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MORPHOMETRIC ANALYSIS, WATERSHED PRIORITIZATION AND ANNUAL SOIL LOSS ESTIMATION USING GIS AND RUSLE TECHNIQUES: THE CASE OF GUDER AND DABUS SUB-BASINS

BY IYASU MILKIAS BANTI

A THESIS SUBMITTED TO HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR, JIMMA INSTITUTE OF TECHNOLOGY, JIMMA UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING.

February, 2020
Jimma, Ethiopia

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Main-Advisor: -Mr. Fiseha Behulu (PhD)

Co-Advisor:-Mr. Fayera Gudu (M.sc)

February, 2020
Jimma, Ethiopia

DECLARATION

I hereby declare that this thesis entitled “Morphometric analysis, watershed prioritization and annual soil loss estimation using GIS and RUSLE techniques the case of Dabus and Guder sub-basin” has been carried out by me under the guidance and supervision of my Advisors Mr. Fiseha Behulu (PhD) and Mr. Fayera Gudu (M.sc). The thesis is original and has not been submitted to for any university or institutions.

Researchers’ Name	Signature	Date
Iyasu Milkias	_______________	February, 2020
Advisors’ Name	**Signature**	**Date**
Fiseha Behulu(PhD)	________________	February, 2020
Mr. Fayera Gudu(M.sc)	________________	February, 2020

APPROVAL PAGE

As thesis research advisors, we hereby certify that we have read and evaluated this thesis and prepared under our guidance, by Iyasu Milkias, entitled "Morphometric analysis, Prioritization of watershed and annual soil loss estimation using GIS and RUSLE techniques: The case of Dabus and Guder Sub-basin" and we recommend that it can be submitted as fulfilling the thesis requirement.

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As members of the Board of Examiners of the MSc Thesis Open Defense Examination, we Certify that we have read, evaluated the Thesis prepared by Iyasu Milkias and examined the candidate. We recommended that the Thesis be accepted as fulfilling the requirement for the degree of Master of Science in Hydraulic Engineering.

Members of Examining Board

Chairperson	Signature	Date
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Final approval and acceptance of the thesis is contingent upon the submission of final copy of the thesis to council of graduate studies (CGS) through the departmental or school graduate committee (DGC or SGC) of the candidate.

ABSTRACT

Soil erosion is dramatically increasing and accelerating in developing countries like Ethiopia. It has worrisome economic and environmental impacts and causes nutrient loss on agricultural land, sedimentation in rivers and reservoirs, clogged canals and other water supply systems. Determination critical erosion prone area and calculating soil loss rate in upper Blue Nile sub-basin watershed is an important priority for prioritizing the area for watershed management practices in order to reduce soil erosion. Watershed prioritization has gained importance in natural resources management, especially in the context of watershed management. Basin morphometric analysis is a means of mathematically quantifying different aspects of a drainage basin. In present study, Morphometric analysis and prioritization of the sub-watersheds and soil loss estimation for significantly affected area have been done. The model has been used to assess the hydrological characteristics and soil erosion potentials based on the morphological characteristics. The study was carried out using DEM data 30mX30m resolution in GIS environment, rainfall, soil data, and land use land cover. Morphometric analysis was carried out for linear, shape and relief aspects. Under linear aspect bifurcation ratio, drainage density, stream frequency, drainage texture ratio and length of over land flow were analyzed. Under shape aspect; elongation ratio, circularity ratio, form factor and constant channel maintenance were evaluated. Finally, under relief aspect; basin relief, relief ratio, ruggedness number and relative ratio have been analyzed. The compound factor for sub-watersheds of both Guder and Dabus sub-basin have been calculated and classified into erosion tolerance class. Accordingly, the G-7(one of the sub-watersheds) has been the first ranked and classified under high erosion severe class with compound factor value of 2.82.

*To estimate annual soil loss of the G-7 sub-watershed, Revised Universal Soil Loss Equation (RUSLE) with the ArcGIS 10.3 integration have been used. RUSLE parameters such us rainfall erositivity(R-factor), soil erodibility(K-factor), slope length and slope steepness(LS-factor), cover management (C-factor) and support practice(P-factor) have been calculated and used as data input in annual soil loss calculation. By integrating these five map layers in GIS raster calculator, the required spatially distributed annual average soil loss rate was determined. Accordingly, the result of the analysis for the existed conditions depicted that the amount of soil loss ranges from 0 to 167.47ton ha-1 yr-1 with average annual soil loss rate of 15.34*ton ha-1 yr-1 *from the whole catchment.* T*otally the annual soil loss of the watershed was found to be 3,617,172ton. Such losses could threaten the sustainability of land productivity in the study area and at the same time, excessive sedimentation and eutrophication problem at the downstream proposed reservoirs on Guder River and also on Ethiopian Great Renaissance Dam.*

Key Terms; *Morphometric analysis, watershed Prioritization, soil loss modeling, ArcGIS and RUSLE techniques.*

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AGRONOMY AND ABBREVIATION

ARS:	Agricultural Research service
DEM:	Digital Elevation Model
EFAP:	Ethiopian Forest Action Program
EMA:	Ethiopian Mapping Agency
GIS:	Geographical Information System
MoA:	Ministry of Agricultural
MoWIE:	Ministry of Water, Irrigation and Electricity
NMA:	National Metrological Agency
RUSLE:	Revised universal soil loss equation
SDR:	Sediment Delivery Ratio
SLMP:	Sustainable Land Management Project
SYI:	Sediment Yield Index
SWAT:	Soil and Water Assessment Tool
SWC:	Soil and water Conservation
UBNR:	Upper Blue Nile River
USLE:	Universal Soil Loss Equation
OWWDSE	Oromia Water Work Design Supervision Enterprise
A:	Basin Area
Bh:	Basin relief
Cc:	Compactness coefficient
C:	Constant channel maintenance
CP:	Compound value Parameter
Dd:	Drainage density
Dt:	Drainage texture ratio
Ff:	Form factor
Fs:	Stream frequency
Lb:	Length of Basin
Lof:	Length of overland flow

Lu:	Stream length
Nu:	Stream number
P:	Basin perimeter
Rb:	Bifurcation ratio
Rc:	Circulatory ratio
Re:	Elongation ratio
Rh:	Relief ratio
Rl:	Stream length ratio
Rn:	Ruggedness number
Rr:	Relative relief
U:	Stream order

1. INTRODUCTION

1.1. Background

In Ethiopia, where population pressure is continuously increasing land and water resource are limited and their wide utilization is imperative. Soil erosion is dramatically increasing and accelerating in developing countries like Ethiopia. It has worrisome economic and environmental impacts and causes nutrient loss on agricultural land, sedimentation in rivers and reservoirs, clogged canals and other water supply systems. Drainage basins and sub-basin is the fundamental unit for resource management purposes especially in soil and water conservation. Morphometric is measurement and mathematical analysis of configuration of the earth's surface, shape and dimension of its land forms (Fatima *et al.*, 2018).

The influence of drainage morphometric characteristics is very significant in understanding the landform processes, soil physical properties and erosional characteristics. The geographic information system (GIS) technique is the effective method for understanding such morphometric characteristics and analysis. Moreover, GIS have effective tools to overcome most of the problems of land and water resources planning and management rather than conventional methods of data process. For example, in continental Europe attempts have been made to classify stream systems on the basis of branching or bifurcation. In this system of stream orders, the largest, most branched, main or stream is usually designated as of order one and smaller tributary streams of increasingly higher orders (Horton, R.E. *et al*., 1945).

Land and water are the two most valuable and vital resources essentially required not only for sustenance of life but also for the economic and social progress of the country throughout the world and it is strongly affected by anthropogenic influences (Debelo *et al*., 2017; Hindersah *et al*., 2018). Accordingly, the need to protect the quantity and quality of water resources can affect potential land uses and land management practices, while water availability is a pre-requisite to preparing land uses required for irrigation purpose. The other factor is land erosion, the process by which material on the surface of the land dislodged, transported and deposited. Land erosion becomes a water quality stressor when the transported materials reach surface waters. When this occurs, the sediment itself is considered as pollutant. Sedimentation is the build-up of eroded soil particles that are transported in runoff from their site of origin and deposited in drainage systems, on other ground surfaces, or in bodies of water or wetlands. Through erosion, the topsoil which is presumed to have high in organic matter, fertility and soil life, is relocated elsewhere "on-site" where it builds up over time or is carried "off-site" where it fills in drainage channels. Moreover, soil erosion will be resulted in various issues including: (i) reduction of cropland productivity and pollution of adjacent watercourses, wetlands and lakes. (ii) a slow process that continues relatively unnoticed or can occur at an alarming rate, causing serious loss of topsoil, (iii) soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinization and soil acidity problems.

Population growth in the Blue Nile Basin has led to fast land-use changes from forest to agricultural land, which resulted in speeding up the soil erosion processes producing highly negative impacts on the local soil fertility and agricultural productivity. The eroded sediment transported to downstream by water and sinks in the lower basin where it significantly reduces reservoir storage and irrigation canals capacity. Moreover, erosion may be exacerbated in the future because of a more vigorous hydrologic cycle as a result of climate change *(*Debelo, *et al*., 2017). Poor land use practices, improper management systems and lack of appropriate soil conservation measures have played a major role for causing land degradation problems in Ethiopia(Asad, *et al*., 2016*)*. The soil erosion as a function of water spatial variation ranges from 16 to 300 ton per ha per year in Ethiopia (Tesfaye *et al*., 2014). Balthazar reported that the rate of soil erosion in Blue Nile river basin shows considerable spatial variation from 4 to 4935 ton per square kilometer per year (Balthazar *et al*., 2012). This variation resulted from variation in land cover, soil characteristics, land slope, rainfall, temperature and life stock density (Awulachew *et al*., 2010). The only effective solution to mitigate the sedimentation problem is to limit the sediment inputs from upstream by locally implementing erosion control practices. But this requires identification of soil erosion potential and critical erosion prone area. Accordingly in this thesis morphometric analysis of Guder and Dabus sub-basin has been carried out using GIS, to prioritize the erosion risk area among the sub-watersheds. The alterations in land use and land cover have increased erosion rates in many areas of the world and causing considerable land and environmental degradation land degradation.

1.2. Statement of the problem

Soil erosion has been described as one of the most critical environmental hazards in modern times, because of its adverse economic and environmental impacts. Soil erosion begins with detachment, which is caused by break down of aggregates by raindrop impact, shearing or drag forces of water and wind. Detached particles are transported by flowing water and wind, and may get deposited when the transport capacity of water or wind decreases. However, water is probably the most important single agent causing soil erosion. Accelerated erosion due to human activities is a serious environmental problem as it increases level of sedimentation in the rivers and reservoirs reduce their storage capacity and life, causes flood due to reduction in carrying capacity of rivers and streams. These include diminished land resources and reduced land productivity, as well as sediment delivery, which reduce the storage capacity and life span of reservoirs (Ali *et al*., 2014).

Ethiopia has been described as one of the most seriously affected nation in the world by soil erosion (Hurni *et al*., 1988; Mitiku *et al*., 2002; Gizachew *et al*., 2015). Soil erosion and sediment yield from catchments are therefore key limitations to achieve sustainable land use and maintaining water quality in rivers, lakes and other water bodies (Benedict and Andreas, 2006).

Many of Ethiopia's hydroelectric power and irrigation reservoirs such as Aba-Samuel, Koka, Angerib, Melka Wonka, Borkena, Adarko and Legedadi has been threatened by the heavy sedimentation. Therefore, these dams have been suffered from reduction in their capacity and life span, quality of water and require costly operation for removal and operation and thus these dams loss their intended services (Kebede *et al*., 2012; Gelagay *et al*., 2016).

The effects of soil erosion go beyond the loss of fertile land; it leads to increased pollution and sedimentation in streams and rivers, clogging waterways and causing declines in fish and other species. Degraded lands are also often less able to hold onto water, which can worsen flooding. In developing countries like Ethiopia, most of the population depends on agriculture, which basis their life is ploughing the land traditionally and low awareness in conserving natural resource are in serious problem. Water erosion moves nearly 1.9 billion tons of fertile soil from the highlands of Ethiopia annually, this amount is found to be equivalent to an average soil loss of 130 tons per hectare per year from cultivated lands (Hurni *et al*., 2018)

The study on upper Blue Nile River show that with a gradual increase of the degraded areas from 10% in the 1960s to 22% in 2000s, the observed discharge pattern and sediment concentration can be simulated well. Simulated annual runoff increased by 10% over the 40-year periods as a result of the increase in degraded soils. Sediment loads appeared to have increased many times more, but this needs to be further validated, as data availability is limited.

The annual loss of storage capacity of the world’s reservoirs due to sediment deposition is estimated at 0.5–1.0%(Palmieri et al., 2003). In large reservoirs with infrequent drawdown, the majority of the deposited sediment load occupies parts of the usable storage capacity. This accumulation pattern in large reservoirs poses a serious threat to the sustainability of major hydraulic systems(Zhou *et al.*, 2014).

Soil erosion from the upstream of the basin and the subsequent sedimentation in the downstream area is an immense problem threatening the existing and future water resources development in the basin. The benefits gained by the construction of micro-dams in the upper Nile are threatened by the rapid loss of storage volume due to excessive sedimentation(Betrie *et al.*, 2011).

Major factors responsible for soil erosion include rainfall, soil type, and vegetation, topographic and morphological characteristics of the basin. This study is, therefore, carry out Morphometric analysis of the watershed for its ability to predict level of vulnerability of watersheds for prioritization and soil loss modeling using RUSLE method in GIS environment have been done.

1.3. Objectives

1.3.1. The general objective

The general objective of the study is to undertake morphometric analysis and estimate soil erosion rate of Guder and Dabus sub-basins.

1.3.2. Specific objectives

1. To analyze morphometric parameters of Dabus and Guder River sub-basin.
2. To prioritize sub-watersheds of Guder and Dabus river sub basin based on morphometric parameters of linear, shape and relief aspect.
3. To estimate annual soil loss rate using RUSLE modeling and ArcGIS 10.3 for the highly prioritized or significantly affected sub-watershed.

1.4. Research Questions

The following research questions have been answered through this research process.

1. What are the morphometric and drainage characteristics of Dabus and Guder River sub-basin?
2. Which mini-watershed has been prioritized as high priority by erosion tolerance rate classification?
3. Which part of the two sub-basins is highly prone to erosion? What is the volume of annual soil loss rate from high priority sub-watersheds?

1.5. Scope

This study was a watershed level study and focuses mainly on the morphometric analysis, prioritization of sub-watershed and estimation of annual soil loss rate due to water erosion. The study of watersheds covers Guder and Dabus sub-basin for morphometric analysis and prioritization. The annual soil loss estimation for significantly affected sub-watershed has been calculated using Arc GIS with RUSLE model techniques.

1.6. Significance of the study

Through this result of morphometric analysis and soil loss modeling, critical erosion prone areas of watershed (high severity class) identified and annual soil loss rate have been estimated. Identifying characteristics of watershed helps to understand and model various natural processes occurring in the watershed. Modeling the annual soil loss rate of this catchment has also irreplaceable assist for designers of the hydraulic structure, decision makers and input data for non-governmental and governmental institution for various activities such as policy makers, planners, of various water resource projects. Moreover, figuring out of the amount of soil being eroded from the catchment is a crucial issue for designing and implementations of appropriate soil and water conservation practices and technology interventions in the catchment.

1.7. Limitation of the study

Though, the study has a significant role in providing the information about soil loss severity classification and the status of soil erosion of the high severe area, it has also some limitations. Among the limitations, the soil erosion prediction model (RUSLE) applies only for water erosions; like sheet and reel erosions. Hence, it doesn’t consider soil erosion due to land slide and mass movements of soil. The model also neglects certain interactions between RUSLE factors in order to distinguish easily the individual effect of each other.

2. LITERATURE REVIEW

2.1. General

The Upper Blue Nile basin is the largest river basin in terms of volume of discharge, second largest in terms of area in Ethiopia and is the largest tributary of the Nile River. It comprises 16% of the area of Ethiopia (176000km^2 out of 1100000km^2). The River basin has mean annual discharge of 48.5 cubic kilometers 1912-1997; 1536m^3/s (Conway *et al*., 2000). The basin drains a large portion of the central and south-western Ethiopian Highlands. The river has deep and meandering course through the central Ethiopian Highlands and in some places its gorge is one kilometer deep. Its course flows 900km from Lake Tana until it leaves Ethiopia and crosses into the vast plains of Sudan. With the White Nile, it is one of the two major tributaries of the Nile River. The Blue Nile is so called black because, floods during the summer monsoon erode a vast amount of fertile soil from the Ethiopian High land and carry it downstream as silt, turning the water dark brown or almost black.

The basin faces serious problems including soil erosion, land degradation, loss of soil fertility and deforestation(Yalew *et al.*, 2016). The major causes are a combination of biophysical factors such as seasonal fluctuation in rainfall and climate variability, topographic heterogeneities and anthropogenic factors like, population growth and land degradation in the basin. Land degradation occurs mainly due to gully and surface erosions by heavy runoff in this rugged highland catchment.

Soil erosion is the most deteriorating and land degradation problem in the upper Blue Nile basin, Ethiopia. A new methodological framework was applied to morphometric analysis and prioritizes erosion-prone areas. The basin experiences high soil loss rates with large spatial variability. Erosion risks are strongly linked to population density, lack of watershed management, poor cultivation and poor land use practice. Soil erosion by water results in significant consequences that also affect downstream countries. However, there have been limited comprehensive studies of this and other basins with diverse agro ecologies.

Soil erosion by water represents among the major threats to the long-term productivity of agriculture particularly in the Ethiopian highlands. As a result, productivity is rapidly declining. In Ethiopia 85% of the population are directly supported by the agricultural economy. However, the productivity of that economy is being seriously eroded by unsustainable land management practices both in area of food crops and in grazing lands. All physical and economic evidence shows that loss of land resource productivity is a serious problem in Ethiopia and with continued population growth the problem is likely to be even more challenging in the future. Most studies showed soil erosion is severe in the Ethiopian Highland (Berry *et al*., 2003).

Water erosion moves nearly 1.9 billion tons of fertile soil from the highlands of Ethiopia annually. This amount is found to be equivalent to an average soil loss of 130 tons per hectare per year from cultivated lands(Hurni *et al*., 2018). Soil erosion is the process of detachment, transportation and deposition of soil particles from land surface. Agencies or the energy sources involved in the process of soil erosion are mainly water, wind, sea waves, human beings and animals (Aswathy *et al*., 2018). Soil erosion as "soil cancer" is a complex process and its multiple obvious and hidden social and environmental impacts are an increasing threat for the human existence(Salunkhe *et al.*, 2018).

Natural soil erosion has been occurring since the early period of earth, but accelerated soil erosion is relatively a recent problem. It is always the result of mankind's unwise actions which leave the land vulnerable during times of erosive rainfall or wind storms. Hydrologic modeling in GIS environment focuses on hydrology for flow modeling and watershed delineation. Hydrologic investigation extension in ArcGIS offers a system to define the physical features of a surface using a Digital Elevation Model (DEM) as input. Hydrological model analyze will be used to determine the behavior of where the water comes from and where it is going is important for morphometric analyze through watersheds delineation.

