Delivery Ratio (SDR) methods have been developed based on combinations of the variable physical characteristics of a watershed. The drainage area method is more easy than other parameters in estimating sediment delivery ratio (Vanoni, 1975). The large area have more chances to trap soil particles, thus the amount of sediments reaching the water channel system is low. Therefore, the SDR values is also low. Furthermore, the drainage area method is most often and widely used in estimating the sediment delivery ratios rather than distance method. Nonetheless, their application is limited to only small catchments with adequate data. Therefore, the estimation by this method is irrelevant, because the method is not considered variation of watershed characteristics, geographical features, and their complex interaction. For example, a watershed with steep slope has a higher sediment delivery ratio than a watershed with middle and low slope. A watershed with bare soil land cover has a higher sediment ratio compared to the same watershed with a forest area.

Unlike to the drainage area method, Williams & Berndt, (1972) conducted that the average main stream channel slope is more significant than other parameters in estimating sediment delivery ratio, which is expressed as a function of percent slope of main stream channel. The SDR based on the main stream channel slope was employed by several researchers, it offers got reasonable results with a limited data. In order to determine sediment delivery ratio of the study area mainstream channel was considered to quantify amount of the sediment deliver to the outlet. In this process, DEM was corrected for fill sink as well grids of flow direction, flow accumulation and stream network were determined. Subsequently, conducting terrain pre-processing, the flow length was determined using Arc GIS extension of HEc GeoHMS 10.2 version.

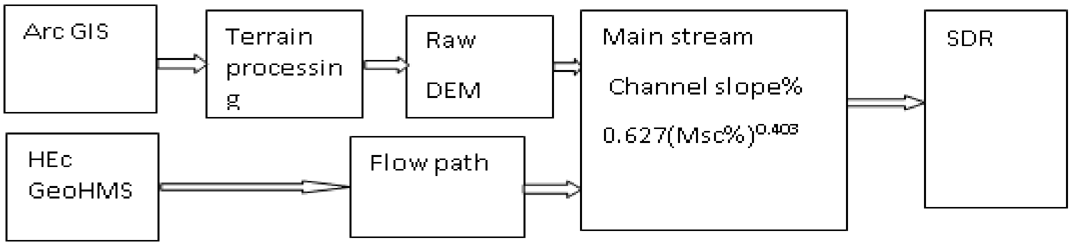

Figure 3:11 Diagrams of sediment delivery ratio

As indicated in the diagram (Figure 3:11), By taking the flow path and Digital Elevation Model, the average mainstream channel slope (Msc) values in percentage for each cell in the flow path was calculated for the estimation of the sediment delivery ratio value for that cell amount upstream from that cell. Each cell in the flow path can be considered as the outlet of its upstream catchment. Therefore, the SDR value of that cell measures the sediment delivery capacity of its upstream catchment as stated by (Williams & Berndt, 1972).

3.1. Methods of Sediment Yield (SY) Estimation

The soil that is eroded from the land surface is delivered to the nearby River section where is defined as sediment yield. The sediment yield from the watershed is the net sediment flux resulting from the upland erosion and in the lowland deposition and transport into the River networks (Sahaar, 2013). Soil eroded from the upland catchment causes depletion of fertile agricultural land and the resulting sediment delivered to the River networks creates River morphological change and reservoir sedimentation problems. Soil erosion is the first step in the sedimentation processes which consist of erosion, transportation and deposition of sediment (Summer & Walling, 2002). A fraction of eroded soil passes through channel system and contributes to sediment yield while some of them deposit in water channels (Geleta, 2010). Expressed as the percent of annual soil erosion by water estimated by RUSLE that is delivered to a particular point in the drainage system.

Accurate estimation of sediment delivery ratio is an important and effective approach. Thus, for this study sediment yield was computed by overlaying the raster layer of mean annual soil loss obtained by RUSLE model analysis (equation 1) and the main stream channel slope based sediment delivery ratio using as following (equation 12)

$$SY = \sum_{i=1}^{n} SDRxSE \qquad (12)$$

Where SDR is the sediment delivery ratio (dimensionless); SY is the annual sediment yield (ton/ha/year), and SE is the gross soil erosion (ton/ha/year) n is the total number of cells over the catchment. The following conceptual flow chart show how to prepared soil erosion risk map and sediment yield map.

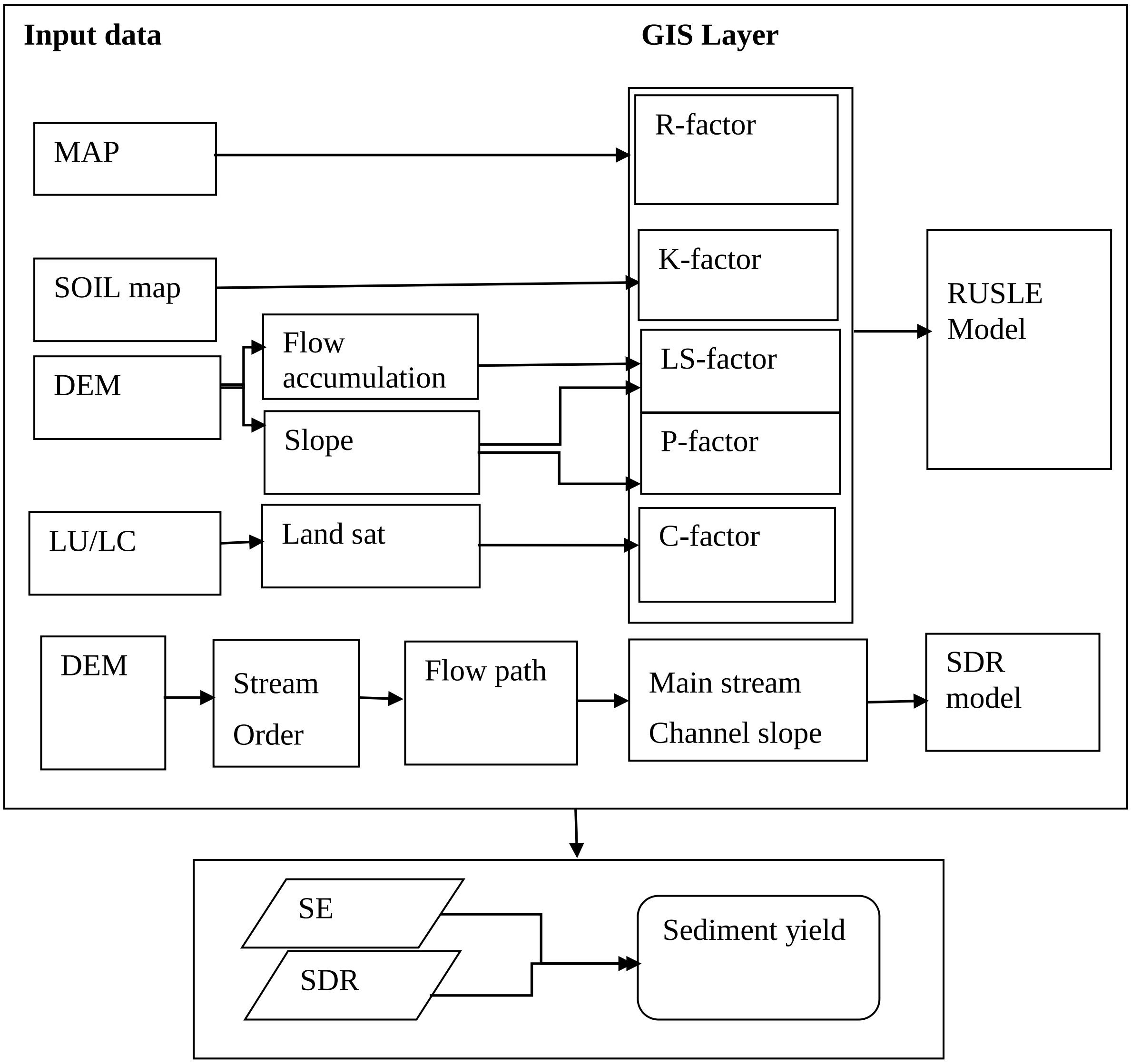

Figure 3:12 Conceptual framework of sediment yield estimation techniques

3.1. Trapping Efficiency (Te) Estimation Method

Several empirical studies; (Churchill, 1948; Brune, 1953; Gill, 1979; Heinemann, 1981) showing the relation between reservoir storage capacity, water inflow, and Te; have been conducted. The Brune (1953) is a most widely used method for estimating the sediment retention in reservoirs. According to Bube and Trimble (1986), the Churchill curves may give a better prediction of Te than the Brune curves, but using Churchill curves method is very difficult to obtain the input data for calculating the sedimentation index. This is commonly the reason of Brune's approach is used so extensively as opposed to that of Churchill. Especially for small dry or semi-dry reservoirs where the outlet is located at the bottom of the embankment, it is very difficult to calculate these data as these outlets only operate during infrequent, short-lasting events.