2.2 Previous Studies on Upper Blue Nile River

The Nile Basin is shared by eleven countries and is the lifeline for more than 238 million people living in the basin (NBI *et al*., 2012). The Nile water is crucial for upstream and downstream users with competing needs such as irrigation, domestic water supply, hydropower, industry, for navigation purpose and other ecosystem services. These competing needs are severely compromised by soil erosion in the upstream part of the basin (e.g., in Ethiopia) and siltation of reservoirs and irrigation canals in the downstream part of the river reach (e.g., in Sudan and Egypt). Climate and land use changes, and poor land management are other biophysical challenges to the water resources in the basin(Hurni *et al.*, 2010). Based on long-term observations (1912–2003) at the basin outlet in Sudan, the discharge of Upper Blue Nile basin on average is 48.9Gm^3/year of water (Tarrant, Dodgson and Wu *et al*., 2014).

The river sustains more than 17 million people (UNEP *et al*., 2013) and supplies 57.3% of the Nile's flow at Khartoum, Sudan (Tesemma, *et al*., 2009). There is significant potential for expanding hydroelectric power and irrigation from the UBNR basin in both Ethiopia and downstream countries (Berry *et al*., 2003). This both hydroelectric and irrigation scheme proposed are more affected off and may be decrease its functionality due to high sediment problem in basin.

Soil erosion by water is a major agent of land degradation in Ethiopia and more specifically in the UBNR basin, and it has significant impacts on ecosystem services (Kling *et al*., 2015;Haregeweyn *et al.*, 2017), crop production (Schauer, *et al*., 2015*)*,downstream flooding and reservoir sedimentation (Garzanti *et al*., 2006; Balthazar *et al*., 2013; Haregeweyn *et al*., 2015b), and economic costs (World Bank *et al*.,2007;Schauer, *et al*., 2015).

A few research reports have been estimated annual sediment yield rates, which express amounts of sediment leaving from the UBNR basin. Estimates of the amounts of sediment passing the gauging station at El Deim, just across the border in Sudan, range from 111 to 140 Mt yr−1 (Haregeweyn *et al.*, 2017; Betrie *et al.*, 2011). In sum, estimates of soil loss and sediment yield at national, regional, and river-basin scales are tentative and inconsistent. The limited information on soil erosion and stream discharge for major Ethiopian river basins hinders our understanding of the dynamics and drivers of soil erosion at larger spatial scales (Haregeweyn *et al.*, 2017*;* Haregeweyn *et al*., 2015). Despite these constraints, SWC activities are taking place in many parts of Ethiopia, including the Abay basin, especially since the Sustainable Land Management Project (SLMP) in 2008 targeted 135 watersheds(Haregeweyn *et al*., 2017; SLMP *et al*., 2013*)*.

Abera *et al.*, 2014, On Assessment of Micro-Watershed Vulnerability for Soil Erosion in Ribb Watershed Using GIS and Remote Sensing; from the total area of the Watershed which is 1240.12km^2, 92km^2 is potential areas for gully development. These micro-watersheds are more vulnerable to erosion compared to the others and they should be prioritized for conservation and other environmental protection activities.

Pomeroy *et al*., 2007, entitled spatial delineation of Soil erosion Vulnerability in the Lake Tana Basin, Ethiopia. The main objective of this study was to identify the most erosion sensitive areas. The GIS tool combines the slope, Land cover, soil and river layers as a major factor which contributes to soil erosion. The SWAT model has shown that 18.4% of the watershed area has high potential for soil erosion which produces an average annual sediment yield of 30 to 65 tons per hectare.

2.3. Morphometric Analysis Review

Morphometry is the quantitative description and analysis of landforms as practiced in Hydro-morphometric. It can be applied to a particular kind of landform or to drainage basins and large regions. Horton 1940 and Strahler 1950 first initiate Morphometric studies in the field of hydrology. Morphological analysis is the systematic description of watershed's geometry and its stream channel system to measure the linear aspects of drainage network, shape aspects of watershed and relief aspects of channel network. The morphometric analysis was done successfully through measurement of linear, shape, relief, gradient of channel network and contributing ground slope of the basin (Rai *et al.*, 2017).

Morphometric parameters within certain value range directly indicate the runoff generation and erosion hazard of a catchment. The erosive condition of the watershed directly indicates the loss of land use and land cover in the watershed. Once the erosive condition is identified the watershed can restored by reducing erosion with the help of watershed management practices (Deshmukh *et.al*, 2010).

The morphometric analysis of the drainage basin and channel network play a vital role for understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology and structural control. Besides, the primary aim of studying drainage basin is to understand the hydrologic nature and its morphometric expression of the basin area (Sarma *et al*., 2013; Reddy *et al*., 2002).

Morphometric analysis is significant tool for prioritization of sub-watersheds by studying different linear, shape and relief parameters of the watershed even without the availability of soil map. Attempts to correlate statistically parameters defining drainage basin characteristics and basin hydrology, as in studies of sediment yield, are generally designated as morphometric analyses. The morphometric parameters considered for analyze of linear, shape and relief are stream length, bifurcation ratio, drainage density, stream frequency, drainage texture ratio, form factor, circulatory ratio, elongation ratio, constant channel maintenance, basin relief, relief ratio, ruggedness number and relative ratio.

2.3.1. Basic parameters

Area(A) and perimeter(P): The drainage area is the most hydrological variable characterizes watershed. It reflects the volume of water that can generate from precipitation. The basin perimeter refers to the length of the water divide line of the sub-watershed.

Stream order: The stream order parameter is uses to describe the drainage network quantitatively. The flow of first order stream has no tributary; it depends totally on the surface overland flow to it. Similarly, the second order stream has a higher surface flow, and the third order streams receive flow from two-second order streams.

Total Stream length (Lu): The number of different stream orders corresponding to each sub-watershed was computed, and their lengths where measured.

Basin length (Lb): Basin length refers to the ratio of the longest dimension of a watershed, to its main channel (i.e. from the basin outlet to the basin divide). Therefore, basin length has been measured along the longest flow path. Hence, it is a basic input parameter to compute shape parameters. Basin length parameter is decisive in hydrological computation and increases as the drainage increases and vice versa.

2.3.2. Linear parameters

Bifurcation ratio (Rb): Is the ratio of the streams number of a given order to the number of streams of the next higher order. The bifurcation ratio is elaborate as an index of relief and dissection. Bifurcation ratios for drainage basins are often range between two for flat/rolling topography, and six for catchments controlled by geological structure, where the drainage pattern is also highly distorted.

Drainage density (Dd): Drainage density refers to the closeness of spacing of channels. It has been calculated as the total length of streams in a watershed per unit area, thus it is a measure of terrain dissection and runoff potential of the watershed. A high value of Dd indicates a relatively high density of streams and hence, a quick stream response. High drainage density of a watershed is indicative of high runoff, and consequently a low infiltration rate. By contrast, low drainage density of a basin implies low runoff and high infiltration.

Stream frequency (Fu): Is a ratio of total number of streams (Nu) in a catchment to the watershed area (A). It represents the number of streams per unit of area. The stream frequency value depends mainly on the lithology of the drainage basin and, resembles the texture of the drainage network. Stream frequency is positively correlate with drainage density value of the basin, which means the increase in stream population, is connected with drainage density. For small and large drainage basins, values of Dd and Fu are not directly comparable because they normally vary with the size of the drainage area. High Fu values indicate more percolation, and thus, more groundwater potential.

Drainage texture ratio (Dt): Is the ratio of total number of streams of the first order (N1) to the perimeter (P) of the basin. It is fundamental factors in morphometric analysis of a catchment. Drainage texture ratio depends on lithology, infiltration capacity, and relief aspect of drainage basins.

Length of overland flow (Lo): Represent the length of water over the land surface before it is concentrated into defined stream channels. It is equal to half of drainage density. The length of overland flow ascribes inversely to the average slope of stream channel, and considered as a significant independent parameter influencing hydrographic and hydrologic development of drainage basins.

2.3.3. Shape parameters

Form factor (Rf); Represents the ratio of the area of the basin to the square of basin length. It uses to predict the intensity of the basin of a confined area. For a perfectly circular basin, it is suggested that the Rf parameter value is less than 0.79.

Shape factor (Bs); Represents the ratio of the square of the basin length to the area of the basin, and is inversely proportion to form factor. It delivers an indicator regarding the circular character of the drainage basin. The greater the circular character of the basin, the greater the fast response of the watershed to heavy rainstorm event.

Elongation ratio (Re); Represents the ratio between the diameters of the circle of the same area as presented by the drainage basin to the maximum basin length.

Constant of channel maintenance

Constant of channel maintenance (C) is the inverse of drainage density. It indicates the number of Square kilometers of watershed required to sustain one linear Kilometer of channel. It not only depends on rock type permeability, climatic regime, vegetation, relief but also as the duration of erosion and climatic history. The constant of channel maintenance is extremely low in areas of close dissection.

Circularity ratio (Rc); is considered the ratio of basin area (A) to the area of circle having the same circumference as the perimeters of the basin. Length and frequency of the streams, geological structures, morphology, land use/cover, climate, of the catchment are control circular ratio. Drainage basins with a range of circularity ratios of 0.4 to 0.5 are indicating that they are strongly elongated. High circular ratio values denote young, mature, and old stages of geomorphic development of drainage basin.

2.3.4. Relief Parameters

Basin relief (Bh)

Relief is the difference in elevation between any two reference points. Relief measure of a region indicates the potential energy of a drainage system. A region having a high relief can transfer high energy into the drainage system. Maximum basin relief within a sub-watershed is naturally the difference in elevation between the highest and lowest points.

Ruggedness Number

Strahler's (1956) ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length. An extreme high value of ruggedness number occurs when both variables are large and slope is not only steep but long as well (Strahler *et al*., 1956).

Relief Ratio (Rr)

The difference in the elevation of the highest and lowest points in a watershed is its basin relief, whereas the ratio of basin relief to basin length (horizontal distance along the longest dimension of the basin parallel to the principal drainage line) is Relief Ratio (Rh). It is used to measure the overall steepness of a river basin and is an indicator of intensity of erosion processes operating on the slopes of the basin. Normally, it has inverse correlation with drainage area and size of drainage basin

2.4. Soil erosion

Soil erosion is three-phase phenomena consists of the detachments of individual soil particles from the soil mass and their transport by erosive agents, such as running water and wind, when sufficient energy is no longer available with erosive agents to transport the particles then third phase or a deposition is take place. Potential for soil erosion varies from watershed to watershed depending on the configuration of the watershed (topography, shape, the soil characteristics, the local climate conditions and the land use and management practices implemented on the watershed (Arora K *et al.*, 2003, Suresh R *et al.*, 2000). The removal of topsoil by water is takes place in following ways

2.4.1. Sheet Erosions:

The continuous detachment of soil particles by rain drop particularly during high intensity and long duration rainfalls keeps the run-off water loaded with finer and more valuable particles. The run-off water also detaches and transports more and more soil particles as it flows down streams. That process of erosion resulting in the uniform removal of thin layers of soil from the land surface is commonly referred as sheet erosion (NRCS *et al.*, 2011*).*

2.4.2. Rill Erosion

Rills are small gullies created because of concentration of run-off in small well-defined channels with a potential to develop into gullies if left unchecked. Unlike sheet erosion where soil particles are primarily detached by raindrop impact, the energy of flowing water is the primary agent of detachment in rill erosion. Both detachability and transportability are more serious in rill erosion than in sheet because of higher velocities of concentrated flow. Physically, rills are small enough to be removed (Haregeweyn *et al.*, 2017).

2.4.3. Gully Erosion

Gully erosion is a kind of channel erosion that cuts deeply into the soil such that the ground cannot be smooth easily as is the case in rill erosion. Gullies often develop in natural depressions where run-off accumulates from the adjacent uplands. The process of gully development involves channel erosion by downward scour of top soil and upstream movement of the gully in width and depth(NRCS *et al*., 2011)

2.5. Revised Universal Soil Loss Equation

The original soil erosion model, Universal Soil Loss Equation (USLE) is empirically derived from more than 10,000 plots and years of runoff and soil loss data contributed from 49 locations in the United States (Renard *et al.*, 1997). It is the most widely used erosion model to predict soil loss (Wischmeir and Smith, 1978). USLE was designed to provide a convenient tool for soil conservation and can be used to any geographic region with its modified factors, RUSLE. In many situations, land managers and policy makers are more interested in the spatial distribution of soil erosion risk than in absolute values of soil erosion loss, to address this need the combined use of GIS and erosion models has been shown to be an effective approach to estimating the magnitude and distribution of erosion (Mitasova *et al.,* 1996*;* Yitayew *et al.,* 1999). Among numerous mathematical models applicable to estimate or simulate soil erosion, the RUSLE is widely used and accepted models to predict the average soil erosion rate from certain area (*Williams, 1975).* Therefore, modified USLE or RUSLE have been used to estimate the soil loss rate of study area.

2.6. GIS Application

GIS techniques are considered an effective tool for watershed delineation, prioritization, soil loss modeling, sustainable development and management of environmental resources. Morphometric analysis is a key to understand the hydro morphological processes, and characteristics of drainage networks. Basic, linear, shape and relief morphometric parameters can be calculated from watershed delineated using 30x30 resolution digital elevation model

(DEM). ArcGIS tool, and mathematical formulas elaborated for this purpose*(*Farhan *et al.*, 2016).

Morphometric analysis, identification of critical erosion prone areas and prioritization was done through several mechanics and application. Soil erosion studies are of great importance, not only from a scientific, but also from a practical point of view. In this study, soil loss assessment has been carried out by RUSLE methods through techniques of Geographic information system (GIS). ARC-INFO is used for the storage of the data layers on each factor controlling soil erosion. The main advantage of the GIS methodology is in providing quick information on the estimated value of soil loss for any part of the investigated area. The results obtained by the different calculations are slightly different. An evaluation of the results and of the methods is given in the discussion.

Applications of GIS techniques are much efficient, time-saving accuracy and suitable for spatial planning. GIS can handle complex issues and large databases for manipulation and retrieval. The use of computer has made GIS automated and today the technique is not only capable of handling large datasets, but can also solve many complex issues besides facilitating retrieval and querying of data. It's important to mention that this study indicate GIS techniques application to prioritize catchment-basin based on morphometric parameters analysis and RUSLE techniques of soil loss estimation *(*Amani *et al.*, 2015***).***

2.7. Research gap

Morphometric analysis of drainage basin is significant in identification and prioritization of watershed susceptible to erosion to manage natural resource like land and water resource. Dabus and Guder river sub basin are categorized to tributaries of Abbay basin which contributes high water flow and sediment yield. Erosion is serious problem of the basin, in losing the fertile soil which decreasing the agricultural production and degradation land impact the environment and sedimentation in down streaming reservoir. Most of the above applications are successfully attempted to estimate sediment yield at small catchment scale or evaluate soil erosion model. However, literature shows a lack of information on mitigation measures in the Abay basin. Therefore, the objective of this study is to analyze morphometric parameters to prioritize sub-watershed and soil loss modeling for more affected watershed.

3. METHODOLOGY

3.1. Description of the Study Area

Guder and Dabus sub-basins are two of the sub-basins found in Abbay basin which emanates from Lake Tana in the Northwestern Ethiopian highlands. After leaving Lake Tana, Abbay River passes through deep gorges and valleys for about 1609km before entering Sudan. Geographically, It is located between 7°40’ to 12°5’N and from 34°25’ to 39°49’E and the largest catchment that covers about 16% of the total area of Ethiopia. The basin's climate varies from humid to semi-arid and the annual precipitation increases from northeast to southwest and ranges from 1200 to 1600mm.The elevation ranges from 500m at Sudan border to 4230m at the top of highlands. The upper Blue Nile River (UBNR) (also called the Abay River) of Ethiopia is a major tributary of the Nile River that drains a basin with an area of 173,000km^2. The Abbay river sustains more than 17 million people (UNEP *et al.*, 2013) and supplies 57.3% of the Nile's flow at Khartoum, Sudan (Tesemma *el al.*, 2009).

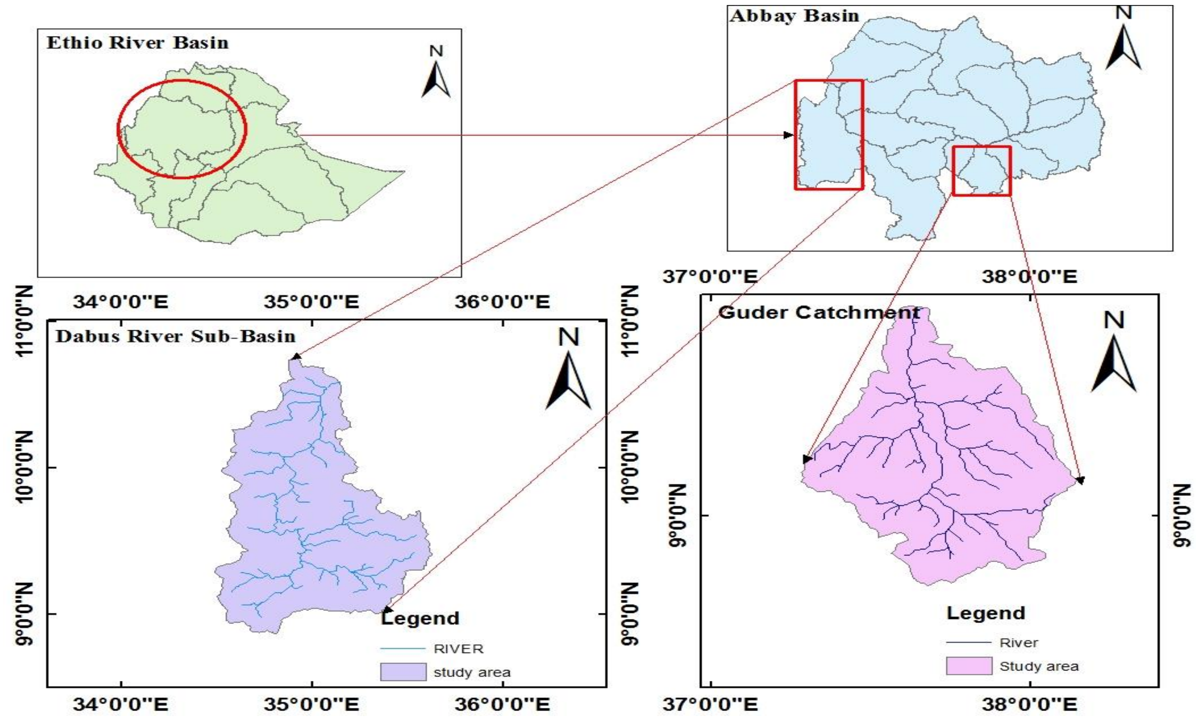

Figure 3.1 Location of the study area or Guder and Dabus sub-basin.

3.1.1 Dabus River Sub-basin

Dabus River sub-basin is the north-flowing tributary of the Abbay river in southwestern Ethiopia; it joins its parent stream at 10º36’38”N and 35º8’58”E. The Dabus has drainage area of 21,032km2 and the elevation of drainage basin ranges from 467m to 3130m above sea level. It drains northwards into the lower Abay and has the highest mean rainfall in the basin (2200mm). This high mean annual rainfall is reflected in its high contribution to the total Blue Nile flows.