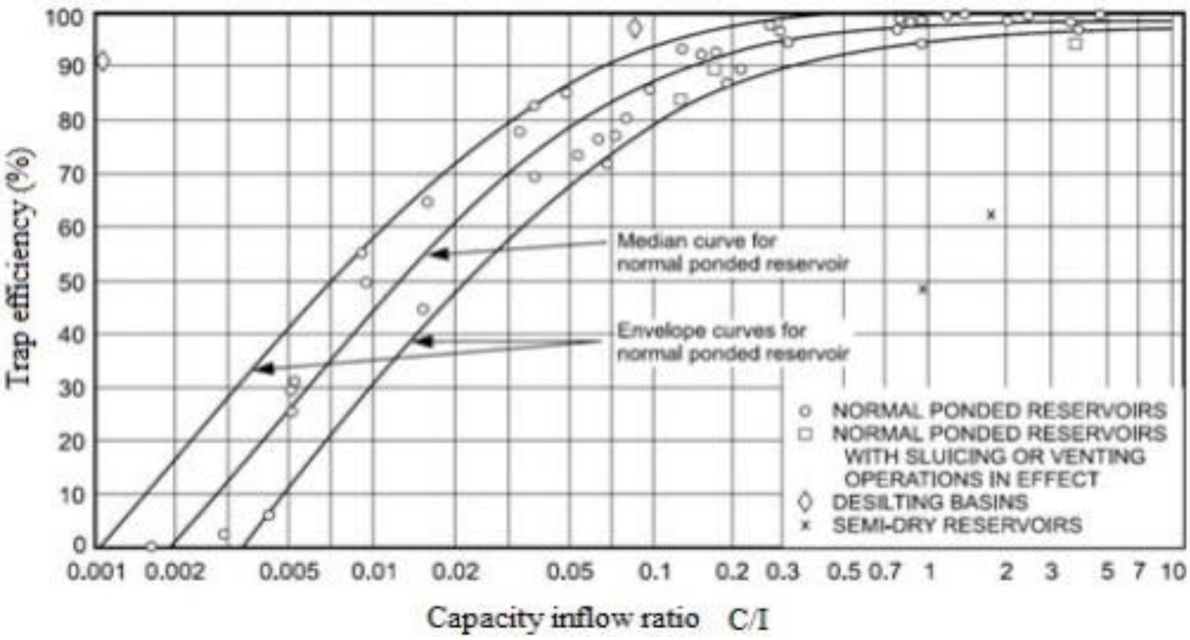

Figure 3:13 Brune's Curve for Estimating Sediment Trapping Efficiency (Source: Brune, 1953)

Brune (1953) curves were drawn based on data from 44 normal ponded reservoirs in the United States. Brune (1953) plotted the Te against the reservoir C/I. The Brune (1953) graph is composed of three curves, one median and two envelop ones.

Primarily Highly Flocculated and Coarse Grained Sediments

$$\mathbf{T}_{e} = \frac{\left(\frac{C}{I}\right)^2}{0.994701\left(\frac{C}{I}\right)^2+0.006297\left(\frac{C}{I}\right)+0.3*10^{-5}} \quad \ldots\ldots\ldots\ldots 13$$

Median Curve (for Medium Sediments)

$$\mathbf{T}e = \frac{(\frac{C}{I})}{0.012+1.02(\frac{C}{I})2} \quad \text{.. 14}$$

Primarily Colloidal and Dispersed Fine-grained Sediments

$$\mathbf{T}e = \frac{\left(\frac{C}{I}\right)^3}{1.02655\left(\frac{C}{I}\right)^3+0.02621\left(\frac{C}{I}\right)^2-0.133*10^3*\left(\frac{C}{I}\right)+0.1*10^{-5}} \quad \text{.............................. 15}$$

For this study capacity inflow (Brune curve) method has been selected to estimate trap efficiency of Geffersa reservoir. Because, Brune's curve which equates capacity to inflow ratio requires little input data, is simple to apply and has been very widely used to estimate reservoir trap efficiency.

3.2. Reservoir Useful Life Estimation Method

A direct method for useful life estimation of a reservoir was proposed by Gill (1979) which correlates the reservoir capacity with age in years algebraically. With the relationship between sedimentation rates, Te, specific weight of sediment deposited, the storage available after sedimentation for a given period change of time was estimated using the following equation:

$$Co - C = \frac{G*Te*\Delta t}{\gamma} \quad \text{...16}$$

where, *Co* is the initial capacity of reservoir; *C*, is reduced capacity of reservoir at any time *t*; *G*, is characteristic weight of annual sediment inflow; *Δt* is a short interval of time in years in which capacity is reduced from *Co* to *C* ; and γ is specific weight of sediment deposited.

3.2.1. Specific weight of deposited reservoir sediment

To obtain the rate of sedimentation in the reservoir, an average specific weight of reservoir sediment is required. Sediments coming to the reservoir are usually mixture of sand, silt and clay in different proportion. The specific weight of this sediment mixture can be determined by adding the fractional weights of sand, silt and clay. The bulk density or the specific weight (unit weight of dry sediment material in kg/m^3) of the deposits will vary with the proportions of sand (>0.05mm), silt (0.01 to 0.05mm) and clay materials (<0.01mm), the type of reservoir operation (exposed or submerged sediment deposits) and the consolidation period. Different density of deposited sediment has been used by different Authors. For example, Tadese (2013), considered 1.12 t/m^3 for GERD reservoir; ENTRO (2007) based their calculation by assuming density of sediment deposit as 1.5 t/m^3 and Ahmed (2008), stated that the most common density is 1.12 t/m^3 which was used for Mandaya reservoir sedimentation study. Collecting sediment sample and laboratory test is time consuming and tedious at this level, fortunately experimental test was carried out by Tectabel and others (2002). Accordingly, the result was showed that the mean bulk density of deposited sediment in the Geffersa reservoir is predicted to 1.45t/m^3. Additionally, master plan review (2011), confirmed that estimation and the sediment density of Geffersa and Legadadi reservoir were estimated to 1.45ton/year.

4. RESULTS AND DISCUSSION

The average annual soil loss and sediment yield were calculated by combining each factor layer together according to the RUSLE formula (equation 1) and SDR (equation 11) using the raster calculator of algebra functions and associated packages in a GIS framework.

As the results in previous section showed, the rainfall erosivity factor value range between 679 and 697 MJ mm/ha/year (Figure 3:6) with the lowest values being in the Western part and highest values in the North-Eastern part of the watershed. Soil erodibility factor values range from 0.04 to 0.032 metric ton/ha/MJ per mm. The topographic Factor (LS) value for the entire watershed ranged from 0 to 10.45. The value of the Cover Management Factor (C) ranged between 0 and 0.6. The highest value shows the more erosion capacity in comparison with bare land area (Figure 3:9). The Support Practice Factor (P) value ranged from 0.55 to 1 where a higher value indicates there is no support practice such that erosion is at its maximum due to the absence of any supportive practice (Figure 3:10)

After preparation of the appropriate maps as data layers, the maps for values of the RUSLE parameters factors were integrated in ArcGIS using a raster calculator to form a composite map of terms RKLSCP. The map of composite term where represents soil loss of different grid cells. High values of this term indicate the higher potential of soil erosion in the cell and low values show the low potential of erosion.

4.1. Estimation of Annual Soil Loss of Geffersa Watershed

RUSLE model has five parameters such as rainfall erosivity, soil erodibility, slope length and steepness, cover management, and support practice factors. In order to estimate the average annual soil loss in the Geffersa watershed has been computed by multiplying all those parameters of the RUSLE model using the developed raster calculator function tool of the ARC

GIS 10.3 environment. Finally soil erosion map displays the average annual soil loss of the Geffersa watershed as indicate here (Figure 4:1).

The result shows that the potential annual soil loss of Geffersa watershed ranges from 0 to 728.48 t/ha/year. The soil erosion hazard map of the Geffersa watershed the highest raster value shows that areas which are extremely vulnerable to soil erosion, while lowest raster values indicate the study area which is less vulnerable to soil erosion. Actually estimated annual soil loss range found in the study area was exceeds the maximum ranges estimated by FAO (1986).