3.1.2 Guder River Sub-basin

Guder sub-basin which has a drainage area of 7011km2 is located in the Northwest of Ethiopia; in the Southeastern part of the Blue Nile Basin approximately between 7º30' to 9º30'N latitude and 37º00' to 39º00'N longitude. The Guder River originates from the mountainous area of south of the towns of Ambo and Guder at an elevation of 3000m above sea level. The Guder sub-basin borders with the Muger sub-basin to the east, the Awash Basin to the south and the Fincha sub-Basin to the west. It collects water from a number of streams for instance; Huluka, Fatto, Indris and Debis along its way to the lower Guder, where it meets the Blue Nile River. The Guder sub-basin obtains most of its rainfall from June to September.

3.1.3. Climate

Precipitation, temperature, wind, humidity and solar radiation are climatic attributes that affect erosion. According to Hurni 1986 description of Agro climatic zones of Ethiopia, the catchment consists of three agro-climatic zones “*kola, weyna dega* and *dega*” with elevation variation of 500-1500, 1500-2300 and above 2300m, respectively.

Table 3. 1: Maximum and minimum temperature of the study area, Sub-watershed.

	Average Monthly Temperature (^{0} c) of Ambo Station												Mean
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Maximum	26.2	27.6	28.4	29.7	26.3	24.1	21.4	21.7	22.3	23.1	23.6	24.3	24.89
Minimum	12.1	12.3	12.4	13.2	14.7	13.3	13.2	13.5	14.9	15.6	14.9	13.5	13.63
	Average Monthly Temperature(^{0} c) of Tikur hincini												Mean

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Maximum	25.9	26.8	27.4	29.4	26.4	25.5	22.8	22.1	22.6	23.2	24.6	25.9	25.22
Minimum	12.2	12.6	11.4	12.3	13.1	12.4	14.8	14.7	12.2	12.7	15.1	13.3	13.07

The climate of the sub-basin is marked by wet season from May to September, with average monthly rainfall varying from 161.92mm in June to 386.90mm in August. The rainfall distribution and intensity also varies across the elevation variation and the seasons of the year.

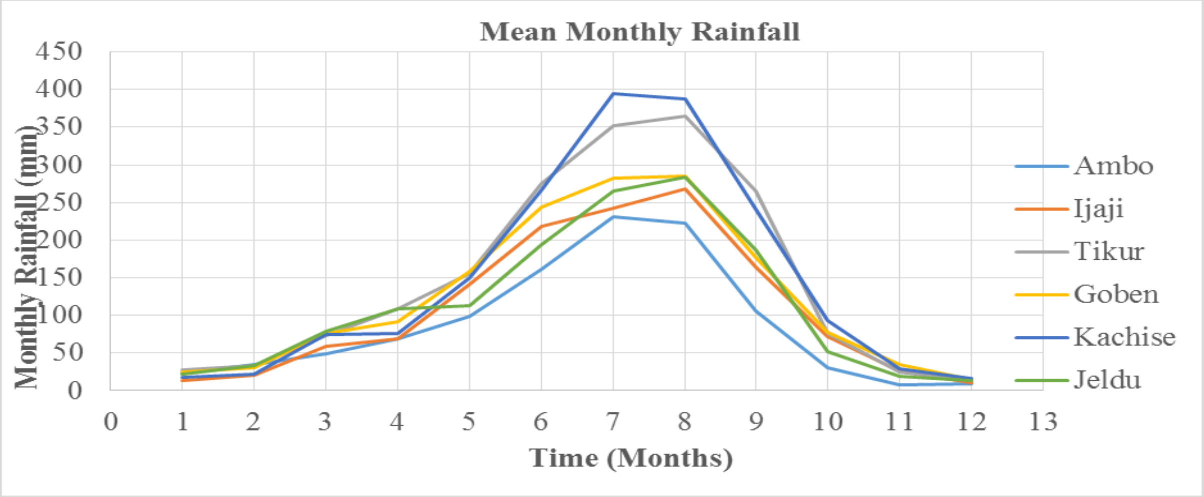

Figure 3.2 Mean monthly rainfall

3.1.4. Topography

Catchment area, relief and drainage density are some of the factors related to catchment topography which are found to influence sediment yield. The morphometric analyze and annual soil loss estimation which is sub-watersheds of the Guder and Dabus sub-basins has variety of landscape with different land features. The effect of topography on erosion is complex because, the local slope gradient (S) influences flow velocity and rate of erosion, slope length (L) describes the distance between the origin and termination of inter-rill processes.

3.1.5. Soil and Geology

Soil erosion is severe in study area and poses a major threat to continued agricultural production in the area. Virtually all topsoil, and in some places parts of the subsoil, has been removed from sloping land leaving stones or bare rock at the surface.

The regional geology of the study area was developed from three types of geological terrains. These are Quaternary sediments, Paleozoic to Mesozoic rock, Precambrian rock (from youngest to oldest). Most of the area is covered with intrusive Precambrian rocks mainly granite with coarse grained texture and massive in nature which is overlaid by thick black to brownish cotton soil (OWWDSE *et al*., 2015).

3.1.6 Materials Used

To execute the different procedure in this thesis, different materials and tools were used. The materials and tools used in this study are indicated in Table 3.2

Table 3. 2: Materials and software or tools used.

S/N	Software/Models used	Purpose of the software or tools	Remarks
1	ArcGIS 10.3	Analyzing, Displaying and viewing of the spatial data	Done
2	Arc hydro tool	Watershed multiple point delineation and classification	Done
3	RUSLE(Revised universal soil loss equation)	To estimate or quantify annual soil loss rate.	Done

3.2. Data Collection

To analyze the morphometric parameters and annual soil loss estimating different climatic and spatial data were collected. These data were collected from governmental and non-governmental institution.

3.2.1 Digital Elevation Model (DEM)

Digital Elevation Model (DEM) with 30x30 resolutions has been used. It has been used in watershed delineation and maximum and minimum elevation extracting.

1.3.3. Rainfall

The daily recorded data of rainfall where collected from National Meteorological Agency (NMA). Out of the collected station selected for this thesis, Ambo, Ijaji, Jeldu, Tikur Enchine, Kachise and Goben where used. The thirty-four (34) year (1984 to 2017) inclusive recorded data of precipitation have been utilized.

Table 3. 3: Location and rain gauge stations with their respective average annual rainfall.

S/N	Rain gauge station name	Latitude(N)	Longitude(E)	Altitude(m)	Average annual rainfall(mm)
1	Ambo	8.9846	37.8396	2068	1042.2
2	Ijaji	8.9999	37.5867	1900	1301.8
3	Jeldu	9.155	37.8833	2952	1372.3
4	Tikur Enchine	8.8363	37.6877	2467	1746.1
5	Kachise	9.312	37.685	2520	1772.3
6	Goben	9.1725	37.6187	2500	1498

3.2.2. Soil data

Soil map are used in showing diversity of soil types and/or soil properties in the area of interest. Soil map and major soil physico-chemical properties for the Guder and Dabus river sub basin have been obtained from the FAO soil (1998). The clipped map of soil types from FAO soil map for the study area was identified as, Eutric nitosols, Pellic vertisols, cambic arenosols and Humic combisols.

Table 3. 4: FAO soil types and characteristics.

Group name	Soil unit Map	Soil type	Soil characteristics	Area km2	Area (%)
Ne(Ne20-3b)	Eutric Nitosols	heavy clay	Seasonally cracking soil, very poorly drained, heavy clay	1224.4	51.4
Vp(Vp14-3a)	Pellic vertisols	Densed Clay	Very acidic with a clay-enriched subsoil and high nutrient-holding capacity	353.2	14.98
Qc(Qc5-1c)	Cambic Arenosols	Sandy to silty soil	Easily erodible sandy soil with slow weathering rate, low water and nutrient holding capacity and low base saturation.	424.2	17.99
Bh(Bh11-1b)	Humic cambisols	loam to silty clay	Shallow over hard rock and comprise of very gravelly material. They are found mainly in mountainous regions	356.2	15.11

3.2.3. Land use land cover (LULC) data

For this study, the land use land cover map of 2013 was used. The classified map was collected from Ethiopian Mapping Agency (EMA). It shows detailed classification of the LU/LC in the specified year for the whole Ethiopia. From The LU/LC map about eight different land use and land cover types were identified. These are Agricultural land (Dominated and moderately cultivated area), Urban, Grass land, Swamp, Water body, Bush land, Afro alphine and Woodland open.

Table 3. 5: Summary of data types, sources, description and purpose used.

Types of data	Source	Description	Purpose
DEM	MoWIE	30mx30m resolution	Watershed delineation, slope map and LS- factor generation
Rainfall	National Metereology Agency	34 years data of six stations	Calculate erosivity of rainfall (R-factor).
Soil data	MoWIE	FAO (1998) Digital soil map	Estimate erodibility of soil (K-factor)
Land use land cover	Ethiopian mapping agency	2013 land use land cover classification	To extract c-factor and P-factor

3.3. Data Quality control

The data were rearranged and qualified as per requirement. Homogeneity, consistency and missing values of the data were checked. Errors resulting from lack of appropriate data processing were serious because they lead to bias in the final answers. The data were appropriately adjusted for inconsistency, corrected for errors, extended for insufficient, filled for missing and checked for outlier.

3.3.1 Missing data Filling

Daily recorded data of rainfall were missed due to; stability of the record has been broken, absence of recorder, carelessness of the observer and failure of instruments. Missing data have been estimated and filled by using the data of neighboring station.

3.3.2. Checking the Consistency of Data

Rainfall data consistencies were checked through the method of double mass curve analysis. A plot of accumulated rainfall data at a station of interest against the accumulated average at the surrounding stations was generally used to check consistency of rainfall data. Therefore, for this thesis each of the station was checked for consistency of rainfall series by using double mass curve (appendix 2).

3.3.3. Test for outliers

An outlier is the data that was significantly detached from the rest of the series. Outliers in data series affects sample statistics like mean, standard deviation, coefficient of variation, and coefficient of skewness. To make reliable frequency analysis outliers were carefully detected and removed. The Grubbs-Beck test defines high and low outlier thresholds as:

$$X_H = x + k_N - S_x$$

$$X_L = x - k_N - S_x$$

Where x and Sx are the mean and the standard deviation of the sample data and the critical k_N values are given in Grubbs and Beck according to the sample size N. Outlier test graph that show the X_L, lower and X_H, higher limit data (appendix 3).

Table 3. 6: Summary of the outlier data of stations

S/N	Station name	Year of Outlier	High and low Outlier limit	Detention data	Remarks
1	Ambo	1988	77.06-24.12	81	Limited to high outlier
2	Ijaji	2007	101.55-32.74	104.4	Limited to high outlier
3	Tikur Enchine	2007	118.59-23.42	261.4	Limited to high outlier
4	Jeldu	None	71.66-25.06	free	The data was normal
5	Kachise	2006	117.64-38.48	166.5	Limited to high outlier
6	Goben	1999	75.26-31.39	81.7	Limited to high outlier

3.4. Morphometric analysis and prioritization

In this thesis work Guder and Dabus River sub-basin watershed prioritization has been performed on the basis of the morphometric analysis and soil loss rate modeling of RUSLE was done for the area of high erosion risk or significantly affected sub-watershed. Morphometric parameters analysis and prioritization of watershed was done using the resolution 30mx30m DEM. The digitization of dendritic stream pattern was carried out in GIS environment. The stream network of the basin was analyzed and the stream ordering was made using Strahler's law. For each sub-basin, watershed and basin boundary was delineated with the help of Arc hydro Tool. Delineation and characteristics of the basin at outlets was processed and the stream channels were divided into sub-watershed.

Arc Hydro tool extension which was integrated with ArcGIS 10.3 was used in watershed classification and point delineation. Finally, ArcGIS software was used to analyze morphometric parameters and prioritize the watershed. In morphometric analysis linear, shape and relief parameters were considered for the sub-watershed prioritizations. Stream order (u), stream number (Nu), stream length (Lu), mean stream length (Lsm), drainage texture (Dt), length of overland flow(Lof), bifurcation ratio (Rb), drainage density (Dd) and stream frequency (Fs) were used in this study for linear parameters. Whereas form factor (Ff), circulatory ratio (Rc), elongation ratio (Re) and constant channel maintenance (C) was used for shape parameters. Finally relief parameters like basin relief (Rb), Ruggedness coefficient and form relief (Rf) was used in watershed morphometric analyze and prioritization.

The steps that have been used in priority determination of watershed include,

- Generation of digital input maps
- Computation of morphometric parameters.
- Ranking of each watershed of the catchment according to calculated values of morphometric parameters.
- Determination of average ranking and assigning of priority for watershed

Table 3.7 shows the morphometric parameters, formulas and corresponding references that was used in morphometric analyze.

Table 3.7: Morphometric parameters and their corresponding formulas.

	Morphometric Parameters	*Formula/Definition*	Reference
Basic aspect	Area of the basin	*A= Area in km2*	
	Basin Parameters	*P, Perimeter in km*	
	Stream order (u)	*Hierarchical order*	Strahler, 1964
	Basin Length (Lb)	$Lb=1.312 * A^{0.568}$ *Where, Lb=Length of Basin (km), A=Area of Basin (km2)*	K.Nookaratnam *et.al*, 2005)
	Stream Length (L)	*Length of the stream*	Horton, 1945
Linear aspect	*Bifurcation Ratio (Rb)*	*Rb= Nu/Nu+1. Where, Rb= Bifurcation Ratio,* *Nu=Total Number of stream segment of order u.* *Nu+1=Number of segments of the next higher order*	Schumm, 1956
	Mean Bifurcation ratio (Rbm)	*Rbm=Average of bifurcation ratio of all orders*	Strahler, 1964
	Drainage density (Dd)	*Dd =Lu/A Where, Dd=Drainage density* *Lu=Total stream length of all order, A=Area basin (km2)*	Horton, 1945
	Stream frequency (Fu)	*Fu=Nu/A Where, Nu=Total number of stream of all order, A=Area of basin (km2)*	Horton, 1945
	Texture ratio (T)	*T=Nu /P, Where, Nu=Total no streams of all order,* *P=Basin Perimeter (km)*	Smith, 1950
	Overland flow Length (LO)	*LO=½Dd, Where, LO=Length of over land flow,* *D=Drainage density*	Horton, 1945
Shape Aspect	*Form factor (Rf)*	$Rf=A/Lb^{2,}$ *Where, Rf=Form factor* *A=Basin area (km2),* Lb^{2}*=Basin length*	Horton, 1945)
	Shape factor (BS)	$BS=Lb^{2}/A$*, Where, BS=Shape factor* *A=Basin Area (km2),Lb=Basin length*	
	Elongation ratio (Re)	*Re=(2/Lb)x(A/π)0.5 Where , Re=Elongation ratio, Lb=Length of basin(km), A=Area of basin(km2)*	Schumm, 1956)
	Compactness Constant(Cc)	*Cc=0.2821 P/A0.5 where, Cc=Compactness Ratio,* *A=Area of basin(km2), P=Perimeter of the basin(km)*	Horton, 1945
	Circulatory ratio (Rc)	*Rc=4πA/P2,A=Area of basin , Where, π=3.14,* *Rc=Circulatory ratio, P=Perimeter of basin(km)*	Miller, 1953

3.5. Annual soil loss estimation

To calculate spatial distribution of soil erosion rate for significantly affected sub-watershed, RUSLE techniques framed with ArcGIS environment has been used. Respective individual RUSLE factors such as R, K, LS, C and P were generated in ArcGIS database and combined cell by cell grid to predict soil loss rate in a spatial domain.

In order to generate spatially distributed annual average soil loss rate, secondary data such as, DEM, rainfall, land use land cover and soil data were collected from Ministry of Water, Irrigation and Electricity and National Meteorological Agency. To estimate the total rate of soil erosion, the data layers or maps of R, K, LS, C, and P factors of RUSLE model which were extracted from the collected data were integrated through multiplication algorithm within the raster calculator in ArcGIS database. According to Renard *et al.,* 1997, the empirical equation of RUSLE model is given by Equation (3.1).

$$A=R*K*LS*C*P \quad \text{……………………………………………………………….. 3.1}$$

Where, A, Annual soil loss per unit area in [ton ha-1 yr-1], R, rainfall erosivity factor in [MJ mm ha-1 hr-1 yr-1], K, soil erodibility factor (soil loss per erosion index unit for a specified soil measured on a standard plot of 22.13m long, with uniform 9% slope, in continuous tilled fallow) in [ton ha hr ha-1 MJ-1 mm-1], LS, slope length and steepness factor (the ratio of soil loss from the field's slope length and steepness to standard slope length of 22.13m and steepness of 9% slope) (dimensionless), C, land use and land cover factor (ratio of soil loss from a specified area with specified cover and management to that from the same area in tilled continuous fallow) (dimension less), and P, conservation practice factor (ratio of soil loss with a conservation practice like; contour tillage, strip-cropping, terracing to soil loss with row tillage parallel to the slope (dimensionless). The procedure of data processing in morphometric analyze, prioritization and annual soil loss estimation was done as follow.

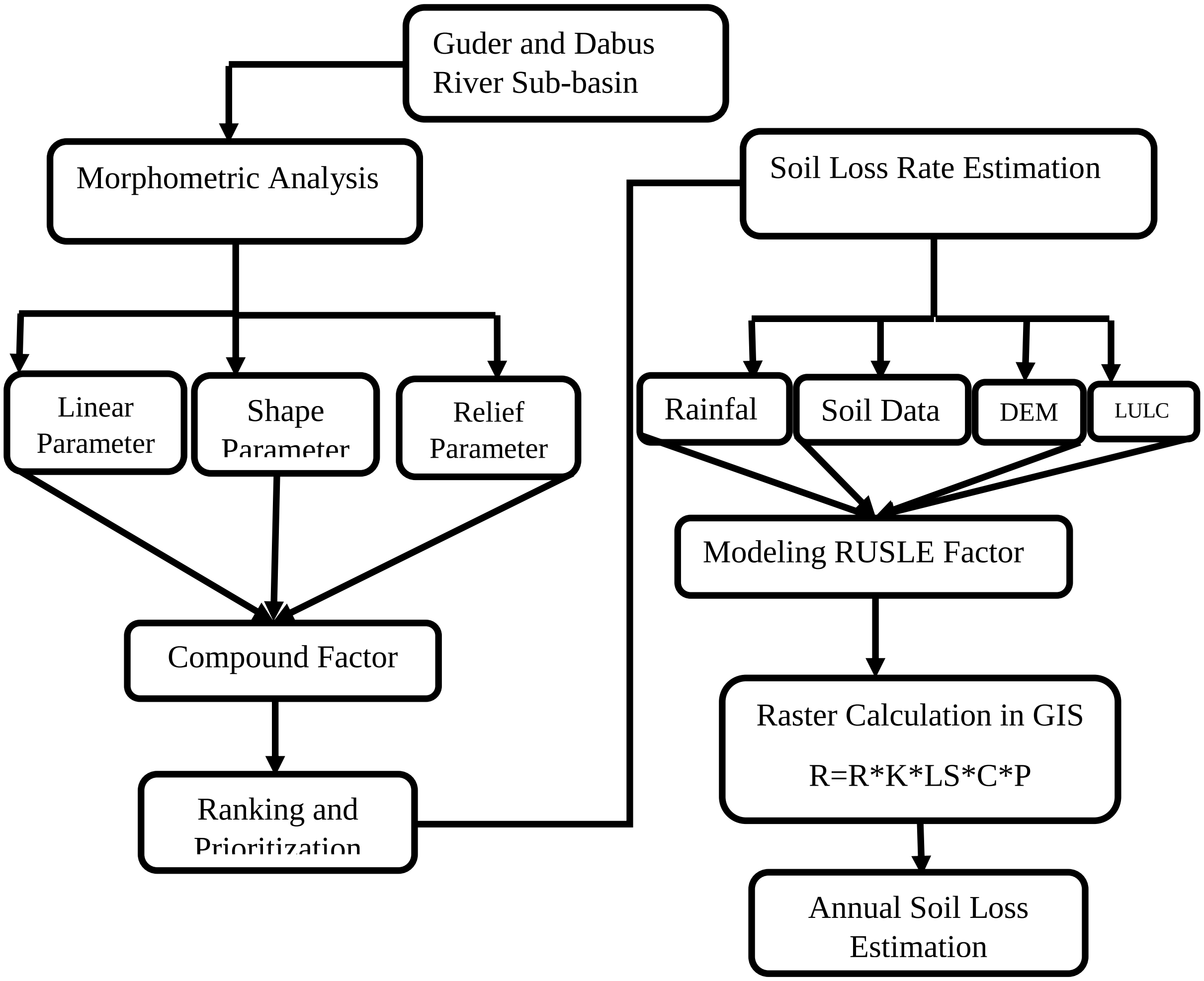

Figure 3.3 Flow chart of morphometric analysis and Annual soil loss estimating.

3.6. RUSLE factor Estimation

Rainfall erosivity factor(R), soil erodibility factor (k), slope length and slope steepness factor (LS), cover management factor (C), conservation practice factor (p) are the major parameters in application of RUSLE model of soil loss estimation method. Their assessment procedures for the different factors mentioned above employed in RUSLE model is described in the following sections.

3.6.1. Rainfall Erosivity (R)

Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff (Morgan *et al.*, 1994). Rainfall erosivity is used to describe the potential for soil to wash off disturbed, vegetated areas and into surface waters during storms.

R is the measure of rainfall erosivity factor which is the product of storm kinetic energy and maximum 30-minute intensity EI30. When other factors are constant, storm losses from rainfall are directly proportional to the product of the total kinetic energy of the storm (E) times its maximum 30-minute intensity (Arnoduls *et al*., 1978). Most of the time rainfall intensity and storm kinetic energy data are not available at National meteorological agency. Due to the absence of rainfall intensity and storm kinetic energy data, mean annual and monthly data have been used to estimate the R-factor (Arnoldus *et al*., 1978).

For the areas where there is no such map or rainfall intensity map, different soil scientists develop empirical equations with the function of average annual rainfall (Table 3.8). These empirical formulas were formulated and applied in different parts of the world. For instance, the first equation in Table 3.8, works well for Ethiopia and Egypt whereas the second equation was developed for Thailand.

Therefore, in this study the first Equation in table 3.8 was used to determine R-factor values from annual average rainfall and presented in table 3.9. This empirical equation was developed by Hurni *et al*., 1985 from a spatial regression analysis for Ethiopian conditions. The equation is based on the readily available mean annual rainfall data and used by other similar studies in Ethiopia (Bewket and Teferi *et al*., 2009; Tadesse and Abebe *et al*., 2014; Kebede *et al*., 2015; Gelagay and Minale *et al*., 2016).

Table 3. 8: Summary of empirical equations for determination of R- factor

S/N	Erosivity formula	Applicable area	References
1	Ethiopia and Egypt	R=0.55*MAP-24.7	Hurni,H. 1985
2	Thailand	R=38.5+0.33*MAP	Harper,1987
3	Entire Indian	R=79+0.363*MAP	Singh *et al*,.1981
4	*Ivory coast and Burkina Faso*	R=p*0.5	Morgan and Davidson, 1991
5	Northern Jordan	R=23.61*exp(0.0048*MAP)	Eltaif *et al*,.2010
6	Kenya	R=117.6*1.00105^^{MAP}	Kassam *et al*,. 1992
7	Malaysia	R=9.28*p-8838	Morgan (1974)
8	Australia	R=0.0438*p^$^{1.61}$	Mikhailova *et al*,.(1997)

According to Hurni, H.(1985)

R= 0.55 *MAP-24.7……...3.2

Where; R is erosivity factor (MJ mm ha^{-1} hr^{-1} yr^{-1}), P is mean annual precipitation (mm);

Table 3. 9: Mean annual precipitation and erosivity factor of the all station

Rain gauge station	Mean annual precipitation(mm)	Erosivity factor,MJ mm ha^{-1} hr^{-1} yr^{-1}
Ambo	1042.20	548.51
Ijaji	1301.80	691.29
Tikur Enchine	1746.10	935.655
Jeldu	1372.30	730.065
Kachise	1772.30	950.065
Goben	1498.00	799.2

Using ArcGIS 10.3 the Interpolating of point data of rainfall was used to change the point data to area representation form. The Inverse Distance Weighted (IDW) interpolation method was used in order to form a surface data from the scattered set of point data as given in Figure 3.7. Finally, the R-factor values were interpolated to generate erosivity map and clipped in GIS database.

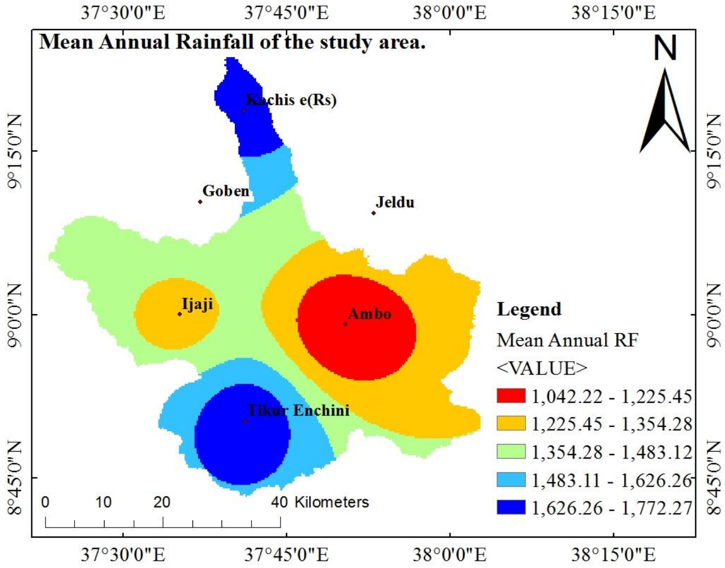

Figure 3.4: Mean annual Rain fall interpolated by Inverse distance weight (IDW) map.

3.6.2. Soil Erodibility (K)

The soil erodibility factor (K) is a quantitative description of the inherent erodibility of a particular soil type; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. The main soil properties influencing the K factor are soil texture, organic matter, soil structure and permeability of the soil profile.

The erodibility of a soil is an expression of its inherent resistance to particle detachment and transport by rainfall. It is determined by the cohesive force between the soil particles, may vary depending on the presence or absence of plant cover, the soil's water content and the development of its structure (*Wischmeier and Smith, 1978*). Texture is the principal factor affecting K-values; structure, organic matter and permeability are also important contributors (*Robert and Hilborn, 2000).*

The soil types in the study area was as per from FAO (1998) soil map. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard unit plot of 23.13m long slope length with 9% of slope gradient(Ganasri and Ramesh, 2016), it reflects the rate of soil loss per rainfall erositiviyity(R) index. In the absence of soil structure and soil permeability value as need in original equation(Wischmeier and Smith, 1978), the equation provided by references(Williams and Arnold, 1997) which is uses William equation (1995) and FAO (1998) soil was used to estimate soil erodibility factor (k),

$$K=Fcsand*Fsi\text{-}cl*ForgC*Fhisand \ldots\ldots 3.3$$

Where,

$$Fcsand= (0.2+0.3\exp [-0.256*Ms*(1-Msilt/100)] \ldots\ldots 3.4$$

$$Fsilt\text{-}cl= (Msilt/ (Mc+Msilt))^{0.3} \ldots\ldots 3.5$$

$$Forg = \underline{(1-0.0256*orgC)/} (orgC+\exp [3.72-2.95*orgC) \ldots\ldots 3.6$$

$$Fhisand=(1-0.7*(1-Ms/100)/(1-Ms/100) + \exp[-5.51+22.9*(1-ms/100)]) \ldots\ldots 3.7$$

Whereas, Ms, Msilt, Mc, and orgC is the percent of sand, silt, clay and organic carbon content respectively.

Table 3. 10: Summary soil of types, its contents of silt, sand, clay and organic carbon

FAO soil	Sand content (%)	Silt content (%)	Clay content (%)	Organic carbon (%)	K-factor (ton ha hr ha^{-1} MJ^{-1} mm^{-1})
Ne	68.4	10.5	21.2	0.6	0.137944
Vp	25.1	12.2	62.7	0.68	0.116327
Qc	63.5	19.2	17.3	0.76	0.15484
Bh	55.2	21	23.8	3.8	0.169345

Fcsand, gives a low soil erodibility factor for soil with coarse sand and a high value for soil with little sand content. All fraction of soil; sand, clay, silt, and organic carbon where represented to the top soil layer of the watershed because it is affected directly by the raindrop energy.

Fsi-cl, 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

Finally, the clipped soil map (Figure 3.8) and the resulting shape file attribute table was edited and K-factor values were added. Then the map changed to grid file or raster format with cell size of 30X30m resolution in ArcGIS to generate erodibility factor map.

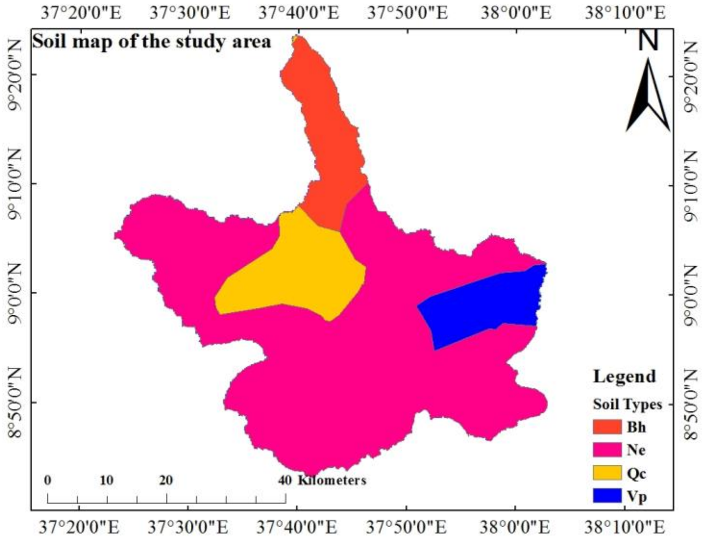

Figure 3.5: FAO soil types of the study area

3.6.3. Slope length and Steepness Factors (LS)

The LS factor (topographic factor) accounts for the effect of topography on erosion in RUSLE. The slope length factor (L) represents the effect of slope length on erosion, and the slope steepness factor (S) reflects the influence of slope gradient on erosion. For this study L, is the flow length and S, is slope steepness which is given by meter and percent respectively. Basically, the LS factor can be estimated through field measurement or from a digital elevation model (DEM). With the incorporation of Digital Elevation Model (DEM) into ArcGIS 10.3, the slope gradient (S) and slope length (L) may be determined accurately and combined to form a single factor known as the topographic factor (LS). The precision with which it can be estimated depends on the resolution of the digital elevation model (DEM). Slope length is the distance from the point of origin of overland flow to the point where either the slope decreases enough that deposition begins or runoff water enters a well-defined channel (Wischmeier and Smith, 1978).

Generally, the greater the slope length, the greater the velocity of runoff water as a result of progressive accumulation of runoff in the down slope. Consequently, the greater erosion expected. On the other hand, slope steepness is the gradient from point of origin of flow to the point where either the slope decreases enough that deposition begins or runoff water enters a well-defined channel (Wischmeier and Smith, 1978). The effects of this combined factor is expressed as the ratio of soil loss from the field’s slope length and steepness to standard slope length of 22.1m and steepness of 9% slope (Wischmeier and Smith, 1978). This factor is the major contributing factor for soil erosion as the slope length and steepness increase, the resulted concentrated flow velocity and instability of soil particle increases (Renard, 1997).

To generate topographic factor (LS) map, a DEM with 30mX30m resolution was used. It is possible to calculate both slope length ‘L’ and gradient ‘S in single factor (LS). The spatial analysis tool of ArcGIS was used to generate raster layer of slope from DEM data. Flow direction and Flow accumulation map were also processed and generated from DEM after fill operation in Arc Hydro tools of Arc GIS extension to use as an impute for the calculation of LS-factor. The equation used to determine this topographic factor (LS) was developed by Moore and Burch et al., 1996, was used in raster calculator of Arc GIS.

$$LS=Power\left[(FA)*\frac{Resolution)}{22.1}, 0.6\right]*Power\left[(\sin(slope)*0.01475)/0.09, 1.3\right]\ldots\ldots\ldots\ldots 3.8$$

Where, FA (flow Accumulation) is a raster-based total of the accumulated flow to each cell, and resolution is cell size or length and width of pixels side (Figure 3.9).

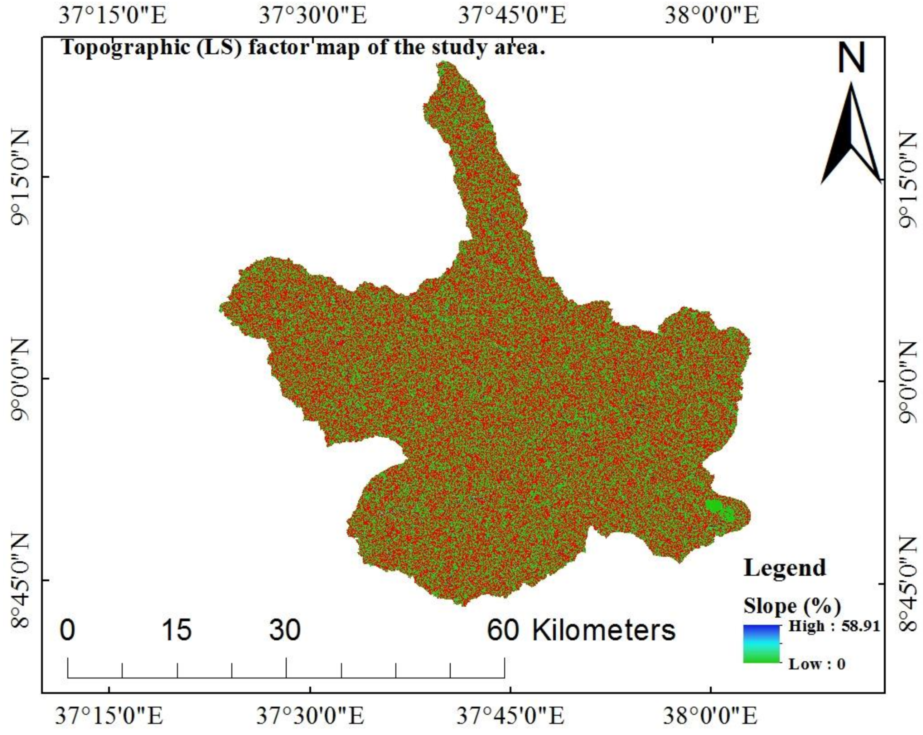

Figure 3.6: Map of flow accumulation and slope in (%)

3.6.4. Land Cover factor (C)

The cover management factor (C) is used to reflect the effect of cropping and other management practices on erosion rates. Vegetation cover is the second most important factor next to topography that controls soil erosion risk. The land cover intercepts rainfall, increases infiltration, and reduces rainfall energy. In areas where land uses other than cropping dominate, the C factor is normally assigned based on a simple assessment of vegetation cover, rather than close analysis of agricultural cropping patterns. In this study, Land Use/Land Cover (LULC) produced by Ethiopian land use land cover map of 2013 was used for preparing a C-factor map; by the raster calculator tools of the spatial analyst extension of ArcGIS software package the C-factor was calculated.

First, the raster map was converted to polygon and the attributes with same land use type were merged in ArcGIS. From this, eight types of land use were obtained (Table 3.11). For each land use type, C-factor values were assigned through reference(Panagos *et al.*, 2015) from different literature. The C factor ranges from 0 to approximately 1, where higher values indicate no cover effect and soil loss comparable to that from a tilled bare fallow, while lower C-factors value means a very strong cover effect resulting in no erosion(Erencin, 2000). Based on the land cover classification map, the analysis of crop management factor (C-value) was made.

Table 3. 11: Land Use Land Cover types and corresponding C-factor values

LU/LC types	Area km^2	Coverage (%)	C-factor Value	References
Dominated agricultural	2052.91	87.10	0.71	HURNI (1985)
Moderated agricultural	133.12	5.65	0.63	HURNI (1985)
Urban	5.30	0.23	0.03	
Grass land	35.39	1.50	0.01	Van Lammeren (1996)
Swamp	34.06	1.44	0.3	
Water body	7.49	0.32	0	HURNI (1985)
Bush land	76.78	3.26	0.6	CGIP (1996)
Afro alphine	10.13	0.43	0.01	
Wooden land open	1.84	0.08	0.06	

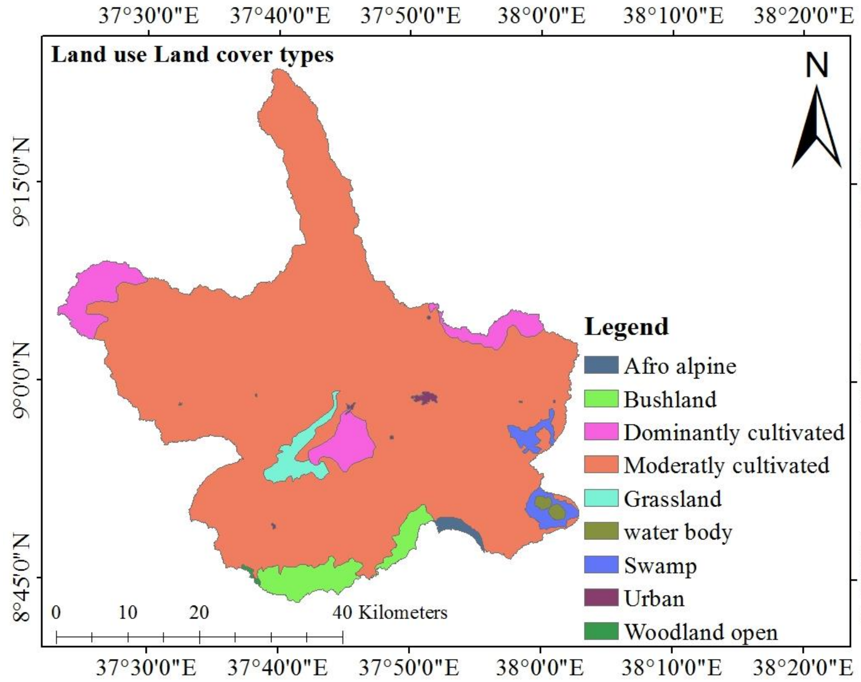

Figure 3.7: Land use land cover map of the study area.