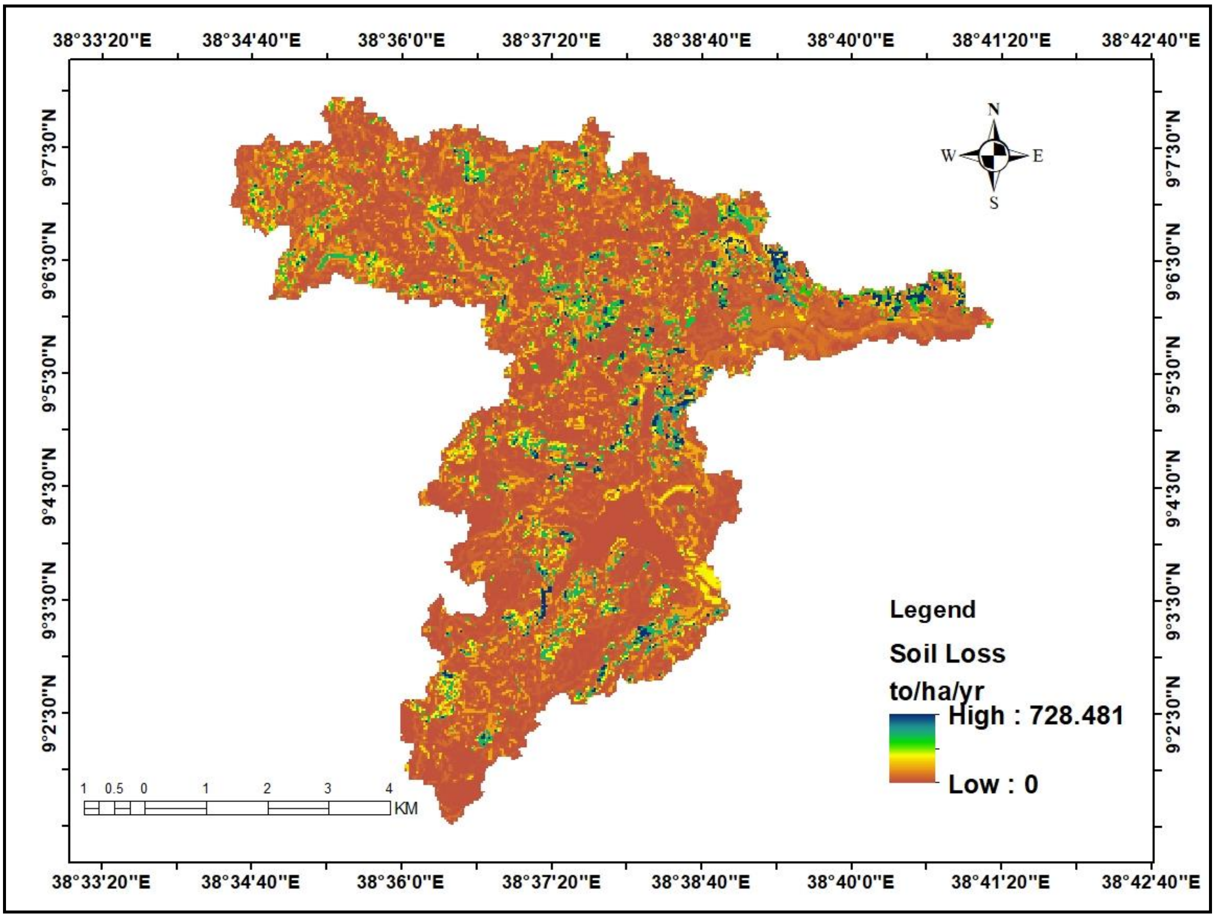

Figure 4:1 Annual soil loss rate of the study area

According to the estimation of FAO (1986), the annual soil loss of the highlands of Ethiopia ranges from 1248–23400 million ton per year from 78 million hectare of pasture, ranges and cultivated fields throughout Ethiopia, which means equivalent to 16 to 300 t/ha/yr. The mean annual soil loss rate of the study area is 23.6 ton/ha/year, which found that average annual soil loss of the watershed is higher values than the tolerable level of Ethiopian 0-18 tons/ha/year reported by (Hurni, 1985). However, the tolerable limit of soil loss depends on the local parametric variation such as soil type and its depth, land use/ land cover, topography and the amount of rainfall (McCool et al., 2000).

Validation of the model estimates was challenging in this study, due to limited available data to weigh against the model estimates with the actual soil loss. However, the ranges of the soil loss have been much related to estimate for Koga watershed 0-750 ton/ha/year (Molla & Sisheber, 2017) and Gedalas watershed 0-935 ton/ha/year (Yesuph & Dagnew, 2019) in the northern highlands of Ethiopia. According to Kouli et al. (2009), any soil loss rate which exceeds 10 t/ha/year will not be reversed in a time span of 50 to 100 years. The estimated average annual soil loss rate found in Geffersa watershed exceeds this maximum tolerable soil loss rate. This fact indicates how far soil erosion is a serious dangers to the Geffersa watershed. Increasing agricultural activities and settlement area are the major reasons to increases erosion in the watershed. The investigation developed by (Belayneh et al., 2019), demonstrates that the soil erosion rates are highly dependent on the agriculture use. Moreover, the characteristics of watershed in terms of the topography and land use land cover are significant impacts on soil erosion in the study area.

Different researchers use various soil loss severity classes depending on the purpose of the study and the geographical context of the study area. Therefore, the spatial distribution of the soil loss map of the watershed was reclassified, adopted from (Haregeweyn et al., 2017), then the erosion risk map was prioritized depending on the severity classes.

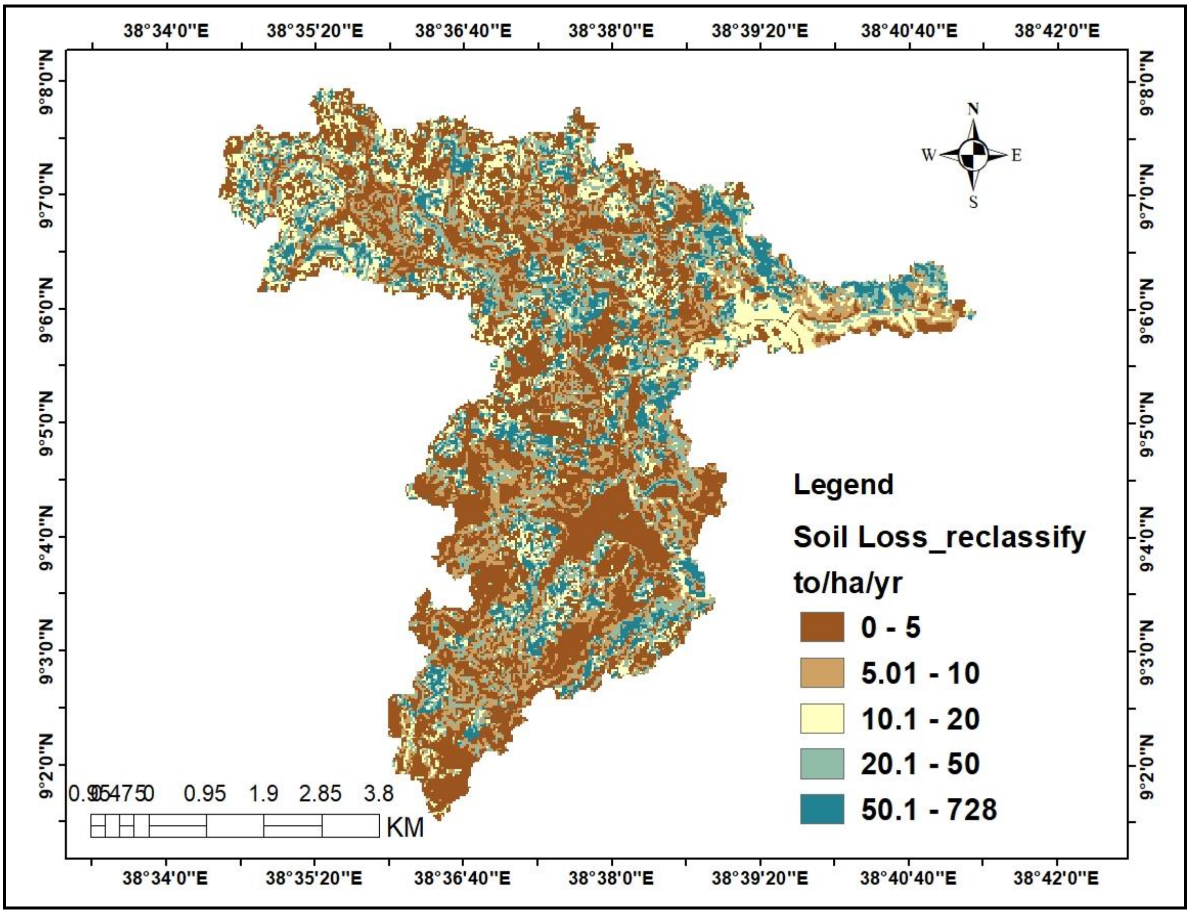

Figure 4:2 Spatial distributions of potential annual soil loss and severity classes

The annual soil loss of Geffersa watershed is categorized in to five classes. Soil loss less than 5 t/ha/year which is described as very slight soil erosion risk class; between 5 and 10 ton/ha/year described as slight soil erosion risk class; between 10 to 20 described as moderate soil erosion risk class; between 20 and 50 ton/ha/year described as severe soil erosion risk class; and above 50 ton/ha/year described as very severe soil erosion risk class.

Table 4:1 showed that about 606.34ha of the study area falls under the very severe class and it needs an immediate attention of soil and water conservation treatment. About 772.73ha of the study area falls under the severe class. The remaining area of the study falls under the very low, low and moderate classes. Thus, areas with high erosion severity class needs urgent prioritized soil and water intervention measures to keep the sustainability of land in the Geffersa watershed.

Table 4:1 Annual soil loss rate, severity classes and conservation priorities

No	Erosion risk class and rank	Range of soil loss potential (ton/ha/year)	Area (ha)	Area (%)	Priority classes
1	Very slight	0-5	2334.64	43.37	V
2	Slight	5-10	826.49	15.34	IV
3	Moderate	10-20	845.06	15.69	III
4	Severe	20-50	772.73	14.34	II
5	Very severe	>50	606.34	11.25	I

The area coverage and relative percent of each class have been derived from the soil erosion map of the study watershed. The annual erosion map is helpful in identification of hotspot areas to soil erosion. The land use land cover, slope steepness and supportive management parameters are the main factors governing soil erosion potential at a particular location to the erosive power of rainfall.