3.6.5. Conservation Practice Factor (P)

The soil conservation practice factor describes the supporting effects of practices like contouring, strip cropping, and terraces. Most often this variable is assigned a value 1 indicating that there are no practices in place. Conservation practice factor indicates the rate of soil loss according to the various cultivated lands. There are contours, cropping, and terrace as its methods and it is important factor that can control the erosion(W.P., 1869). The P values range from 0 to 1, where the value 0 represents a very good anthropic erosion resistance facility and the value 1 indicates a non-anthropic resistance erosion facility (Table 3.12).

In this study area of the sub-watershed, farming practices in sloppy agriculture land occur through the construction of terraces that closely resembles the contour farmland, which is a mean of conservation farming. Thus, we consider the contour farmland as an agricultural conservation practice. The management factor P indicates reduced erosion potential, with a range between 0.0-1.0 because of farming practices or conservation measures. The only farming practice increasing erosion (P factor value >1) instead of reducing it is ploughing in the direction of the slope (Hurni and Centre, 2016)and *CGIP, 1996)* have found different P values for various management practices and land use and cover. In this study depending on the site observation and some literature written to the area of study area contouring method of erosion controlling measurement are popular, so the erosion control potential is estimated to be reduced by a factor P, 0.55 – 1.0.

Table 3. 12: Conservation practice factor (p) values for slope of contouring practice method

Slope Class in (%)	Contouring method practice value
0-7	0.55
7-11.3	0.6
11.3-17.6	0.8
17.6-26.8	0.9
>26.8	1

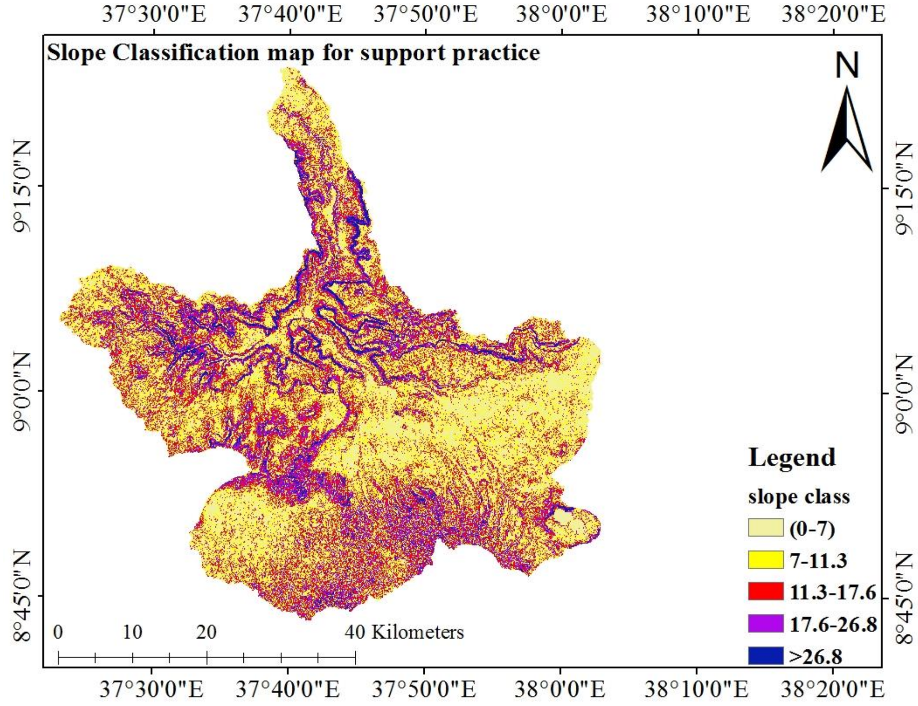

Figure 3.8: Slope classification map in support practice management.

Using the RUSLE factors the GIS tools software has been calculate the rate of annual soil loss for significantly affected Sub-watershed. The estimation of average annual soil loss (A) has been calculated through full integration of the RUSLE parameters in a GIS environment, in order to compute soil loss rate. Mathematically the equation used was denoted as below.

$$A\ (\text{tons/ha/year}) = R*K*LS*C*P \tag{3.9}$$

Where,

A: Mean annual soil loss
R: Rainfall erositivity factor
K: Soil erodibility factor,
LS: Slope length and slope steepness factor
C: Crop management factor
P: Conservation practice factor

4. RESULTS AND DISCUSSIONS

4.1. Watershed Delineation

The entire area of each Guder and Dabus sub-basins were divided into seven sub-watersheds respectively. Arch Hydro were used in automatic sub-watersheds classification. These sub-watersheds were then prioritized based on morphometric analysis.

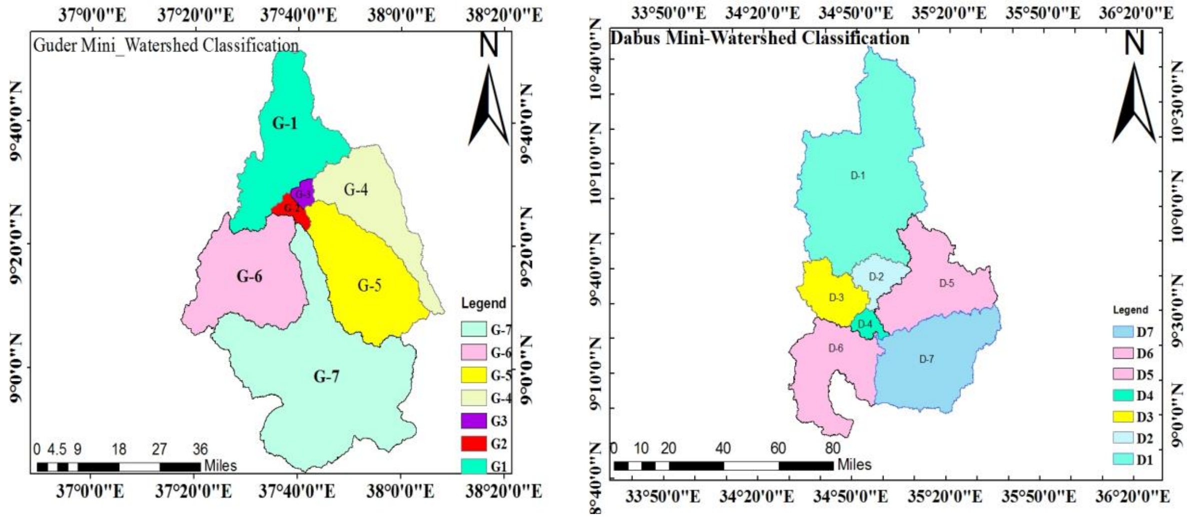

Figure 4.1 Guder and Dabus sub-basin sub-watershed

4.2. Basic parameters

The calculated basic parameters for the fourteen (14) sub-watersheds of both Dabus and Guder are: the area (A), perimeter (P), and stream number (Nu), stream order (u), basin length (Lb), and stream length (L).

4.2.1. Area (A) and perimeter (P)

The drainage area is the most hydrological variable to characterize a watershed. It reflects the volume of water that can be generated from precipitation. The sub watershed areas for Guder varies between 50.72km2 to 2408.93km2; whereas, for Dabus it was found to be between 215.97km2 to 5670.45km2. Also the sub-watershed perimeters for Guder sub-basin varies between 43.28km to 467.91km; whereas, for Dabus it was found to be between 126.7km to 763.73km..

4.2.2. Basin Length (Lb)

It is considered as basic input parameter to compute shape parameters and decisive in hydrological computation. Basin length is increases as the drainage increases and vice versa. Accordingly, the basin length of sub-watershed for Guder sub-basin varies between 12.20km to 109.35km; whereas, for Dabus it was found to be between 27.79km to 177.82km respectively.

Sub-Basin		Area(A) Km^2	Perimeters(p) km	Basin Length(Lb)km
Guder Mini Sub-watershed	G-1	1026.98	299.14	67.38
	G-2	66.55	62.68	14.24
	G-3	50.72	43.28	12.20
	G-4	765.07	249.47	57.00
	G-5	1047.79	225.62	68.15
	G-6	1078.30	256.17	69.27
	G-7	2408.93	467.91	109.35
Dabus Mini Sub-Watershed	D-1	5670.45	763.73	177.82
	D-2	541.80	221.51	46.85
	D-3	929.14	248.92	63.65
	D-4	215.97	126.7	27.79
	D-5	2244.25	475.89	105.04
	D-6	2042.83	478.49	99.57
	D-7	2740.92	439.89	117.67

4.2.3. Stream number (Nu)

Number of streams decreases as the stream order increase. The total stream number of all order for each sub watershed of Guder and Dabus were expressed in table 4.2. The maximum and minimum stream number of sub-watersheds for Guder were 685(D-1), 265(G-7); whereas, for Dabus found to be 25(D-4), 7(G-3) respectively. Moreover, the presence of large number of streams in the basin indicates that the topography is still undergoing erosion, and at the same time, less number of streams indicates mature topography or erosion risk is as much not be frightened.

Table 4. 1: stream number of Guder and Dabus sub-watershed

Sub-basin	Sub-watershed of Guder and Dabus sub-basin							Total stream number
	-1	- 2	- 3	- 4	- 5	-6	-7	
Guder	151	9	7	95	109	113	265	749
Dabus	685	69	111	25	257	225	308	1680

4.2.4. Stream Order (u)

It is hierarchical relationship between stream segments and their connectivity to each other. A second order stream is created after two first order streams meet to each other. Stream order was used to analyze the drainage pattern of the area. When two channel of different order join then the higher order is maintained. The trunk stream is the stream segment of highest order. In this thesis, the whole drainage of both Guder and Dabus sub-basin was disseminated in six orders and their respective stream numbers have been described below.

Table 4. 2: Guder and Dabus watershed stream order

Sub-basin		Stream Number (Nu) of all order						Total
		Order 1	Order 2	Order 3	Order 4	Order 5	Order 6	
Guder Mini Sub Watershed	G-1	74	40	4	-	2	31	151
	G-2	3	1	-	1	4	-	9
	G-3	2	-	-	2	3	-	7
	G-4	48	26	9	12	-	-	95
	G-5	59	26	18	6	-	-	109
	G-6	57	32	18	6	-	-	113
	G-7	133	60	39	17	16	-	265
Dabus Mini Sub Watershed	D-1	341	158	106	6	-	74	685
	D-2	33	15	7	2	1	11	69
	D-3	56	32	11	12	-	-	111
	D-4	11	5	1	0	2	6	25

	D-5	129	57	42	16	13	-	257
	D-6	113	62	23	14	13	-	225
	D-7	155	80	37	16	20	-	308

4.2.5. Total Stream length and Mean stream length

It is an indicator of the area contribution to the watershed, steepness of the drainage watershed as well as the degree of drainage. The mean stream length of a channel is a dimensional property and reveals the characteristic size of the drainage network components and its contribution watershed surfaces. It is expressed in 'km'. The total stream length and mean stream length for both Guder and Dabus sub-watershed were presented in Table 4.4 and 4.5 respectively. The stream of relatively smaller length is characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradient.

Table 4. 3: Total stream length of Guder Sub-watershed orders.

Sub-basin		Stream length (Lu) of all order (km)						Total (km)
		1st	2nd	3rd	4th	5th	6th	
Guder Min- watershed	G-1	189.67	100.21	10.87	-	0.037	49.36	350.15
	G-2	10.65	3.062	-	0.021	9.77	-	23.5
	G-3	5.87	-	-	0.037	10.8	-	16.7
	G-4	19.07	21.41	74.34	122.07	-	-	236.89
	G-5	168.36	78.21	47.03	37.9	-	-	331.5
	G-6	190.24	131.9	70.77	21.34	-	-	414.25
	G-7	491.63	229.74	130.78	36.8	59.35	-	741.3
Total(km)		1075.49	564.53	333.79	218.17	79.96	49.36	2114.29

Table 4. 4: Total stream length of Dabus Sub-watershed orders

Sub-basin		Stream length (Lu) of all order (km)						Total (km)
		1st	2nd	3rd	4th	5th	6th	
Dabus Min- watershed	D-1	1054.9	524.9	314.9	21.94	-	159	2075.61
	D-2	96.75	42.57	30.09	6.42	0023	32.02	207.89
	D-3	215.4	112	30.15	23.33	-	-	380.85
	D-4	63.04	22.59	4.98	-	0.037	13.59	104.24
	D-5	38.27	45.85	144.2	161.6	421.3	-	811.23
	D-6	42.9	224.7	101.8	38.87	39.1	-	837.42
	D-7	507.5	313.2	129.3	53.15	48.98	-	1052.07
Total		2018.76	1285.81	755.42	305.31	532.417	204.61	5469.31

The table reveal that the total length of stream segments is maximum in first order stream and decreases as stream order increases. The sum of mean stream lengths of first, second, third, fourth, fifth and six order streams (Table 4.6) also indicates that, the fourth order streams are longer than the other order streams for Guder and the fifth order was longer than the other in case of Dabus sub-basin (Table 4.7). However, in some of the sub-watersheds stream length were smaller than their lower order which is due to the variation in relief over which the segments occur.

Table 4. 5: Mean Stream Length of Guder sub-watershed

Sub-Basin		Mean stream length (Km)					
		1st	2nd	3rd	4th	5th	6th
Guder sub-basin	G-1	2.56	2.51	2.72	-	0.02	1.59
	G-2	3.55	3.06	-	0.02	2.44	-
	G-3	2.94	-	-	0.02	3.6	-
	G-4	0.4	0.82	8.26	10.17	-	-
	G-5	2.85	3.01	2.61	6.32	-	-
	G-6	3.34	4.12	3.93	3.56	-	-
	G-7	3.7	3.83	3.35	2.16	3.71	-
Total		19.34	17.35	20.87	22.25	9.77	1.59

Table 4. 6: Mean Stream Length of Dabus sub-watershed

Sub-Basin		Mean stream length of order(Km)					
		1st	2nd	3rd	4th	5th	6th
Dabus sub-basin	D-1	3.09	3.32	2.97	3.66	-	2.15
	D-2	2.93	2.84	4.3	3.21	23.	2.91
	D-3	3.85	3.50	2.74	1.94	-	-
	D-4	5.73	4.52	4.98	-	0.02	2.27
	D-5	0.3	0.8	3.43	10.10	32.41	-
	D-6	0.38	3.62	4.43	2.78	3.01	-
	D-7	3.27	3.92	3.49	3.32	2.45	-
Total		19.55	22.52	26.34	25.01	60.89	7.33

4.2.6. Stream Length Ratio

The Stream length ratio varies at the basin and sub-watershed levels. The values of the mean R_L vary from 0.00 (G-3) to 0.85 (G-7) for Guder sub-watersheds and from 0.25 (D-5) to 2.22(D-2) for Dabus sub-watershed. These variations of stream length ratio (RL) values between streams of different order in the basin reveal that there are variations in slope and topography.

4.3. Linear parameters

The linear parameters which are considered in prioritization of watersheds through morphometric analysis are: bifurcation ratio, drainage density, stream frequency, drainage texture ratio and length of overland flow.

4.3.1. Bifurcation Ratio

Bifurcation ratio is related to the branching pattern of a drainage network. Bifurcation ratio is demonstrated as a dimensionless property and shows a small range of variation for different regions or different environmental conditions, except where the geology dominates. The mean Bifurcation ratio of the Guder sub-basin varies from 0.667 to 3.972 and it was from 1.803 to 7.105 for Dabus sub-basin.

Table 4. 7: Bifurcation Ratio of both Guder and Dabus sub basin

Sub-basin		Bifurcation Ratio (Rb) of all order						Mean Rb
		Order 1	Order 2	Order 3	Order 4	Order 5	Order 6	
Guder Sub-watershed	G-1	1.85	10	_	_	0.065	_	3.972
	G-2	3	_	_	0.25	_	_	1.625
	G-3	_	_	_	0.67	_	_	0.667
	G-4	1.85	2.89	0.75	_	_	_	1.828
	G-5	2.27	1.44	3.00	_	_	_	2.238
	G-6	1.78	1.78	3.00	_	_	_	2.186
	G-7	2.22	1.54	2.29	1.06	_	_	1.778
Dabus Sub-Watershed	D-1	2.16	1.49	17.67	0.00	_	_	7.105
	D-2	2.20	2.14	3.50	2.00	0.09	_	1.987
	D-3	1.75	2.91	0.92	_	_	_	1.859
	D-4	2.20	5.00	_	_	0.33	_	2.511
	D-5	2.26	1.36	2.63	1.23	_	_	1.869
	D-6	1.82	2.70	1.64	1.08	_	_	1.810
	D-7	1.94	2.16	2.31	0.80	_	_	1.803

The analysis result showed that the mean Bifurcation ratio of both Guder and Dabus sub-watersheds were varied for all orders. Geological and lithological development of the drainage basin may be the reason for these variations. Low mean Rb value indicates poor structural disturbance and the drainage patterns have not been distorted (Strahler, 1964), whereas the high mean Rb value indicates value of Rb is also indicative of the shape of the basin that has structural disturbance. The irregularities of the drainage watershed depend upon lithological and geological development, leading to changes in the values from one order to the next. An elongated basin is likely to have high bifurcation ratio (Rb), whereas a circular basin is likely to have a low bifurcation ratio (Rb).

4.3.2. Drainage density (Dd)

A high value of Dd would indicate a relatively high density of streams and hence, a quick stream response. High drainage density of a watershed is indicative of high runoff, and consequently a low infiltration rate. By contrast, low drainage density of a basin implies low runoff and high infiltration. (Farhan *et al.*, 2015) Postulated that low Dd occurs when basin relief is high. In the case of Guder and Dabus sub-basin the basin relief value is 2032m and 1805m respectively. Other significant factors determining Dd are infiltration–capacity of the soil, and initial resistance of terrain against erosion. The values of (Dd) drainage densities of Guder sub-watersheds were varied from 0.310 km/km^2 to 0.394km/km^2 and that of Dabus sub-watersheds were found to be 0.366 km/km^2 to 0.483km/km^2. The values of Dd for the fourteen sub-watersheds both sub-basins were arranged below in (Table 4.9), which implies the presence of highly dissected topography, steep slopes and permeable subsurface materials.

Table 4. 8: Drainage densities of Guder and Dabus sub-watersheds

Sub-Basin	Drainage Density; (Dd)=∑Lu/A						
Guder	G-1	G-2	G-3	G-4	G-5	G-6	G-7
	0.341	0.353	0.329	0.310	0.316	0.3842	0.394
Dabus	D-1	D-2	D-3	D-4	D-5	D-6	D-7
	0.366	0.3837	0.410	0.483	0.361	0.410	0.384

4.3.3. Stream frequency (Fs)

Stream frequency for sub-watersheds ranges from 0.104 to 0.147 and 0.11 to 0.127 for Guder and Dabus sub-basin respectively. The stream frequency depends mainly on the lithology of the drainage basin and, resembles the texture of the drainage network. Stream frequency is positively correlated with drainage density (Dd) value of the sub-watershed, which means that the increase in stream population is connected with that of drainage density. For small and large drainage basins, values of drainage density (Dd) and stream frequency (Fs) are not directly comparable because they normally vary with the size of the drainage area. High stream frequency (Fs) values indicate more percolation, and thus, more groundwater potential.

Table 4. 9: Stream Frequency of Guder and Dabus sub-watersheds

Sub-Basin	Stream frequency; (Fs)=∑Nu/A						
Guder	G-1	G-2	G-3	G-4	G-5	G-6	G-7
	0.147	0.135	0.138	0.124	0.104	0.105	0.110
Dabus	D-1	D-2	D-3	D-4	D-5	D-6	D-7
	0.121	0.127	0.119	0.116	0.115	0.110	0.112

4.3.4. Drainage Texture ratio (Dt)

Drainage texture ratio depends on lithology, infiltration capacity, and relief aspect of drainage basins. The value of drainage texture ratio ranges generally from 0.144 (G-2) to 0.556 (G-7), and 0.197(D-4) to 0.897(D-1) for both the sub-watersheds of Guder and Dabus respectively, which denotes that the watershed is of relatively moderate runoff.

Table 4. 10: Drainage texture ratio of Guder and Dabus sub-watersheds

Sub-Basin	Drainage Texture ratio; (Dt)=∑Nu/p						
Guder	G-1	G-2	G-3	G-4	G-5	G-6	G-7
	0.505	0.144	0.162	0.381	0.483	0.441	0.566
Dabus	D-1	D-2	D-3	D-4	D-5	D-6	D-7
	0.897	0.311	0.446	0.197	0.540	0.470	0.700

4.3.5. Length of overland flow (Lof)

The length of overland flow ascribes inversely to the average slope of stream channel and is considered a significant independent parameters influencing hydrographic and hydrologic development of drainage basins. The length of overland flow for the sub-watershed of Gudar and Dabus from minimum to maximum ranges from 0.155 (G-4) to 0.197 (G-7) and 0.181(D-5) to 0.241(D-4) respectively.

Table 4. 11: Length of Overland Flow of Guder and Dabus sub-watersheds

Sub-Basin	Length of Overland Flow; (Lof)=(1/2Dd)						
Guder	G-1	G-2	G-3	G-4	G-5	G-6	G-7
	0.170	0.177	0.165	0.155	0.158	0.192	0.197
Dabus	D-1	D-2	D-3	D-4	D-5	D-6	D-7
	0.183	0.192	0.205	0.241	0.181	0.205	0.192

4.4. Shape parameters of morphometric analysis

Shape parameters include elongation ratio, circularity ratio, form factor, shape factor, and compactness coefficient (ratio).

4.4.1. Elongation ration (Re)

It has been founded that the values of elongation ratio (Re) often vary between 0, in highly elongated shape and 1, in the circular shape over a wide range of geological and climatic conditions. Values close to 1.0 depict regions with very low relief, whereas values in the range of 0.6-0.8 are often characteristic of catchments with dissected topography, high relief, and steep hillside-slopes. The low values of elongation (Re) indicate that a particular mini watershed is more elongated than others. Where the elongation ratio (Re) approaches 1.0, the shape of the drainage basin approaches a circle. It has been stated that a circular basin is more efficient in runoff than an elongated one. Based on Re values, drainage basins were classified into five groups, i.e. circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<0.5). The elongation ratio of Guder and Dabus sub-basins were range from 0.507(G-7) to 0.659(G-3) and 0.478(D-1) to 0.5979(D-4) table 4.13. The elongation ratio of sub-watersheds is almost categorized as elongated and more elongated.

Table 4. 12: Elongation ratio of Guder and Dabus sub-watersheds

Sub-Basin	Elongation ratio; (Re)=(2/Lb)*(A/π)$^{0.5}$						
Guder	G-1	G-2	G-3	G-4	G-5	G-6	G-7
	0.537	0.647	0.659	0.548	0.536	0.535	0.507
Dabus	D-1	D-2	D-3	D-4	D-5	D-6	D-7
	0.478	0.561	0.541	0.597	0.509	0.512	0.502

4.4.2. Circularity ratio (Rc)

Circulation ratio (Rc) is the ratio of sub-watershed area (A) to the area of circle having the same circumference as the perimeters of the sub-watersheds. Circulation ratio (Rc) is controlled by the length and frequency of the streams, geological structures, morphology, land use/cover, climate, of the catchment. High Rc values denote young, mature, and old stages of geomorphic development of drainage basin. If the circularity of the main basin is low, then the discharge was slow as compared to the others, and so the possibility of erosion was less. The average circularity ratio of Guder and Dabus sub-basin was 0.208 and 0.147 respectively. Whereas, circulation ratio (Rc) values for the fourteen sub-watersheds range from a minimum value of 0.138 (G-7) to a maximum value of 0.34(G-3), and a minimum value of 0.112(D-6) to a maximum value of 0.188(D-3) which indicates a high possibility of rapid discharge and active erosion.

Table 4. 13: Circulation ratio of Guder and Dabus sub-watersheds

Sub-Basin	Circulaion ratio; (Rc)=(4π*A)/p^2						
Guder	G-1	G-2	G-3	G-4	G-5	G-6	G-7
	0.144	0.213	0.340	0.154	0.259	0.206	0.138
Dabus	D-1	D-2	D-3	D-4	D-5	D-6	D-7
	0.122	0.139	0.188	0.169	0.124	0.112	0.178

4.4.3. Form factor (Rf)

Form factor (Rf) represents the ratio of the area of the sub-watersheds to the square of basin length. It is elaborated to predict the intensity of the basin of a confined area. The basin with high form factor is characterized with high peak flow of shorter duration, whereas, an elongated sub-watershed with a low form factor, has a low peak flow of longer duration. The average form factor (Rf) value for Guder and Dabus sub-basin was 0.25 and 0.22 respectively, for the fourteen sub-watersheds ranges from a minimum of 0.201(G-7) to a maximum of 0.341(G-3) and a minimum of 0.179(D-1) to a maximum of 0.280(D-4) for Gudar and Dabus respectively, which indicates the dominance of elongated shape for the sub-watersheds, thus characterized with flatter peak flow for longer duration.

Table 4. 14: Form factor of Guder and Dabus sub-watersheds

Sub-Basin	Form factor; (Rf)=A/Lb^2						
Guder	G-1	G-2	G-3	G-4	G-5	G-6	G-7
	0.226	0.328	0.341	0.235	0.226	0.225	0.201
Dabus	D-1	D-2	D-3	D-4	D-5	D-6	D-7
	0.179	0.247	0.229	0.280	0.203	0.206	0.198

4.4.4. Constant channel maintenance

Constant channel maintenance is the area of the sub-watershed surface needed to sustain a unit length of a stream channel. It is inversely relation with drainage density and signifies how much drainage area is required to maintain a unit length of channel. It depends on rock type, permeability, climatic regime, vegetation cover, as well as period of erosion. The Guder and Dabus sub-watersheds the Constance channel maintenance value varying from of 2.54(G-7) to 3.23(G-4) and 2.072(D-4) to 2.766(D-5) respectively.

Table 4. 15: Constant channel maintenance of Guder and Dabus sub-watersheds

Sub-Basin	Constant channel maintenance; C=1/Dd						
Guder	G-1	G-2	G-3	G-4	G-5	G-6	G-7
	2.933	2.832	3.035	3.229	3.161	2.603	2.540
Dabus	D-1	D-2	D-3	D-4	D-5	D-6	D-7
	2.732	2.606	2.440	2.072	2.766	2.439	2.605

In this thesis, watershed indicates that weakest or very low-resistance soils, sparse vegetation, mountainous terrain, relatively higher run off and lower permeability, while higher value of C of both sub basin were associated with resistance soils, dense vegetation and comparably plain terrain.

4.5. Relief Aspect

Relief aspect of drainage basin relates three dimensional features of the basin involving area, volume and altitude of vertical dimension. The relief aspects include Basin relief (Bh), relief ratio (Rh), ruggedness number and relative relief.

4.5.1. Basin Relief

Basin relief (Bh) is the maximum vertical distance between the lowest and highest elevation in a sub-watershed of Guder and Dabus sub-basin. This is an important factor in understanding the denudation characteristics of a basin. It is also known as total relief and expressed in km. The maximum and minimum elevation of Guder sub-basin is 3301m and 878m respectively, whereas in Dabus sub-basin, it varies from 3223m and 446m respectively. Therefore, the maximum and minimum basin relief of both Guder and Dabus sub-watersheds was ranges from 2.03km to 0.80km and 1.81km to 0.50km respectively. The higher value of Basin relief of Guder sub basin shows that it has lower infiltration and higher runoff than Dabus sub-basin.

Table 4. 16: Relief Aspect Analysis Result for Guder Sub watershed.

Sub-Watershed	Perimeter (km)	Basin length(km)	Drainge density (Dd)	Elevation (m)		Relief Aspect			
				Max	Min	Bh=Max-Min	Rh=Bh/Lb	Rr=Bh/P	Rn=Bh*Dd
G-1	299.14	67.38	0.341	2592	892	1.7	0.025	0.0057	0.58
G-2	62.68	14.24	0.353	2123	1176	0.947	0.067	0.0151	0.33
G-3	43.28	12.20	0.329	1969	1173	0.796	0.065	0.0184	0.26
G-4	249.47	57.00	0.31	3206	1270	1.936	0.034	0.0078	0.60
G-5	225.62	68.15	0.316	3206	1268	1.938	0.028	0.0086	0.61
G-6	256.17	69.27	0.3842	3050	1268	1.782	0.026	0.0070	0.68
G-7	467.91	109.35	0.394	3300	1268	2.032	0.019	0.0043	0.80

Table 4. 17: Relief Aspect Analysis Result for Dabus Sub watershed

Sub-Watershed	Perimeter,km	Basin length(km)	Drainge density(Dd)	Elevation (m)		Relief Aspect			
				Max	Min	Bh=Max-Min(km)	Rh=Bh/Lb	Rr=Bh/P	Rn=Bh*Dd
D-1	763.73	177.82	0.366	2203	464	1.739	0.010	0.0023	0.64
D-2	221.51	46.85	0.384	1743	1247	0.496	0.011	0.0022	0.19
D-3	248.92	63.65	0.410	2205	1282	0.923	0.015	0.0037	0.38
D-4	126.7	27.79	0.483	2204	1337	0.867	0.031	0.0068	0.42
D-5	475.89	105.04	0.361	2502	1332	1.17	0.011	0.0025	0.42
D-6	478.49	99.57	0.410	3143	1338	1.805	0.018	0.0038	0.74
D-7	439.89	117.67	0.384	2431	1334	1.097	0.009	0.0025	0.42

4.5.2. Relief ratio (Rh)

Relief ratio is the total relief of the basin divided by the maximum length of the sub-watersheds. It measures the overall steepness of sub-watershed drainage and is an indicator of the intensity of erosion process operating on slope of the basin or indicator of the potential energy of the system to drain off. Relief ratio (Rh) normally increases with decreasing drainage area and size of a given drainage sub-watershed. Higher values of Rh indicate that intense erosion processes are taking place and have intrinsic structural complexity in association with relief and drainage density. As analysis result of the areal aspects table 4.17 and 4.18, the relief ratio of Guder Sub-watersheds were varying from 0.019(G-7) to 0.067(G-2) and from 0.009(D-7) to 0.031(D-4) for Dabus sub-watersheds. Higher relief ratio (Rh) value (0.067) indicates more hilly regions in Guder (G-2) sub-watershed which results in lower infiltration and greater discharge compared to that of Guder sub-watershed. On the other hand, knowing this value helps for Rain water harvesting and watershed management plan.

4.5.3. Ruggedness number (Rn)

Ruggedness number is the product of the maximum basin relief and its drainage density. It provides an idea of overall roughness of a sub-watershed. The ruggedness number indicates the structural complexity of the terrain in association with the relief and drainage density. It also implies that the area is susceptible to soil erosion. The low ruggedness value of watershed implies that area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density. In this study, the ruggedness number was ranges in case of Guder (from 0.26 to 0.68) and in case of Dabus sub-watersheds (from 0.19 to 0.74) as seen in table 4.17 and 4.18. This indicates that Guder sub-watersheds were more susceptible to erosion and Dabus sub-watersheds were least susceptible among all the sub-watersheds.

4.5.4. Relative relief (Rr)

Relative relief termed as ‘amplitude of available relief’ or ‘local relief’ is the difference in elevation between the highest and the lowest points in a unit area. It is an important morphometric variable used for the overall assessment of morphological characteristics of terrain. Melton, (1957); suggested relative relief calculated by dividing basin relief to the perimeter of the watershed. Overall Relative relief ratio for Guder sub-watersheds were found to be vary from 0.0057 to 0.0184 table 4.17 and also vary from 0.0022 to 0.0068 table 4.18 incase for Dabus sub-watersheds.

Table 4. 18: Summary of Morphometric Analysis result for Guder sub-watersheds

Sub-basin		Parameters										
		Linear Aspect										
		Rbm	Dd	Fs	Dt	Lof	Rf	Rc	Re	C	Rh	Rn
Guder Mini watershed	G-1	3.28	0.341	0.147	0.505	0.17	0.226	0.144	0.537	2.933	0.025	0.58
	G-2	1.81	0.353	0.135	0.144	0.177	0.328	0.213	0.647	2.832	0.067	0.334
	G-3	0.72	0.329	0.138	0.162	0.165	0.341	0.34	0.659	3.035	0.065	0.262
	G-4	1.97	0.31	0.124	0.381	0.155	0.235	0.154	0.548	3.229	0.034	0.599
	G-5	1.8	0.316	0.104	0.483	0.158	0.226	0.259	0.536	3.161	0.028	0.613
	G-6	2.42	0.384	0.105	0.441	0.192	0.225	0.206	0.535	2.603	0.026	0.685
	G-7	1.895	0.394	0.11	0.566	0.197	0.201	0.138	0.507	2.54	0.019	0.8

Table 4. 19: Summary of Morphometric Analysis result for Dabus sub-watersheds

Sub-basin		Parameters										
		Linear Aspect										
		Rbm	Dd	Fs	Dt	Lof	Rf	Rc	Re	C	Rh	Rn
Dabus Mini watershed	D-1	5.42	0.366	0.121	0.897	0.183	0.179	0.122	0.478	2.732	0.01	0.637
	D-2	1.92	0.384	0.127	0.311	0.192	0.247	0.139	0.561	2.606	0.011	0.19
	D-3	1.886	0.41	0.119	0.446	0.205	0.229	0.188	0.541	2.44	0.015	0.378
	D-4	2.257	0.483	0.116	0.197	0.241	0.28	0.169	0.597	2.072	0.031	0.418
	D-5	4.509	0.361	0.115	0.54	0.181	0.203	0.124	0.509	2.766	0.011	0.423
	D-6	1.822	1.75	0.47	0.11	0.875	0.251	0.001	0.565	0.571	0.041	3.159
	D-7	1.813	0.384	0.112	0.7	0.192	0.198	0.178	0.502	2.605	0.009	0.421

4.5.5. Prioritization of Sub-Watersheds Based on Morphometric Analysis

Prioritization of watersheds for soil and water conservation at different scales: sub-watersheds, min-watersheds, and micro-watersheds. Erosion risk parameters pertained to linear, shape and relief aspect. Morphometric variables were employed for prioritizing watersheds. The linear parameters are: Bifurcation ratio (Rb), Stream frequency (Fs), drainage density (Dd), length of overland flow (Lo), and drainage texture ratio (Dt). Similarly, the shape factors include: form factor (Rf), circularity ratio (Rc), elongation ratio (Re), Constant channel maintenance (C), and basin relief (Bh), relief ratio (Rh), ruggedness number (Rh), and relative relief (Rn).

It has been stated earlier that linear parameters have a direct relationship with erodibility. Therefore, the highest value of the linear parameters was ranked 1, second highest value ranked 2 and so on. By contrast, the shape has an inverse relation with linear parameters, hence, the lower their value, the greater the erodibility. Consequently, the lowest value of shape parameter was rated as rank 1 and second lowest as rank 2 and so on. Compound factor (Cf) was computed by adding up all the ranks of linear parameters, shape parameters and as well as relief aspect ranks and then dividing by the number of all parameters. From the group of sub-watersheds, the highest prioritized rank (score) was affirmed to sub-watersheds having the lowest compound factor and vice versa.

Fig.4.2 illustrates the priority ranks for Guder sub-basin watershed which is based on morphometric analysis.

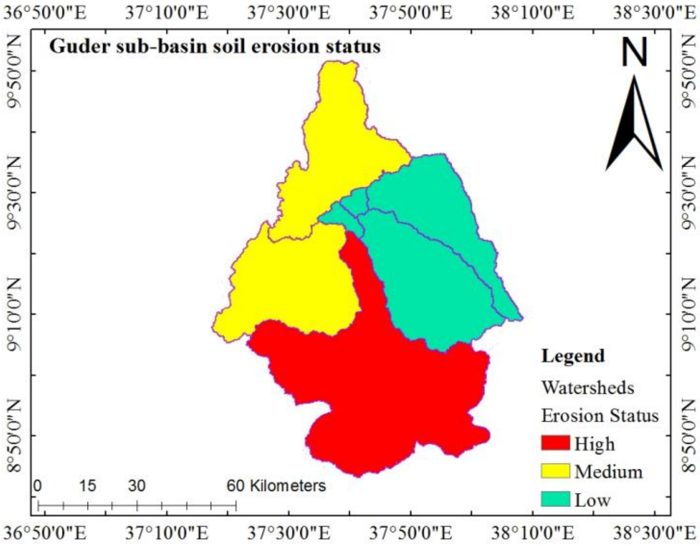

Figure 4.2 soil erosion severity classifications

All sub-watersheds of Guder and Dabus watershed were classified into three priority categories based on the range of compound factor (Cf) values [5]:

(i) High priority

(ii) Medium priority

(iii) Low priority

With respect to the fourteen sub-watersheds of both watersheds, sub-watershed of Guder (G-7) was given rank one with the lowest compound factor, 2.82 table 4.17. It is succeeded by the sub-watershed G-6 and G-1 which was their compound factor is 3.27 and 3.45, as second and third respectively. The values of Cf and related ranks for all sub-watersheds are displayed in table 4.17,table 4.18, out of fourteen sub-watersheds; the MW (mini-watershed) of G-7 is classified as high priority, whereas mini-watershed of G-1, G-5, G-6, D-2, D-3 D-5, and D-6 are ranked as medium priority. The sub-watershed of G-2, G-3, G-4, D-4, and D-7 are ranked as low priority. It can be concluded that 4.28% are classified as high priority, seven sub-watersheds (50%) are classified as medium, and five mini-watersheds (35%) are classified as low priority.

4.5.6. Compound Value parameter

The ranking values of all the parameters were added and averaged to assign Compound values or final weightage. The compound values of Guder and Dabus sub-watersheds were calculated based on the priority rank of the Morphometric analysis result. These compound values were done for the combination each rank of the morphometric result to determine the degree of susceptibility of each watershed to soil erosion potential. Each sub-watershed was prioritized to facilitate the phase wise implementation on the bases of Morphometric analysis result K.Nookaratnam *et.al*, (2005); Kanth and Hassan, (2012). As per analysis result of the Compound values, the sub-watersheds priorities were broadly classified into three priority classes as High, medium and low.

Compound Values	Prioritization Classes
$\leq$3.25	High Priority
3.25-4.36	Medium priority
$\geq$4.36	Low Priority

High Priority: Sub-watersheds falling under high priority were under very severe erosion susceptibility zone. Those watersheds generally consist of high relief and steep slopes, sparse vegetation, low infiltration and high discharge of runoff can be classified under very severe erosion susceptibility zone. Thus, need immediate attention to take up best management for soil and water conservation measures such as Contour binding, Bench terracing, gully control structures and grass waterways to protect the topsoil loss.