4.2. Sediment Delivery Ratio (SDR)

The watersheds with steep slopes, smaller drainage area and the fields with short distance to the streams have a higher sediment delivery ratio than a watersheds with flat and wide valleys, large drainage area and fields with long distance to streams. This is because large areas have more chances to trap soil particles. Thus, the chance of soil particles reaching the water channel system is low. Therefore, more eroded soil in the upstream areas transported into the channels and delivered outlet of the watershed.

The eroded sediment which passes to the channel and contributes to sediment yield ranges from 7.3 to 19.6 percent. In the upper, closest and steeper part of the watershed, 19.6 percent of the eroded soil particles passes to the channel system and delivered to Geffersa watershed streams. It is therefore, this part of the watershed has high capability to transport the eroded material, otherwise less trapping capacity.

The large basins also have more sediment storage areas located between the sediment source and the watershed outlet. Consequently, the lower, flatter and wider part of the watershed only 7.3 percent of the gross soil loss is delivered to the outlet. The 92.7 percent of the eroded materials are redeposited in the area of the watershed and low amount of the sediment delivered to the channel network.

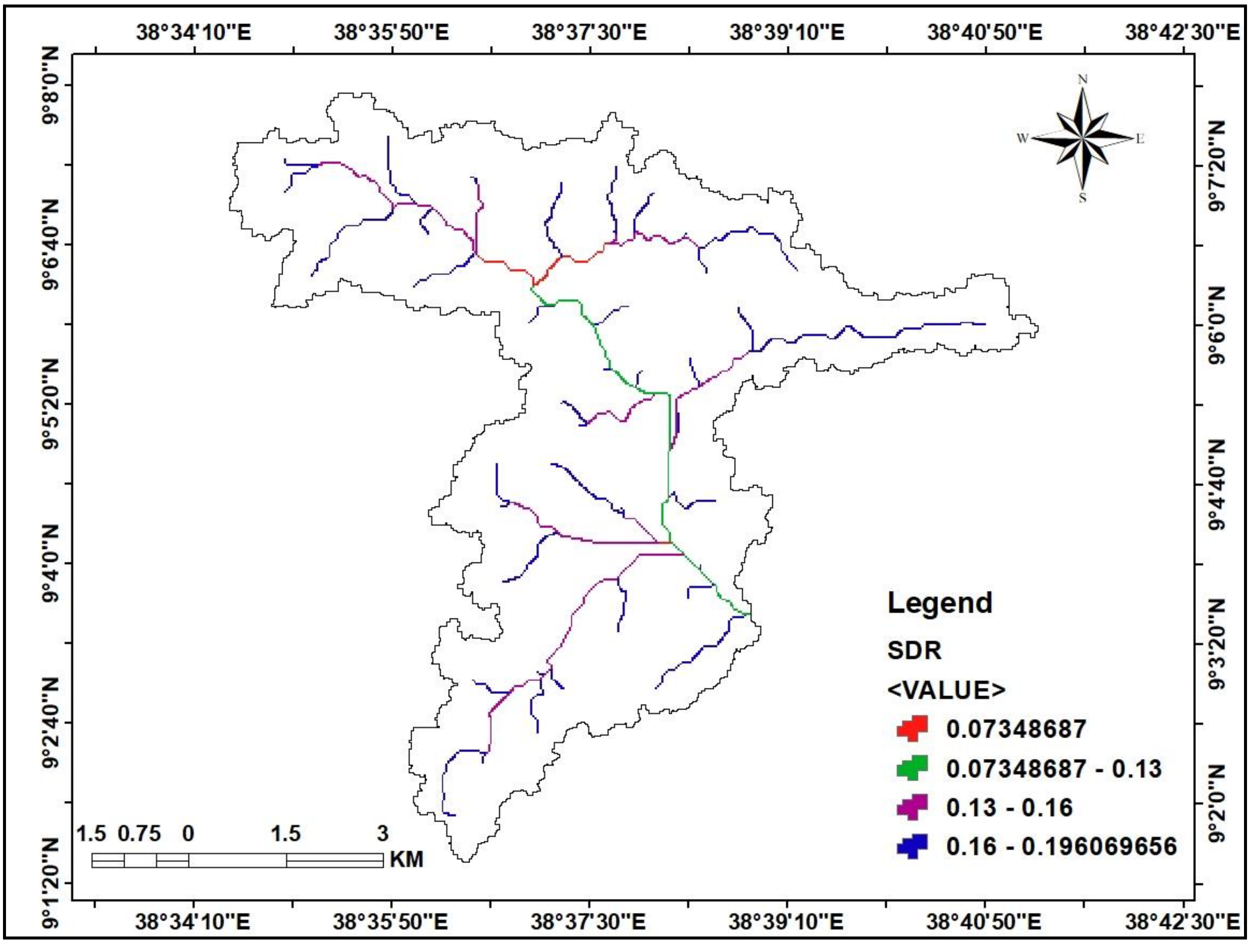

Figure 4:3 Sediment delivery ratio map

The sediment delivery ratio map (Figure 4:3) was showed reasonable because it reflects that the ultimate nature of sediment delivery that erosion occurs in the steeper location will have more opportunities to be transported into the channels than to be deposited downslope. The main channel slope based equation is estimate relevant value when it compared with available fact of watershed. As another investigator conducted that main stream channel slope has given a related estimation (Gelagay, 2016).

4.3. Annual Sediment Yield of the Watershed

Sediment yield was computed using the channel slope based SDR model. It was expressed as annual soil erosion from the watershed estimated by RUSLE that is delivered to a particular point in the watershed system. The annual soil loss in Geffersa watershed was estimated in above section and found between ranges 0 to 728.48 metric tons per hectare annually. Sediment delivery ratio was estimated using the main stream channel slope as a main parameter and on average sediment delivery rate of 16.3 percent was estimated in Geffersa watershed. Finally, spatially distributed map of sediment yield was produced through multiplication of raster layer in Arc GIS10.3 environment. The annual sediment yield of the watershed was estimated by multiplying the soil loss map (Figure 4:1) and the sediment delivery ratio map (Figure 4:3).

As indicated in (Figure 4:4), the Sediment Yield (SY) of the watershed ranges from 0 to 78 ton/ha/year, which has a similar spatial pattern with that of soil loss and sediment delivery ratio map. The average annual sediment yield of the watershed is 5.3 ton/ha/year (that means 28,893.48 ton/year). The higher sediment yield values occur in upper part of the channel. The estimated result is consistent, when it compared with previous study in the same watershed. For example, the study indicates the reduction of siltation that reduced from 32,063.7 ton/year reported by (Tarekegn, 2012), to 28,893.48 ton/year of the sediments. Another researcher (Daba, 2017) estimated that 27,288.75 ton/year. This indicates that sediment yield is a continuously critical problem in Geffersa watershed. The estimated value of sediment yield is still varying and doubtful. The cause of the differences of the estimated sediment yield may be related to the dynamic land use land cover and quality of input data. Additionally, there are several reasons for high sediment yield such as, high steep slopes, many crop field areas along the main channel and streams in Geffersa watershed formation.

The estimated sediment yield from the watershed are in reasonable agreement with most previous studies. The regional sediment yield studied in the UBNR basin reported by (Haregeweyn et al., 2017), spatial variability between 0 and 50 ton/ha/year.