Medium Priority: Sub-watersheds falling in medium priority classes consist of moderate slopes, relatively moderate values of linear and shape parameters. These sub-watersheds can be categorized under moderate erosion susceptibility zone that needs agronomical conservation measure such as Contour farming, Mulching practices, Strip cropping and Mixed cropping to protect the sheet and rill erosion.

Low Priority: Sub-watersheds falling under low priority consist of lower slopes, very low linear and shape parameters. These watersheds can be categorized under very slight erosion susceptibility zone and may need agronomical measures to protect the sheet and rill erosion. The prioritized classifications and the compound value of sub watersheds were done and shown in table 4.19 and 20 for both Gudar and Dabus sub-watersheds respectively.

Table 4. 20: Ranking compound Values and Prioritization of Guder Sub watersheds

Sub-basin	Parameters											Compound Values	Erosion Status
	Linear Aspect												
Guder	Rbm	Dd	Fs	Dt	Lof	Rf	Rc	Re	C	Rh	Rn		
G-1	1	4	1	3	4	4	2	4	4	6	5	3.45	Medium
G-2	6	3	3	7	5	6	5	6	3	1	6	4.64	Low
G-3	7	5	2	6	3	7	7	7	5	2	7	5.27	Low
G-4	4	7	4	5	1	5	3	5	7	3	4	4.36	Low
G-5	2	6	7	4	2	3	6	3	6	4	3	4.18	Low
G-6	3	2	6	2	6	2	4	2	2	5	2	3.27	Medium
G-7	5	1	5	1	7	1	1	1	1	7	1	2.82	High

Table 4. 21: Ranking compound Values and Prioritization of Dabus Sub watersheds

Sub-basin	Parameters											Compound Values	Erosion status
	Linear Aspect												
Dabus	Rbm	Dd	Fs	Dt	Lof	Rf	Rc	Re	C	Rh	Rn		
D-1	1	6	3	1	2	1	2	1	6	6	2	3.26	medium
D-2	3	4	2	2	3	5	4	5	5	5	7	4.09	Medium
D-3	5	3	4	4	5	4	7	4	3	3	6	4.36	medium
D-4	2	2	5	6	6	7	5	7	2	2	5	4.45	Low
D-5	4	7	6	3	1	3	3	3	7	4	3	4.00	Medium
D-6	6	1	1	7	7	6	1	6	1	1	1	3.45	Medium
D-7	7	5	7	2	4	2	6	2	4	7	4	4.55	Low

The analysis result reveals that, From Guder Sub-basin, the sub-watershed G-7 with a compound factor value of 2.82 received the high priority rank, and consequently have been significantly erosion risk. Sub-watershed G-6 having a compound parameter value of 3.27 received the next medium priority classes. Similarly, for Dabus sub-basin, the sub-watershed D-1 with a compound parameter value of 3.26 received the first medium priority classes and so on. This priority indicates the greater degree of erosion susceptibility in the particular sub-watershed and it becomes potential Candidate area for applying soil conservation measures.

The sub-watersheds of the Guder sub-basin falling in priority classification was identified in table above. Medium priority classes (G-1, G-6, &G-5) and low priority classes (G-2, G-3, and G-4,) and from Dabus medium priority (D-2, D-3, D-5 and D-6) and low priority classes (D-4, D-7,). While the medium priority of the sub watershed indicates relatively moderate soil erosion zone and consist of moderate slopes, moderate values of morphometric analysis result and the low priority watershed indicates or consist of lower slopes, very low values of linear and relief, high values of shape parameter, these watersheds can be categorized under very slight erosion susceptibility zone and may need application of agronomical measures such as Contour farming, Mulching practices, Strip cropping and Mixed cropping to protect the sheet and rill erosion.

Moreover, the final priority Map also indicates that; high priority classes of the sub watershed indicates relatively greater degree of erosion susceptibility and consists of steep slopes, high values of morphometric analysis result which is expected to high soil erosion risk. Accordingly, among the fourteen sub-watersheds of Guder and Dabus, sub-watershed the G-7 of Guder sub-basin is more vulnerable to soil erosion risk. So, the annual soil loss estimation of the watershed is calculated in the following part of the research. The G-7 sub-watershed is almost one of the seven watersheds of Guder basin which is found or cover at the inlet parts of the Guder watershed it covers an area of 2357km2 and perimeter of 467.9km.

4.6. RUSLE Model Parameters

To estimate annual soil loss, RUSLE model was integrated with GIS techniques to conduct cell by cell calculation of mean annual soil loss rate. Raster map of each RUSLE factor parameters derived from different data source were produced and discussed as follows

4.6.1. R-Factor

The long-term duration mean annual rainfall amount was varied between 1042.22mm to 1772.27mm. Owing to this variation in mean annual rainfall amount within the study area, variation in rainfall erosivity was observed. Accordingly, the rainfall erosivity values estimated from mean annual rainfall of the selected rainfall stations, varied from 548.52MJ mm ha$_{-1}$ hr$_{-1}$ yr$_{-1}$ at Ambo and 950.05MJmm ha$_{-1}$ hr$_{-1}$ yr$_{-1}$ at Kachise. The calculated values in table 3.9, Section 3.6.1) show that as the mean annual rainfall increases, the rainfall erosivity also increases. Following this, the study area faces highly erosive rainfall at Southern and northern part of the study area around Kachise and Tikur Enchine station, gradually decreases towards the central and western parts of the study area around Jeldu and Ambo respectively. The areas in between the two extremes (Kachise and Tikur Enchine), shares the values of erosivity in between the maximum and minimum erosivity value distributed spatially. Figure 4.3 shows the spatial variation of erosive power of rainfall in the study area.

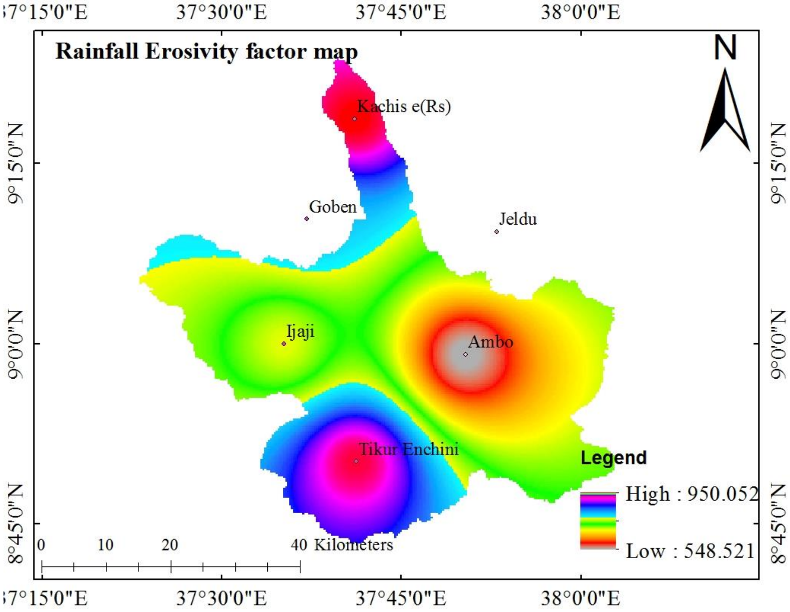

Fig 4.3: Map of rainfall erosivity factor(R).

4.6.2. K-Factor

Soil erodibilitty factor was calculated on basis of FAO soil and William equation (1995). The dominant soil type, Eutric Nitosols covers the larger area which is about 51.4% of the total area. This soil type exists almost overall central, southern and western part of sub-watershed figure 4.4. Cambic Arenosols, which cover about 17.99% of the total area, is the second largest coverage area, found at northern to central part of the catchment. Humic Cambisols is third soil type that cover the 15.11% of the total area which is highly resistance to erosion is found at the northern parts of the catchment.

Finally the fourth soil type by area coverage was Pellic Vertisol which covers 14.98%. The erodibility characteristics of the existed soils were varied with the range of K-factor value of 0.12 to 0.17-ton ha hr ha-1 MJ-1 mm-1. As the K-factor values approaches to 1, it indicates the susceptibility of the soil to erosion and as the K-factor values close to 0, it indicates the soil having good erosion resistance capacity. Hence, the K-factors of Eutric Nitosols, Cambic Arenosols, Humic Cambisols and Pellic Vertisols was 0.14, 0.15, 0.17 and 0.12 respectively as shown in table 3.10, the highest K-factor values of 0.17 ton ha hr ha-1 MJ-1 mm-1 (Humic Cambisols), which covers third area about 15.11 %, and the lowest K-factor values of 0.12 ton ha hr ha-1 MJ-1 mm-1 (pellic Vertisols), which indicates that the soil is less susceptible to erosion table 3.10. Therefore, in terms of soil erodibility condition, the catchment characterizes with moderately vulnerable to erosion.

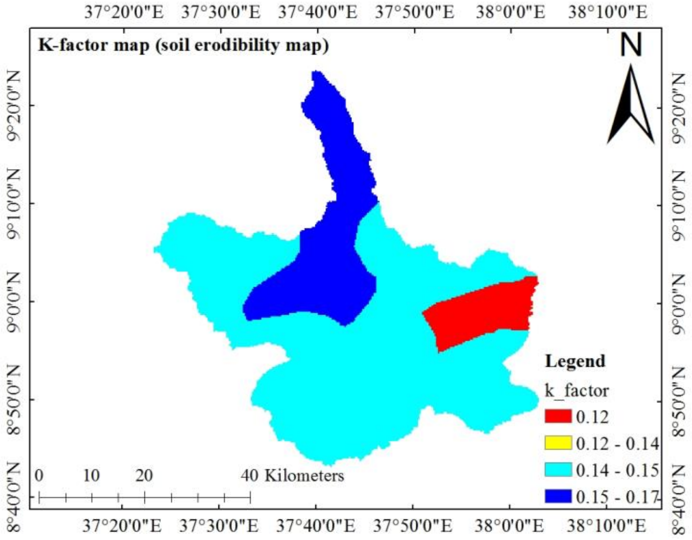

Figure 4.4 Soil erodibity (K-factor) map

4.6.3. LS-Factor

Slope steepness in percent and slope length were generated from DEM using ArcGIS 10.3. The LS factor was calculated using equation 3.8. The values of LS-factor vary between 0 (flatter and lower part) to 58.91(steeper and at the downstream of the Guder River (lower part of the watershed). As illustrated in figure 4.5, most of the watershed parts shows a lower LS-factor value of 0 to 0.69, 10.86. The higher LS- factor values of 41.12 to 58.91 were mostly observed at the mountainous and hilly region, along the side (bank) of the rivers and in stream channel. This is because, as the slope gradient increases, the value of LS-factor also increases. Consequently, soil erosion also increases. Therefore, at the area, where smaller LS-factor values existed, the expected soil erosion due to this factor would be less and at the area where, larger LS-factor values existed, the expected soil erosion would be more.

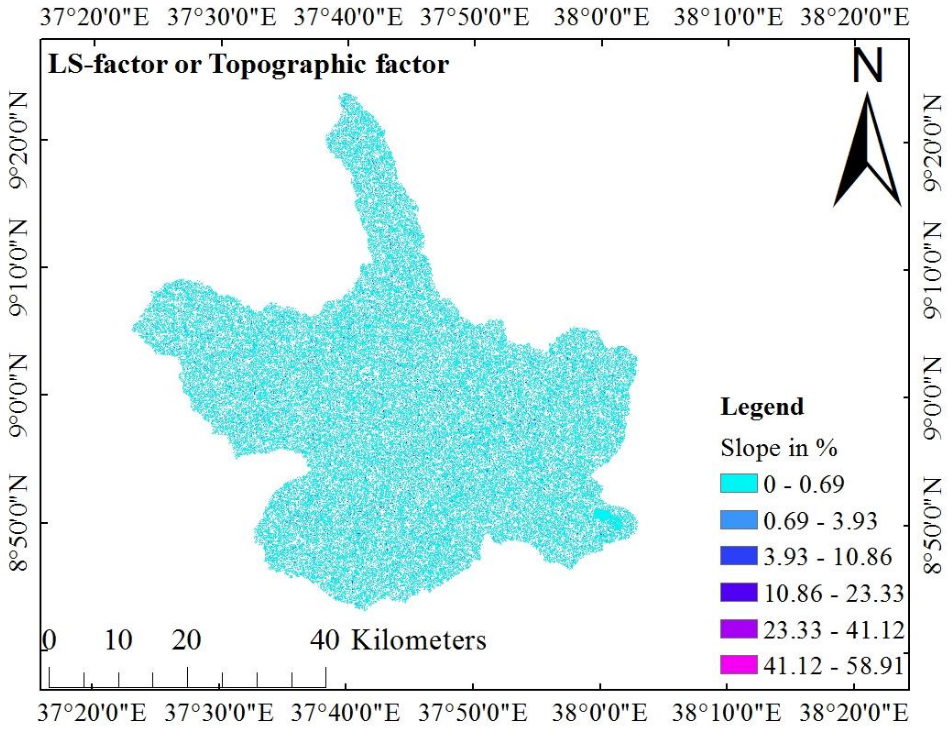

Figure 4.5: Topographic or LS- factor map.

4.6.4. C-Factor

As mentioned in section 3.6.4 the value of C-factor was obtained from different literature depending on the land use and land cover. The classified LULC classes of the area were, generated and presented in section 3.6.4, table 3.11. Based on the generation used Arc GIS

10.3 the land use land cover of the study area was clipped from Ethiopia LULC map of 2013. It was observed that the study area was almost covered with agricultural land (moderately and dominantly cultivated). Were the other land covers with urban, Grassland, swamp, water body, bush land, afro alphine and woodland open which all together cover very small area. The agricultural land which have C-factor values of 0.63, collectively covers almost an area of 87.5% and produce more soil erosion from the area since rainfall drop were directly strike the surface specially during farm preparation and cereals development consequently runoff affect the erosion.

Soil erosion from this area was expected to be high because of the soil is exposed to the first rainfall events without any cover. For this area, the maximum C-factor value of 0.63 was assigned for agricultural lands as well as the minimum C-factor value was assigned for water body and swamp areas were 0 and 0.01 respectively. As it is seen from the map figure 4.6 the cultivated land covers most of the study area parts with the others scattered in different part of the study area. Even some land use land covers types was not seen unless the map were scrolled out therefore, their impact or contribution of this factor types for erosion on soil was rare. This can be seen clearly on C-factor map for respective land use and land cover class on figure 4.6.

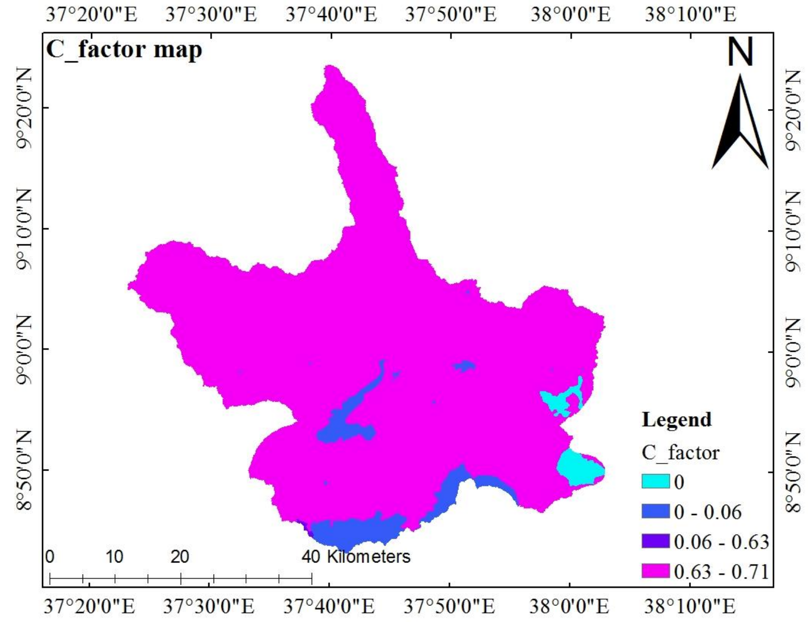

Figure 4.6: maps of LU/LC and corresponding C-factor

4.6.5. P-Factor

Depending on the land management practice employed in the study area currently on varied slope gradient, the value of P-factor ranges from 0.55 to 1 figure 4.7. The Support Practice Factor (P) value ranged from 0.55 to 1 where a higher value indicates there is no any support practice such that erosion is at its maximum due to the absence of any practice. The result of support practice factor have been indicates that, the central, south and north-East part of the study area characterizes with high P-factor values and the other parts of the study area shows the lower to medium P-factor values. As shown in slope classification map in support practice management Section 3.6.5, Figure 3.11, the most part of the area were highly flat and gentle slope from 0 to 11.3% and the Southern, Eastern and Northern parts is steeper slope which is more than 11.3 to 26.8% slope. Because of the P-factor values are highly influenced by slope steepness conditions, this upper part was characterizing with higher value of P-factor. Considering an implementation of watershed conservation and management practice method which was contouring with fully developed the P-factor values ranges from 0.55 to 1. Therefore, from the central, southern and northern parts the expected soil erosion would be higher due to the higher LS-factor values in this particular area and the outer upper sloppy part contributes larger erosion.

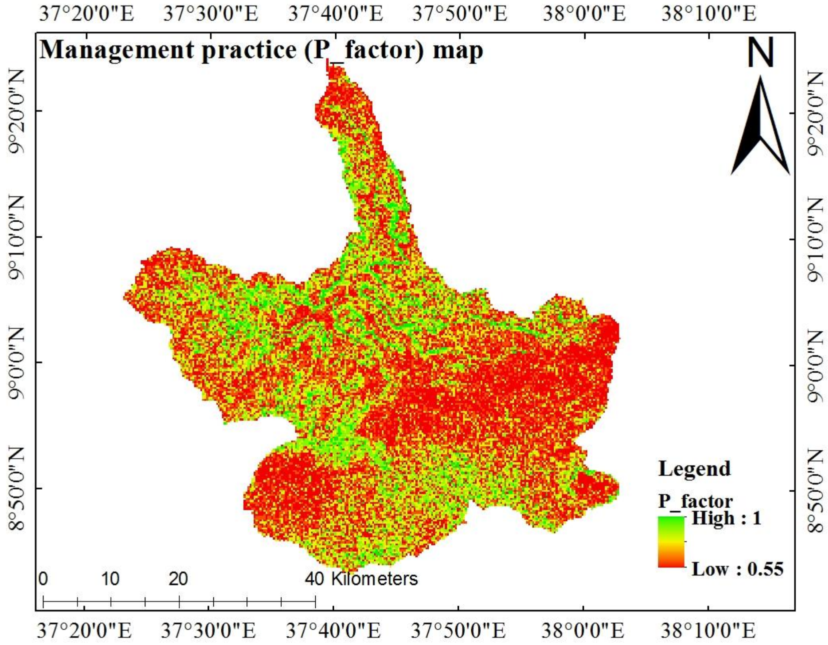

Figure 4.7: support practice factor map (p-factor).

4.7. Estimated average annual soil loss

This study used a modeling approach of the RUSLE based method to develop a detailed spatial assessment of the annul soil loss across significantly affected sub-watershed (G-7). The sub-watershed was one of the Guder sub-basin classifications identified in morphometric analysis and prioritization using ArcGIS and automated analysis of land cover and slope gradient. The cell by cell calculation based modeling results show that the spatial distribution of the annual soil loss rate varied from 0 ton ha-1 yr-1 in water body, low land and flat area to 167.47ton ha-1 yr-1 in degraded sloppy area with average annual soil loss rate of 15.34 ton ha-1 yr-1 for the entire study area (Figure 4.8). On annual basis, the total soil loss of the watershed was found to be 3617172tons per year of sediment from 2358 Km2 of study area.