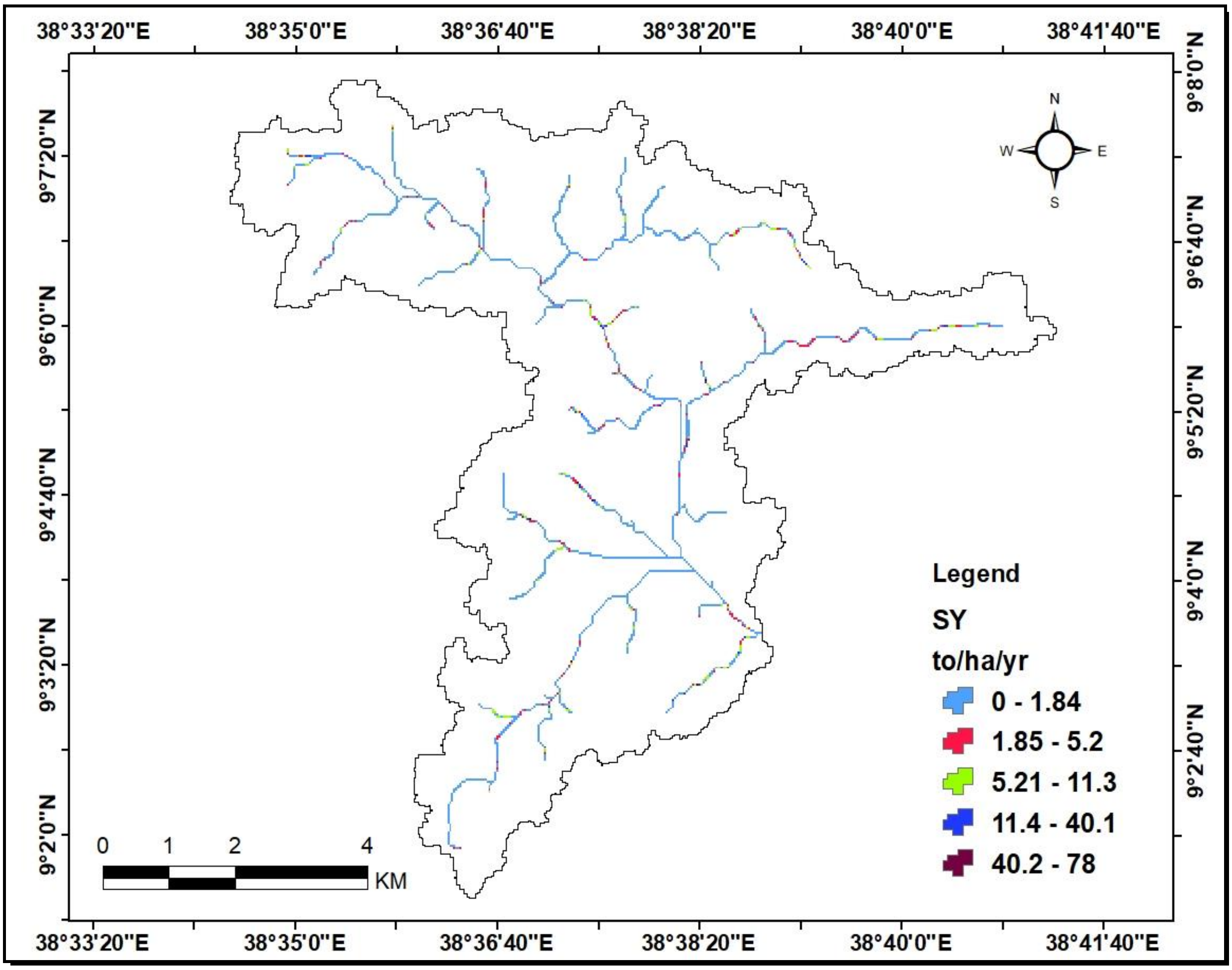

Figure 4:4 Sediment yield map of the study area

This finding is also consistent with the work of (Gelagay, 2016) and others who have reported that under comparable area in Ethiopia regions. Similarly, without consider channel erosion (Fernandez et al., 2003), estimate 3.5 ton/ha/year average annual sediment yield at Lawyerk Ceek watershed. However, the result is much lower than the annual sediment yield ranges estimated for Pra River basin with 0 to 195 ton/ha/year by (Attua et al. 2015).

As the results showed that, the amount of the sediment yield delivered to the outlet of the watershed is very low when compared with estimated gross soil erosion. It indicates the rate of sediment carried out by the natural streams is much less the gross erosion on its upstream watershed. The most of the sediment is redeposited at intermediate locations whenever the transport capacity of runoff is insufficient to sustain transport (Sahaar, 2013). This indicate between the source and the outlet, varying proportions of the eroded materials are deposited, for example particles eroded from bare upland areas trapped in flat vegetated areas.

4.4. Useful life of Geffersa Reservoir

The sediment trap efficiency of Geffersa reservoir was also calculated from the estimated capacity ratio using figure 3:13. The result indicated a trap efficiency value of 94 percent. This corresponds to sediment trap efficiency estimated for GERD (97%) by Tadese, (2013). Based on the average annual sediment yield to Geffersa reservoir useful life of reservoir has been estimated. The useful life of the Reservoir has been estimated by considering various scenario of filling the storage with sediment. In terms of volume loss of the reservoir the total accumulated rate of the sediment is 0.0199Mcm^3 per year. If the same rate of sedimentation continues, the total storage volume will be filled up in 394 years.

Table 4:2 Estimated useful life of reservoir

Capacity ratio C/I (MCM)	Trap efficiency	Estimated SY(G)ton	Estimation of (BS) TL (years)	Estimated TL (years)
0.2956	94	28893.48	310	394

From Table 4:2 it is found that present study useful life estimation shows good agreement with bathymetric survey estimation. Present study estimation is also very close to MPR, (2011) estimation. The volume of the reservoir observed during renovation by bathymetric survey (7.39 Mcm^3), the annual reduction in storage capacity could be estimated as 0.269%. To determine the useful life, time periods at which 20%, live storage; 30%, 50%, 80%, 100% of live storage would fill with sediment are considered. The present study Te equation and sediment rate equation may be applied to the Geffersa Reservoir for the future estimation.

Table 4:3 Useful life of reservoir per time to expect

Loss capacity	Estimated Life Time (year)	Remained volume
20% storage	78	5.929 MCM
30% storage	118	5.18 MCM
50% storage	197	3.7 MCM
70% storage	276	2.22 MCM
80% storage	315	1.49 MCM
100% storage	394	0

As reported earlier, bathymetric survey (1979) estimated the volume of sediment retained using hydrographic survey method, and the rate of sedimentation and Trapping efficiency using Brune (1953) median curve methods showed relative estimation to the study. As the study estimation it is considered that the reservoir have a long remaining life expectancy, and in all cases, even if the soil erosion conditions in the catchments change dramatically, the study can expect that for at least the next 100 years they will continue to operate and supply the Addis Ababa water distribution network.

4.5. Reservoir Sedimentation Management method

After the major sediment sources and amount of sediment yield are known, the next section describes what type of opportunities available to manage the reservoir sedimentation in a sustainable manner. It to determine management activities can be adopted that is feasible to the study area to prolong the life of the reservoir. Reservoir sedimentation is another indirect measure of soil erosion, is one of the major outside watershed damages caused by soil erosion (Kusimi et al., 2015).

4.5.1. Sediment Routing

It is one of the sediment management techniques and refers to the movement of sediment around or through the reservoir (Basson, 2013). One of the method is to pass sediment loads through a reservoir is sluicing. A sluicing approach may be employed at reservoirs of all sizes, but the duration of sluicing depends on the watershed size and the time scale of flow flood occurrences. Successful sluicing depends on the availability of excess water and relatively large bottom outlet at the dam. A major disadvantage of sediment routing is that a significant amount of water must be released during floods to transport sediments (Morris, 2020).

Hydraulically clearing accumulated sediments from a reservoir by releasing flow through low-level outlets at the dam for an extended period of time. For completely flushing the reservoir capacity to mean annual runoff ratio should be quite small, say less than 0.2 year (Basson, 2013). An evaluation of different reservoir conducted by (Sumi & Kantoush, 2011) suggested that sediment routing is very effective for reservoirs with a ratio of total capacity to annual runoff less than 0.1. However, in the case of Geffersa reservoir the reservoir capacity to mean annual runoff ratio is higher than 0.2 in year (Daba, 2017). Therefore, Sluicing is not feasible for the Geffersa reservoir.

Bypass tunnel is also another sediment management method that diverts reservoir inflows of high sediment concentration around the reservoir and downstream of the dam (Kondolf et al., 2014). A numerical model could be used to simulate time periods where sediment concentrations exceed a certain threshold. For those time periods, all or a portion of the inflowing water could be diverted through the bypass tunnel, along with the corresponding sediment load. The remaining sediment inflow can be simulated to enter the reservoir. The sediment transport capacity of the bypass tunnel can computed to verify that diverted sediments will be transported through without deposition. Coarse sediment loads can be expected to cause abrasion of the tunnel lining at some rate, and should be anticipated during design (Basson, 2013).

4.5.2. Sediment Removal

The secondly, curative methods to Sediment deposits in reservoir may be mechanically removed from reservoir by hydraulic dredging or dry excavation and hydro-suction (Morris, 2020; Randle et al., 2019; Sumi & Kantoush, 2011). Depending on the rate of sediment removal, the location of dredging may have to be periodically moved throughout the reservoir.

In addition, fluctuations in reservoir levels may also require different locations of dredging. Dredging may be done at fixed intervals for small or medium-sized reservoirs. It can also be an ongoing operation for some large reservoirs. It is a short-term remedial measure to improve the problem of sedimentation in the reservoir and does not provide a long-term solution to the problem. This method can restore storage to its maximum because it can remove bank deposits which flushing cannot handle.

Dredging is used if other methods (such as flushing, bypass construction, and drawdown flushing) are not successful or feasible, and the dam cannot be raised or replaced. Therefore, Sediment removal by dredging to recover lost storage capacity should be seen as the last option as the removal of sediment deposit is extremely expensive, and it requires site specific equipment and, disposal creates new social and environmental problems (Basson, 2013).

Mechanical excavation is usually much more expensive than dredging due to high transport cost and double handling (Kondolf et al., 2014). Mechanical excavation is best adopted to reservoir that purposed for flood control. This method require completely drawdown. Additionally, excavation is not allowed and very dangerous for hydraulic structures like Geffersa III embankment dam. While applying mechanical removal techniques two things have to consider. The first consideration is that the length of disposal area from the reservoir should be less than 3Km (Daba, 2017). If this condition is fulfilled, checking for environmental and social aspect is very essential. The environmental and social consideration is from the sediment contamination and downstream use of the River point of view. Due to those constraints, removal through mechanical excavation and dredging is not feasible for Geffersa reservoir.

Haregeweyn et al. (2012) conducted that excavation of the sediment using either machinery or manual at the same time promoting the use of the sediment for reclamation of the surrounding land may be a feasible solution. That approach would both increase the lifespan of the reservoir and promote the rehabilitation of eroded farmlands. However, this method is impossible due to the high cost, technically difficult and environmental impacts.

Unlike mechanical excavation and dredging, when topographic conditions are favourable, a large-capacity channel or tunnel can be constructed to bypass sediment-laden flow around the reservoir or part of it (Kondolf et al., 2014). Otherwise, the construction of the tunnel cost much more expensive when it is compared to the economic value obtained by reserving the storage capacity of the reservoir. Therefore, sediment bypassing is also not feasible for the site.

4.5.3. Sediment Yield Control

To enhance the productivity of the land and to decrease siltation of the water body, it is crucial to implement watershed management activities inside the basins (Aga et al., 2018). Due to resources limitations, implementing soil conservation measures in the entire basin at a time is impractical. Therefore, prioritization of hotspot areas based on the severity and hazards of soil erosion is imperative.

Watershed management is includes the implementation of stone bunds to reduce sheet and rill erosion of arable land and hill slopes, check dams in gullies control of overgrazing, and cattle enclosures on steep slopes (Haregeweyn et al., 2017). The implementation of soil and water conservation programs is the most important to limit erosion. If a project is proposed in the contributing watershed to a reservoir, it is often of interest to know how it has been affecting the rate of sedimentation and/or movement of sediment in the reservoir.

The intent of watershed management and soil conservation measures is to substantially reduce erosion and thereby decrease the sediment input to the stream system (Tarekegn, 2012). In this study, the distribution of erosion over the watershed and the area contributing excessive sediment to the reservoir are determined. Thus, conservation measures applied to these areas in a significant reduction of sediment input to the reservoir is needed. The measures include practices such as contour farming and terracing; no-till farming, developing trapping structures, grassed drainage ways, gully erosion control, and stabilization of critical areas by their return to grasslands or forests. Such Conservation measures may take more than a year to implement. Moreover, such measures are the relative costs of various measures to farmers, and the need for farmers to make significant changes in their usual style of farming.

Soil and water conservation program is effective in a small catchment when combined with other methods. As discussed in the above (section 4:1) the vulnerability of the watershed was ranked as their severity to erosion. Therefore, for areas of the very severe class, when the soil-water conservation program is applied with vegetation covers upstream of the reservoir, it is possible to reduce sediment flow into the reservoir.

Finally, Geffersa reservoir is suffering from a critical sedimentation problem that was reducing the supply of water to the Addis Ababa city. This problem is due to both technical and environmental factors. Maintaining the life of the reservoir is a matter of survival of the Addis Ababa residents. Hence, three sediment-mitigating options for prolonging the life of the reservoir were prioritized after different analysis based on MCD adopted from (Haregeweyn et al., 2012). By taking concepts of multi criteria decision evaluation method proposed by (Saaty, 2008) the most effective option of Geffersa reservoir is explained in (Table 4:2).

Table 4:4: Evaluation of sediment management strategies

Selection criteria	Cost	Technical difficult	Required time	Environmental & social acceptance	Total mark	Rank of acceptability
Sediment routing	Medium (2)	High (1)	Low (3)	Low (1)	7	3
Watershed management	Low (3)	Low (3)	High (1)	High (3)	10	1
Sediment removal	High (1)	Medium (2)	Medium (2)	High (3)	8	2

Management of this excess sediment inflow is a main practical management challenge and requires comparison of available sediment management measures. The major practical challenges may be based on the costs, technical, time, environmental impacts, and social acceptability for implementation. Based on the analysis, the curative method or both mechanical sediment removal and sediment route are the least applicable option based on the local situation and constructed dam behaviour. Additionally, that is not a final solution of problems to dry from sources. Sediment removal is expensive and also requires high skill and experience. Similarly, the applicability of sediment routing is limited due to low inflow to reservoir capacity ratio as well as embankment dam and small outlet discharge capacity. Not only that, skill and technology are very essential. On the other hand, preventative method or watershed management was the prominent remedial measure in order to acceptability. It includes afforestation, terraces, enclosing degraded hillside from farming activities, implementation of modern cropping systems and related land management practices. Moreover, the method is acceptable in the face of social and environmental aspect. It is not technically difficult without, it requires social awareness. Therefore, the soil and water conservation program for the prioritized area with vegetation upstream of the reservoir is considered better mitigation to preserve the storage capacity of Geffersa reservoir.

5. SUMMARY AND CONCLUSION

5.1. Summary and Conclusion

Soil erosion induced by water is not only causes land degradation and hinder the development of the agriculture activities, but also enhances sediment yield and sedimentation of the reservoirs. The study tried to estimate that. As explained under the results and discussion section, the goal of the study has been met. Integration of RUSLE model with GIS environment is an effective tool in mapping the spatial distribution of soil erosion from the whole area of the watershed for effective soil conservation interventions. From the result of RUSLE model the annual soil loss of Geffersa watershed ranges from 0 to 728.48 to/ha/year. The mean annual soil loss value was found to be 23.6 ton/ha/year. Areas 2334.67 ha, 826.5 ha, 824.5 ha, 772.8 ha, and 606.4 ha of the study watershed classified as very slight, slight, moderate, severe and very severe soil loss classes respectively. Thus, the areas with high erosion severity class needs urgent prioritized soil and water intervention measures to keep the sustainability of the Geffersa watershed. The watershed map of soil erosion risk generated in this study provides reasonable estimations of the annual soil loss, when compared with the available fact in the watershed. The sediment delivery ratio of the study area ranges from 7.3% to 19.6%, which has been computed based on the main stream channel slope. The mean annual sediment yield of watershed was 5.3 ton/ha/year. Consequently, the amount of sediment yield from the watershed and flow into reservoir is annually ranges from 0 to 266,040.03 tons. This estimation indicates how far sediment yield is a serious threat to the reservoir. The information of the loss of storage capacity and the period of time over which the sediment would interfere with the useful functioning of the reservoir necessitate the reservoir sedimentation studies. The useful life of the reservoir is estimated to be 394 years. Therefore, to reduce sediment yield, watershed management strategies were the best option according to reservoir available situation. Generally, proper watershed management will help to reduce soil erosion, sediment yield, and sedimentation risk and sustainable positive impact will be achieved.

5.2. Recommendation

Based on the result of the study, the prioritized watershed which has fallen under very severe and severe classes needs immediate attention in their order of soil erosion potential for better conservation planning by considering identified priority classes and hotspot areas. Water resources related sectors: especially local governmental and Addis Ababa Water and Sewerage Authority may use this information for better reservoir managements and conservation measures implementation in the watershed.

As the limitation of this study, the RUSLE model does not directly consider gully erosion. Hence, for a further comprehensive record of the erosion risk, identification and measurement of gullies in the watershed should be important to improve the accuracy of soil loss estimation. Calibration of the model in this study was not applied to the actual measurement from the field to validate the result. Measuring data from the field is difficult to validate soil loss estimation in a large area. Therefore, any researcher who is interested to conduct his study on soil erosion can fill this gap for further studies.

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APPENDECIS

Appendix Table 1: Mean annual precipitation and rainfall erosivity

Station	Latitude	Longitude	Altitude	MAP	R-factor
Addis Ababa Bole	9.0	38.8	2354.0	1023.3	567.0
Addis Ababa Obs	9.0	38.7	2386.0	1215.5	675.0
Intoto	9.1	38.7	2903.0	1282.1	712.4
Sululta	9.2	38.7	2610.0	1200.1	666.4
Sebeta	8.9	38.6	2240.0	1250.8	694.8

Appendix Table 2: Average monthly precipitation of gauging station

MONTH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
AA Bole	11.1	27.1	53.3	83.3	77.8	111.6	229.3	252.5	134.6	31.0	4.8	7.0
AA Obs	14.0	31.1	55.9	81.7	78.8	145.4	270.9	296.0	189.1	32.9	9.5	10.3
Intoto	12.1	33.9	51.1	80.8	79.2	151.3	326.4	343.3	155.4	27.3	12.4	8.9
Sululta	13.5	23.9	61.0	69.6	71.7	156.6	300.4	320.2	145.3	21.1	11.5	5.4
Sebeta	14.3	41.7	51.2	104.9	89.1	144.9	296.3	311.3	153.4	26.2	10.1	7.3

Appendix Table 3: Monthly rainfall within the watershed for 30 years

A: Addis Ababa Bole Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1988	9.7	53.4	5.3	144.6	16.6	106.2	277.9	299.3	229.7	59.9	0.0	0.0
1989	0.8	75.9	75.7	154.4	0.5	120.9	357.7	325.3	187.7	14.8	0.0	7.6
1990	0.8	155.9	59.2	106.4	20.0	88.8	218.7	268.6	184.0	16.2	6.0	0.0
1991	0.0	74.5	106.6	34.7	55.3	191.1	248.9	262.6	126.4	3.4	0.0	50.0

1992	20.2	33.7	20.2	41.0	52.0	109.1	248.5	294.7	209.4	69.7	0.0	2.9
1993	10.8	67.2	16.1	157.9	97.2	208.3	274.0	426.5	243.3	62.1	0.0	4.5
1994	0.0	0.0	82.4	82.3	63.3	123.4	308.9	225.0	142.0	0.5	14.7	0.0
1995	0.0	69.0	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0.0	0.0	48.4
1996	28.1	5.2	106.8	128.2	122.0	258.5	266.4	338.7	294.2	0.2	0.2	0.0
1997	39.2	0.0	24.5	51.3	38.5	104.0	272.6	194.3	113.8	62.4	50.3	1.5
1998	55.2	20.5	49.0	48.5	154.2	124.4	285.4	260.0	213.6	126.9	0.0	0.0
1999	2.9	0.3	28.8	16.3	23.8	119.6	268.6	305.3	88.4	75.4	0.0	0.0
2000	0.0	0.0	17.6	49.9	110.0	144.5	244.8	306.2	250.6	46.4	21.1	0.0
2001	0.0	12.2	210.8	25.0	168.0	216.2	428.0	246.4	131.7	13.7	0.0	0.0
2002	14.7	21.0	90.2	56.3	63.1	172.5	256.9	215.9	108.8	0.2	0.0	16.5
2003	10.5	53.3	62.6	99.3	20.2	151.8	291.8	233.3	193.3	0.8	1.5	54.9
2004	24.8	20.3	49.5	139.9	30.1	141.9	238.5	272.6	164.0	76.9	0.0	0.0
2005	45.9	51.6	83.2	160.9	133.7	179.8	246.0	315.2	162.5	19.8	4.4	0.0
2006	0.7	11.2	124.4	78.9	74.6	150.1	356.3	243.6	239.1	54.0	0.3	8.0
2007	51.3	19.1	59.8	73.8	120.1	169.1	261.8	381.2	147.6	24.8	0.0	0.0
2008	0.0	13.0	0.0	49.4	94.3	88.9	277.0	360.9	256.7	88.2	79.4	22.9
2009	21.3	2.7	28.4	80.6	58.9	82.6	349.9	388.3	112.7	45.8	4.4	65.0
2010	2.6	79.8	55.5	97.8	74.4	271.1	313.9	205.8	237.8	1.8	25.7	15.0
2011	14.1	13.1	44.3	22.8	66.1	182.0	180.9	340.8	146.0	0.0	42.3	0.0
2012	0.0	0.0	15.8	71.4	50.2	69.4	324.2	298.0	215.5	2.3	0.0	9.8
2013	4.4	0.0	46.9	92.3	85.0	153.2	227.6	353.2	196.3	58.4	22.3	0.0
2014	1.7	47.4	61.5	26.2	93.6	66.7	219.9	262.4	264.7	35.0	1.7	0.0
2015	0.0	0.0	27.2	15.0	109.3	213.9	217.0	309.9	148.9	0.0	7.7	0.1

2016	59.8	12.1	47.9	136.8	132.7	187.3	182.8	299.9	141.8	15.5	3.6	1.9
2017	0.0	20.7	36.6	33.7	169.0	64.5	290.4	329.8	386.0	10.8	0.0	0.0

B: Addis Ababa Observatory Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1988	9.7	53.4	5.3	144.6	16.6	106.2	277.9	299.3	229.7	59.9	0.0	0.0
1989	0.8	75.9	75.7	154.4	0.5	120.9	357.7	325.3	187.7	14.8	0.0	7.6
1990	0.8	155.9	59.2	106.4	20.0	88.8	218.7	268.6	184.0	16.2	6.0	0.0
1991	0.0	74.5	106.6	34.7	55.3	191.1	248.9	262.6	126.4	3.4	0.0	50.0
1992	20.2	33.7	20.2	41.0	52.0	109.1	248.5	294.7	209.4	69.7	0.0	2.9
1993	10.8	67.2	16.1	157.9	97.2	208.3	274.0	426.5	243.3	62.1	0.0	4.5
1994	0.0	0.0	82.4	82.3	63.3	123.4	308.9	225.0	142.0	0.5	14.7	0.0
1995	0.0	69.0	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0.0	0.0	48.4
1996	28.1	5.2	106.8	128.2	122.0	258.5	266.4	338.7	294.2	0.2	0.2	0.0
1997	39.2	0.0	24.5	51.3	38.5	104.0	272.6	194.3	113.8	62.4	50.3	1.5
1998	55.2	20.5	49.0	48.5	154.2	124.4	285.4	260.0	213.6	126.9	0.0	0.0
1999	2.9	0.3	28.8	16.3	23.8	119.6	268.6	305.3	88.4	75.4	0.0	0.0
2000	0.0	0.0	17.6	49.9	110.0	144.5	244.8	306.2	250.6	46.4	21.1	0.0
2001	0.0	12.2	210.8	25.0	168.0	216.2	428.0	246.4	131.7	13.7	0.0	0.0
2002	14.7	21.0	90.2	56.3	63.1	172.5	256.9	215.9	108.8	0.2	0.0	16.5
2003	10.5	53.3	62.6	99.3	20.2	151.8	291.8	233.3	193.3	0.8	1.5	54.9
2004	24.8	20.3	49.5	139.9	30.1	141.9	238.5	272.6	164.0	76.9	0.0	0.0
2005	45.9	51.6	83.2	160.9	133.7	179.8	246.0	315.2	162.5	19.8	4.4	0.0

2006	0.7	11.2	124.4	78.9	74.6	150.1	356.3	243.6	239.1	54.0	0.3	8.0
2007	51.3	19.1	59.8	73.8	120.1	169.1	261.8	381.2	147.6	24.8	0.0	0.0
2008	0.0	13.0	0.0	49.4	94.3	88.9	277.0	360.9	256.7	88.2	79.4	22.9
2009	21.3	2.7	28.4	80.6	58.9	82.6	349.9	388.3	112.7	45.8	4.4	65.0
2010	2.6	79.8	55.5	97.8	74.4	271.1	313.9	205.8	237.8	1.8	25.7	15.0
2011	14.1	13.1	44.3	22.8	66.1	182.0	180.9	340.8	146.0	0.0	42.3	0.0
2012	0.0	0.0	15.8	71.4	50.2	69.4	324.2	298.0	215.5	2.3	0.0	9.8
2013	4.4	0.0	46.9	92.3	85.0	153.2	227.6	353.2	196.3	58.4	22.3	0.0
2014	1.7	47.4	61.5	26.2	93.6	66.7	219.9	262.4	264.7	35.0	1.7	0.0
2015	0.0	0.0	27.2	15.0	109.3	213.9	217.0	309.9	148.9	0.0	7.7	0.1
2016	59.8	12.1	47.9	136.8	132.7	187.3	182.8	299.9	141.8	15.5	3.6	1.9
2017	0.0	20.7	36.6	33.7	169.0	64.5	290.4	329.8	386.0	10.8	0.0	0.0

C: Entoto Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1988	11.8	151.4	11.1	181.6	87.3	269.0	510.0	514.2	135.6	28.9	0.0	0.0
1989	4.0	76.0	105.4	133.3	5.8	98.2	409.5	323.4	293.9	11.7	0.0	14.5
1990	0.0	156.6	42.8	117.9	17.6	100.5	324.5	499.7	180.8	23.5	1.5	0.0
1991	12.8	64.9	156.2	37.5	39.0	171.2	258.5	395.2	146.7	1.4	0.0	44.2
1992	52.7	31.5	14.6	42.7	84.6	131.6	247.8	387.0	188.4	42.4	0.7	8.1
1993	15.3	44.6	5.7	147.5	49.0	123.3	266.1	407.6	183.2	28.7	0.0	0.0
1994	0.0	0.0	62.2	56.0	91.0	154.8	336.3	307.2	142.5	0.3	24.4	0.0
1995	0.0	96.3	29.7	186.1	83.7	98.0	297.0	222.1	133.7	5.0	0.2	22.7
1996	31.1	12.2	121.6	78.3	95.2	242.7	387.2	493.9	184.7	1.2	0.6	0.0

1997	21.2	0.0	18.6	77.3	27.4	77.2	256.3	240.8	89.3	88.3	90.0	0.2
1998	25.3	25.3	45.2	47.0	149.5	149.2	369.0	376.3	204.8	44.5	0.0	0.0
1999	15.8	6.3	34.9	25.4	37.0	127.7	283.1	280.3	105.0	58.0	0.2	0.0
2000	0.0	0.0	5.2	108.0	91.4	110.7	303.8	359.1	132.8	17.2	33.5	1.7
2001	20.6	5.5	147.5	29.8	141.7	164.3	285.6	321.4	92.5	52.4	0.0	1.8
2002	17.9	50.4	88.8	67.4	49.2	138.7	293.1	262.9	92.1	10.7	0.0	28.0
2003	5.2	47.7	57.1	117.3	13.9	188.0	370.8	248.9	141.1	0.0	6.3	25.6
2004	28.8	31.3	46.7	124.6	13.8	166.0	271.9	334.7	124.8	49.7	1.1	1.6
2005	8.3	11.4	42.8	98.6	143.9	106.4	241.8	339.3	134.4	19.6	8.2	0.0
2006	0.9	19.1	93.8	66.5	79.1	131.5	371.1	311.5	128.7	36.1	0.6	16.5
2007	38.6	16.2	36.4	52.1	106.4	246.7	272.1	322.6	87.0	16.4	0.0	0.0
2008	0.0	9.3	1.5	74.8	45.3	142.5	399.3	359.5	190.6	50.1	95.1	0.5
2009	10.9	3.3	15.9	40.1	28.2	122.7	304.7	326.3	154.2	91.3	7.4	68.4
2010	9.5	73.4	79.4	71.2	107.9	235.2	388.8	288.6	173.2	1.8	0.0	11.9
2011	0.0	0.0	50.3	51.7	96.2	143.2	271.1	366.0	113.6	0.0	43.5	12.3
2012	0.0	0.0	19.5	79.5	77.1	133.2	363.0	366.3	242.7	4.2	0.3	7.8
2013	12.2	59.8	59.8	128.8	82.1	164.6	364.3	462.2	198.1	64.3	10.7	0.2
2014	0.0	16.1	41.8	30.7	80.6	81.7	323.6	282.7	159.2	25.5	14.0	0.4
2015	0.0	4.6	0.0	6.6	119.8	158.1	364.3	322.3	86.3	14.1	29.6	1.2
2016	19.4	0.0	65.1	104.0	163.0	177.4	300.8	301.3	113.6	14.9	2.7	0.3
2017	0.0	3.3	34.0	42.4	168.5	184.3	355.9	276.1	307.8	17.8	1.0	0.0

D: Sululta Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1988	11.2	143.8	15.4	61.4	221.4	180.3	9.5	280.9	151.1	62.5	0.0	0.0
1989	0.0	0.0	223.5	172.9	0.0	102.3	70.3	395.8	211.4	21.1	0.0	0.0
1990	0.0	55.8	174.6	120.9	23.8	124.6	347.6	528.2	319.5	0.0	2.4	0.0
1991	12.3	31.0	274.0	18.0	4.3	371.5	588.6	218.2	92.9	0.0	0.0	22.3
1992	33.3	35.8	63.6	11.9	53.1	48.2	65.2	74.8	63.9	0.9	4.2	0.2
1993	17.4	68.4	22.0	102.9	41.3	200.0	80.7	234.5	129.1	6.8	0.0	4.0
1994	0.0	4.4	27.7	28.6	49.6	174.9	295.3	322.9	43.3	0.0	10.0	0.0
1995	6.4	17.9	37.3	169.9	112.0	174.2	383.3	249.1	48.0	0.0	7.2	14.7
1996	58.9	19.3	83.8	52.8	152.1	221.5	225.9	509.7	100.7	4.1	0.0	0.0
1997	8.7	0.0	18.4	53.5	56.2	64.4	291.8	290.1	48.8	55.1	63.6	0.9
1998	68.5	20.1	6.0	76.9	120.3	190.2	301.6	320.0	112.2	69.8	0.0	0.0
1999	24.2	12.9	28.5	16.0	46.9	189.4	400.7	443.0	146.8	78.7	5.9	0.0
2000	0.0	0.0	7.5	95.8	80.9	164.4	469.9	422.3	138.0	7.0	23.6	13.3
2001	3.6	0.5	164.2	45.3	107.3	166.9	336.9	215.4	79.3	5.1	0.0	0.0
2002	35.6	24.6	97.3	54.5	25.2	153.5	302.3	289.1	81.2	2.5	0.0	35.6
2003	4.1	14.0	32.7	87.0	6.5	162.9	365.4	343.1	139.7	2.0	0.0	8.9
2004	10.1	10.1	36.6	96.5	4.7	127.6	279.4	393.1	165.8	46.5	7.4	1.8
2005	9.6	3.5	33.3	73.9	17.9	41.7	257.7	250.2	155.3	24.3	13.7	0.0
2006	2.5	20.3	82.2	74.5	70.8	178.6	385.5	272.8	185.2	26.4	0.0	14.1
2007	38.6	5.8	41.3	37.0	111.6	244.2	284.2	372.2	120.5	5.7	4.7	0.0
2008	0.0	19.3	11.9	40.1	66.5	89.3	398.9	287.4	132.8	32.9	102.2	0.0
2009	24.3	1.4	5.2	13.2	40.4	126.5	361.5	243.9	140.4	43.3	27.1	6.8

2010	11.3	117.9	56.8	59.7	117.1	267.8	440.9	374.3	243.0	11.0	22.4	10.1
2011	2.6	5.3	73.8	79.6	76.7	228.4	321.9	375.5	180.8	0.8	13.6	0.0
2012	0.0	0.0	37.1	176.3	92.6	124.1	481.8	423.6	301.1	14.9	0.0	25.2
2013	6.2	0.3	29.1	59.5	51.3	153.9	252.5	340.4	145.5	33.4	13.7	0.5
2014	0.0	25.2	46.0	65.8	81.0	60.4	261.1	309.0	121.0	45.0	0.0	0.5
2015	0.0	28.1	18.7	0.8	83.8	134.8	219.0	238.8	98.1	5.4	14.6	2.6
2016	15.5	19.9	40.0	96.7	105.6	142.1	199.5	325.3	171.3	16.2	9.0	0.5
2017	0.0	9.9	41.8	46.3	130.7	88.8	332.8	262.4	292.5	10.5	0.0	0.0

E : Sebeta Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1988	20.4	367.7	15.2	336.7	59.5	682.1	1565.5	1169.5	536.8	108.7	0.0	0.0
1989	3.3	203.9	102.2	355.5	19.4	109.8	305.1	550.4	213.3	19.0	0.0	2.1
1990	0.0	157.9	18.6	115.8	33.5	74.3	245.6	220.5	138.3	23.8	3.4	0.0
1991	2.6	24.4	109.6	28.8	22.0	101.9	207.6	243.5	120.5	16.3	0.0	0.0
1992	41.4	51.3	46.4	41.3	70.6	92.9	328.9	379.7	251.6	119.9	11.7	6.9
1993	25.4	136.2	38.6	413.6	338.4	216.1	525.8	1089.0	295.6	52.4	0.0	0.0
1994	0.0	0.0	135.7	102.1	147.4	220.1	427.7	316.7	114.2	0.0	15.5	0.0
1995	7.6	0.0	50.1	177.1	97.4	69.1	530.4	314.9	113.8	7.0	0.0	18.8
1996	26.0	0.0	111.3	63.2	281.0	340.8	404.6	432.5	130.6	0.0	0.2	0.0
1997	30.0	0.0	33.2	53.5	11.7	274.2	196.5	197.2	50.9	0.0	61.7	0.0
1998	69.6	3.4	15.0	30.3	101.8	129.9	214.5	217.0	105.8	48.9	0.0	35.5
1999	0.0	23.3	48.2	14.0	56.8	98.1	218.0	220.8	77.2	102.1	1.1	1.3
2000	0.0	0.0	3.2	75.7	37.3	96.3	173.7	182.5	216.0	26.8	21.4	24.6

2001	0.0	7.7	158.0	11.1	156.4	118.7	273.3	163.6	65.6	20.5	0.0	0.0
2002	25.4	47.2	100.1	31.8	30.6	154.8	173.0	251.1	113.0	0.6	0.0	21.1
2003	3.0	5.8	52.1	76.4	13.6	122.7	274.9	327.4	118.2	1.2	0.0	39.2
2004	17.2	15.2	46.3	122.8	19.4	136.6	261.5	189.7	166.0	55.9	0.0	0.0
2005	33.0	24.5	61.3	135.3	193.2	91.5	157.2	161.6	69.6	3.2	9.3	0.0
2006	0.0	13.8	53.0	84.0	51.5	81.1	288.2	273.0	185.4	13.1	0.0	0.3
2007	23.6	28.2	31.7	100.1	68.4	125.4	83.6	242.5	128.2	3.6	0.0	0.0
2008	0.0	0.0	0.6	21.5	56.6	134.7	239.4	313.4	201.2	41.5	83.7	0.0
2009	30.1	0.0	4.2	65.3	22.0	62.8	297.0	246.9	115.3	20.2	0.0	47.8
2010	0.2	33.3	72.3	94.3	78.3	109.9	296.0	168.6	79.0	6.3	7.8	19.7
2011	0.9	13.5	26.6	38.9	59.9	154.8	102.6	250.5	99.5	0.0	9.9	0.0
2012	0.0	0.0	19.8	204.9	51.8	88.6	185.8	174.9	196.7	0.0	21.4	0.0
2013	0.0	6.5	75.1	106.1	92.8	97.5	155.7	239.3	124.5	36.6	33.3	0.0
2014	0.0	35.8	18.1	30.2	119.4	79.4	160.1	243.6	129.9	38.4	3.1	0.0
2015	0.0	0.0	18.3	3.4	87.8	70.2	179.5	227.1	114.5	0.0	13.7	1.6
2016	46.5	34.3	22.7	165.3	130.6	112.5	167.2	114.8	96.4	17.4	5.0	0.0
2017	22.4	18.1	48.2	48.2	163.3	100.3	249.3	217.6	234.9	3.9	1.9	0.0

Appendix Table 4 Land use land cover factor values and area

CLASS_NAME	C-factor	Area (ha)
Shrub land	0.014	22.3
water body	0	113.6
Bare land	0.6	756.4
Agricultural land	0.17	1256.3

Dense forest	0.01	25.6
Urban Area	0.05	1301.0
Sparse vegetation	0.015	830.1
Grass land	0.05	1146.5
Total		5451.84

Appendix Table 5 Supportive Management Factors (sources: Shin, 1999)

No	Slope (%)	Contouring	Cropping	Terracing
1	0-7	0.55	0.27	0.10
2	7-11.3	0.60	0.30	0.12
3	11.3-17.6	0.80	0.40	0.16
4	17.6-26.8	0.9	0.45	0.18
5	>26.8	1.00	0.50	0.20

Appendix Figure: 1 Available temporary soil conservation practice by farmers

Appendix Figure: 2 Partial view of Geffersa reservoirs

Appendix Figure: 3 Field Observation