Results shows that the selected sub-watershed from Guder sub-basin is vulnerable to soil erosion hazards (15.34 ton ha-1 yr-1 mean annual soil loss) due to five major factors, a high annual precipitation, the soil characteristics, mainly texture and steep slopes, land covers specially agricultural area and soil conservation practices along the slopes. The total soil erosion of the entirety of G-7 sub-watershed has been estimated to be 36171712ton yr-1 varying from as low as 0 to 167.47ton ha-1 yr-1 which confirms the range rate of soil erosion in Ethiopia. The result of this study is agreed with the finding of the previous studies done nearby the area, other parts of the country and outside the country. The findings of the researchers were given as below.

Accordingly, the mean annual soil loss of the highlands of Ethiopia ranges from 16 to 300 ton ha-1 year-1 from pasture, ranges and cultivated fields throughout Ethiopia(Tesfaye and Tibebe et al., 2018). (Hurni *et al.*, 2010) reported soil erosion from cultivation land in Ethiopian highlands reaches 130 - 170 ton ha-1 year-1. (Mustefa et al., 2018) have been found that soil loss from the Hangar River watershed ranges from 1 to 500 ton ha$_{-1}$ yr$_{-1}$ with average annual soil loss rate of 32 ton ha$_{-1}$ yr$_{-1}$ from the whole catchment. Also over the Ethiopian high lands reveals that the soil loss rate ranges from 0 to 237 ton ha-1 yr-1(Gashaw, Tulu and Argaw et al., 2018).

Other related study conducted by Kebede et al.,2014 shows that the soil loss rate ranges between 0 and 203 ton ha-1 yr-1 from neighboring catchment of the study area, using the same model and from 0 to 150 ton ha^{-1} yr^{-1} was presented by (Betrie et al.,2011) for the whole Blue Nile Basin. (Bewket and Teferi et al., 2013) have found mean annual soil loss ranging from 7-243 ton/ha/yr for a catchment in the Blue Nile basin. While Hawando found the annual soil loss of Ethiopia highlands ranges from 16-300 ton ha-1year-1 from pasture ranges and cultivated fields(Hawando et al., 1997). (Shiferaw et al., 2009) found an erosion rate in the range of 80- 54 ton ha-1 year-1 in northern Ethiopia. (Gemechu et al., 2016) conducted a research in two district, Dedo and Tiro Afeta in the catchment using RUSLE and reported that the mean soil loss rate in the district ranges from 1.59 to 31.7 ton ha-1 year-1. The soil erosion rates in India ranges from 0.5–185 ton ha-1 yr-1 and The rate has been estimated to be 1–70 ton ha-1 yr-1 for Ethiopia, 0.1–200 for the United Kingdom, 0.7–17.9 ton ha-1 yr-1 for Europe, and 10.8–146 ton ha-1 yr-1 for Africa (Maetens et al., 2012).

The result showed that the catchment is experiencing quit large spatial variation of soil loss due to quit large difference in topographical condition, land use land cover variation and higher rainfall variation. It is because; these factors are the major factor affecting soil erosion in the study area. Accordingly, the watershed was classified in to six severity classes to identify the most prone area to erosion, moderately affected area, list affected area and other respective trends of erosion conditions.

Table 4. 22: Soil erosion severity class and corresponding percent coverage area

Erosion rate(ton ha-1yr-1)	Classes	Area(km2)	Area Coverage (%)
0-5	Slightly	273	11.58
5-10	Moderate	1027	43.55
10-20	High	548	23.24
20-40	Very High	372	15.78
40-80	Severe	127	5.38
>80	Very severe	11	0.46

Accordingly, in this thesis the mean annual soil loss rate of the selected sub-watershed has been categorized as high erosion risk.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The present study is conducted in two broad categories. First, morphometric analysis and catchment prioritization were conducted for both Guder and Dabus watershed. Second, the annual soil loss estimation using RUSLE model and Arc GIS 10.3 was done. Basically, the morphometric analysis has been based on hydrology of watershed characterization using GIS environment. The Hydrology in GIS environment focuses on flow modeling and Watershed delineation by taking DEM as input to characterize the watershed system. The morphometric analyze of the watershed was took place in considering linear, shape and relief aspect. Under linear aspect five parameters are considered, bifurcation ratio, drainage density, stream frequency, drainage texture ratio and length of the overland flow. While under shape aspect four parameters are considered, elongation ratio, circularity ratio, form factor, constant channel maintenance and under relief aspect; Basin relief, relief ratio, ruggedness number and relative relief was considered. Linear parameters were direct relationship with soil erosion while shape and relief parameters were indirect relationship with soil erosion.

Accordingly, the linear and relief parameter with high value was ranked as one and the succeeded one was ranked as two and so on. While the shape parameters with small value ranked as one and the succeeded is value have been ranked as two and so on. The compound value has been calculated for all sub-watersheds (14) of Guder and Dabus. The compound value has been calculated as the average of the sum of all ranks of linear, shape and relief parameters. A small value of the compound factor was considered as required high priority or high significantly affected area of erosion. Accordingly, the sub- watershed of G-7 of Guder sub basin which is small values 2.82 of compound factor have been selected as significantly affected area and the annual soil loss rate of the study area has been calculated by RUSLE model and Arc GIS environment.

Soil erosion is a serious problem in the Ethiopian highland areas that increased sedimentation of reservoirs and lakes. To control and take measurement soil erosion at a catchment identification of erosion hot spot areas and prioritizing is essential.

So, this study attempted to present a comprehensive over view of the status of erosion and its distribution in the identified G-7 sub-watershed under present watershed condition and with proposed watershed management practices. The findings of this study reveal that the study area is currently experiencing severe soil erosion by water. The result of this study indicates that the annual soil loss rate for existed conditions ranges from 0 to 167.47ton ha-1 yr-1 with average annual soil loss of 15.34ton ha-1 yr-1, which is fall under high erosion severity class the maximum tolerable soil loss of 11ton ha-1 yr-1. Such losses could threaten the sustainability of land productivity in the study area and at the same time, excessive sedimentation and eutrophication problem at the downstream proposed reservoirs on Guder River and also on Ethiopian Great Renaissance Dam.

Implementation of green legacy policy was the best practice in protecting the strike of rainfall from land and in controlling erosion over the land and conservation practice such as contour ploughing with terracing effectively could reduce the annual average soil loss from high to low severity.

5.2. Recommendation

Based on the findings of this study, the following recommendations in protecting and controlling of erosion in watershed are forwarded.

- Intensive sustainable soil and water conservation practices should be carried out by taking each stream order, since stream meandering was one the cause to erosion along stream and agricultural field as management unit especially in the upper part where most critical sediment source areas are situated.
- The sensitive factor of the RUSLE model should be identified and measurement could be taken, for instance rainfall was the sensitive factor and the way of protecting in rainfall striking the land should be through the changing the existing cover management and support practice development should be done accordingly.
- In this study area agricultural land coverage is around 87.10% which has been high impact in in soil erosion rate increasing, so to control the rate of soil erosion from this area appropriate erosion control measurement should have taken.
- The support practice method of contouring w ith tracing the best option in erosion control mechanism.
- The watershed management for moderate soil erosion area should also be provided in order to protect them from further degradation and erosion. Local stake holders and decision makers should implement both long and short-term timely updated natural resource management systems.

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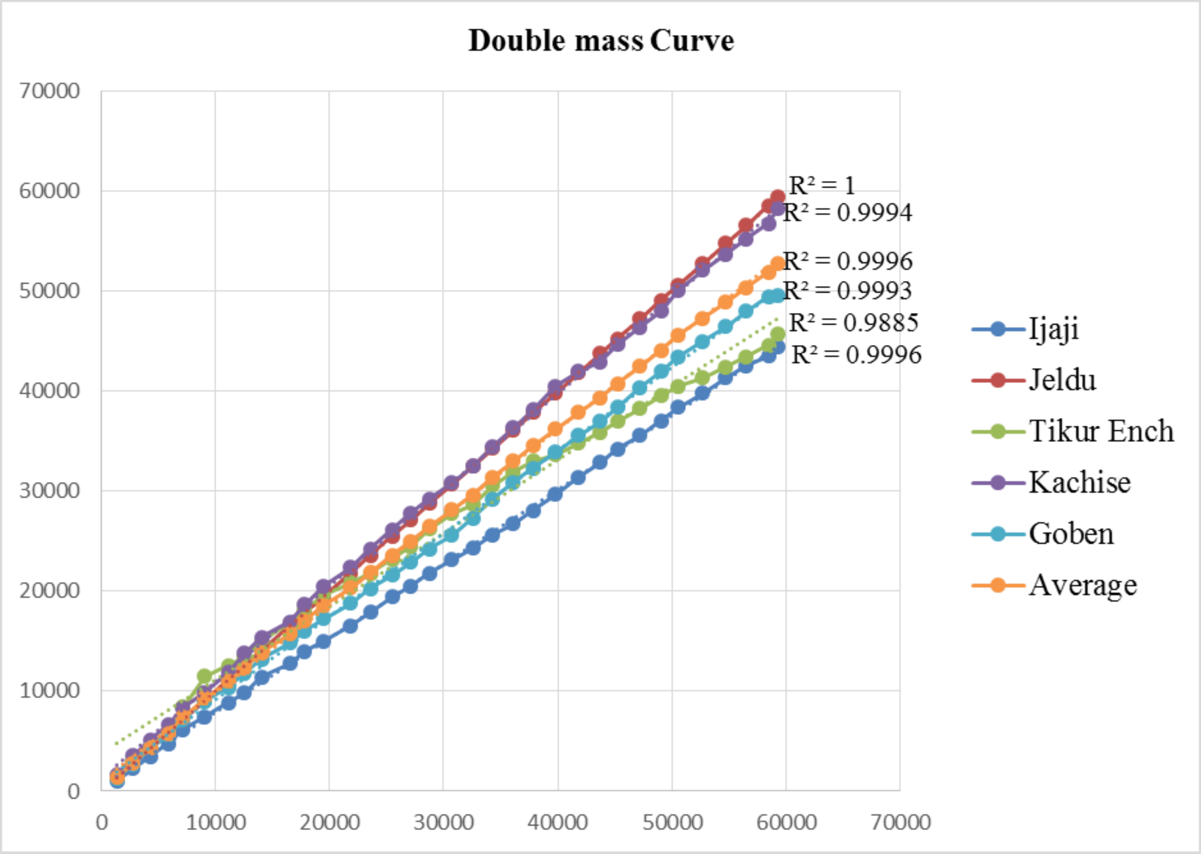
APPENDIXES

Appendix 1: Mean annual rainfall (mm) of selected stations (1984-2017)

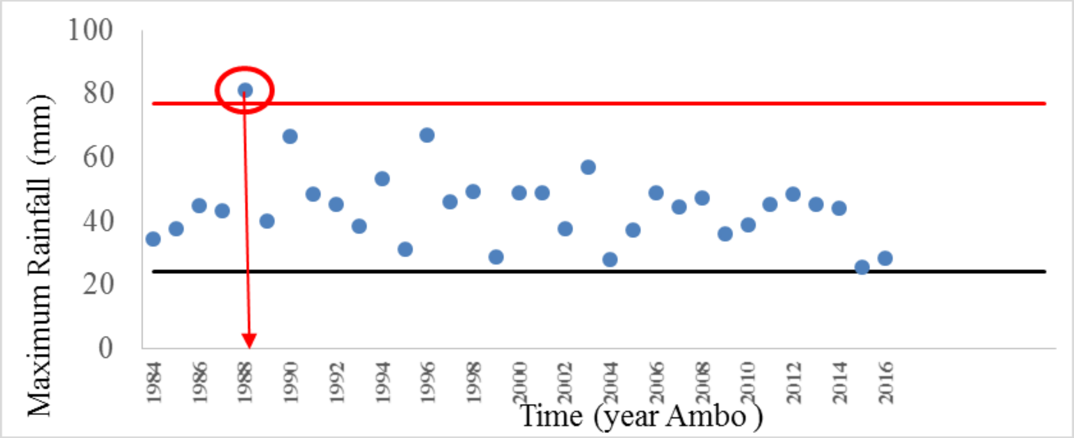
	Selected station for study area.					
Years	Ambo	Ijaji	Jeldu	Tikur Enchine	Kachise	Goben
1984	792.1	1033	1623.4	1366.1	1673.4	1472.5
1985	807.4	1220.4	1576.3	1435.8	1647.3	1389.4
1986	1047.8	1263.5	1498.5	1519.3	1639.8	1547.4
1987	1173.8	1273.1	1598.6	1571.4	2019.9	1498.4
1988	1089.3	1358.3	1478.4	1288.3	1651.3	1341.5
1989	1029.9	1281.7	1465.5	1859.2	1562.9	1370.9
1990	1122.8	1417.5	1482.3	2119.1	1801.7	1598.4
1991	1107.2	989.4	2413.7	1356.9	1595	1313.5
1992	1224.8	1591.4	3086.1	1542.9	2013.47	1591.9
1993	1157.8	1344.6	1104	2465.7	2038.3	1776
1994	1169.9	1223.2	867.8	1294.2	1624.9	1386.5
1995	1111.3	1027.7	1656.7	1690.9	1566.2	1429.1
1996	1409	1496.1	1724.2	2321.7	1846.9	1386.6
1997	877.9	1405	1340.4	1753.2	1901.3	1597.8
1998	1102.2	1501.4	1549.5	1925.2	1888.6	1286.7
1999	821.6	1116.3	1130.1	1598.4	1923	1186.5
2000	904.1	1254.5	933.6	1647.2	2012.9	1509.2
2001	1079.5	1368.1	1422.3	1961.8	1732.1	1470.6
2002	902.2	1116.1	1273.4	1810.1	1499.3	1361
2003	934.6	1375.6	1776.9	1747	1658.4	1284
2004	946.3	1103.1	1541.9	1837.3	1725.6	1369.9
2005	856.6	1322.6	884.6	1734.2	2029.9	1356.6
2006	1112.3	1614.9	1987	1979.7	1902.1	1731.7
2007	1163.1	1713.7	1290.9	2044	1776.8	1877.3

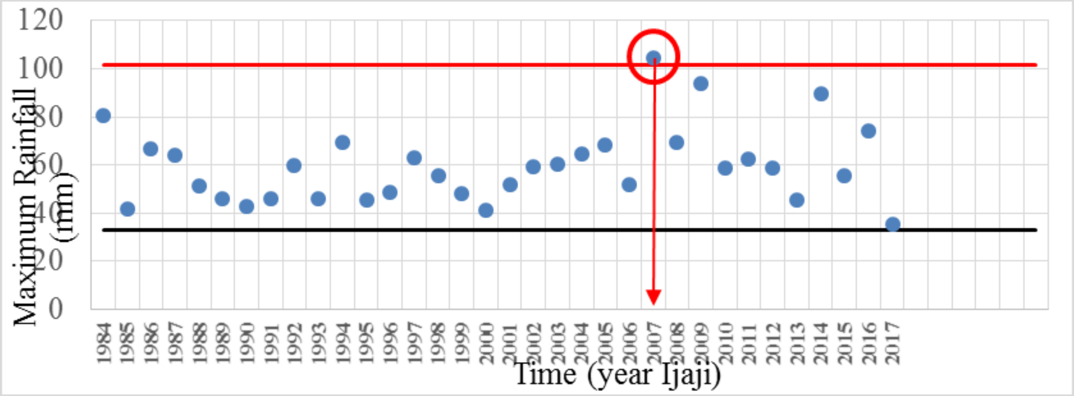
2008	1160.3	1497.7	1049.8	1901.7	2429.5	1662.1
2009	1006.4	1340.9	756.8	1473.4	1489.1	1426.6
2010	1186.6	1317.5	1057.2	2002.6	917.8	1601.1
2011	1703.3	1478.2	1104.7	1818.5	1765.4	1645.1
2012	956.4	1364.3	1040.4	1522.4	1710.2	1415.8
2013	960	1375.8	1325.6	2134.9	1640.1	1419.5
2014	866.1	1543.6	1238.2	2044.1	2125.1	1988
2015	848.6	1241.6	1052.2	1818.9	1984.4	1628.8
2016	872.7	971.4	788.5	1961	1553	1429.8
2017	954.3	869.8	1119.2	862	1533.9	1567.4

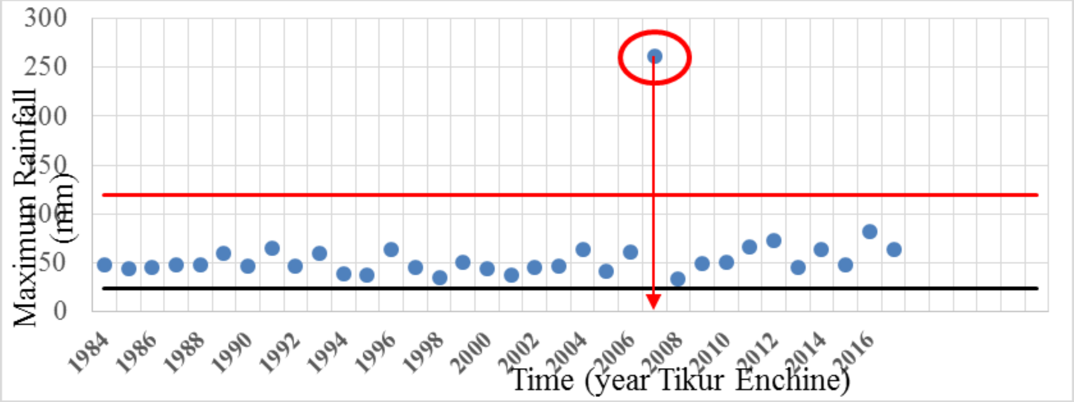
Appendix 2: Double mass curve graph of rainfall consistency analyze

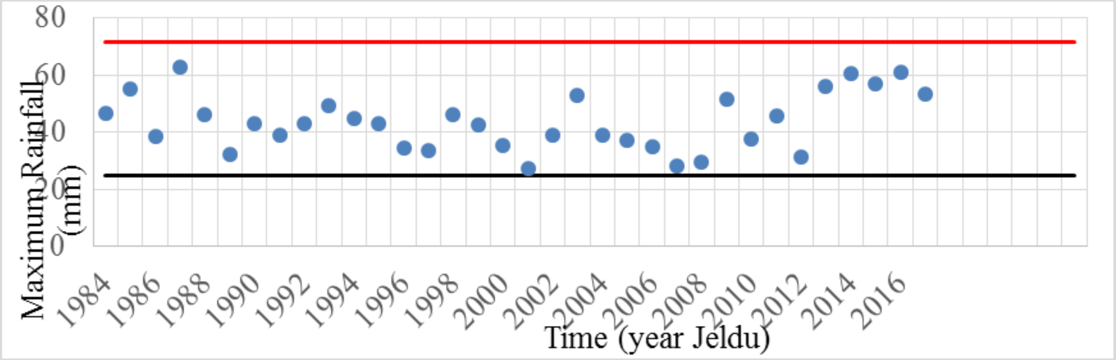


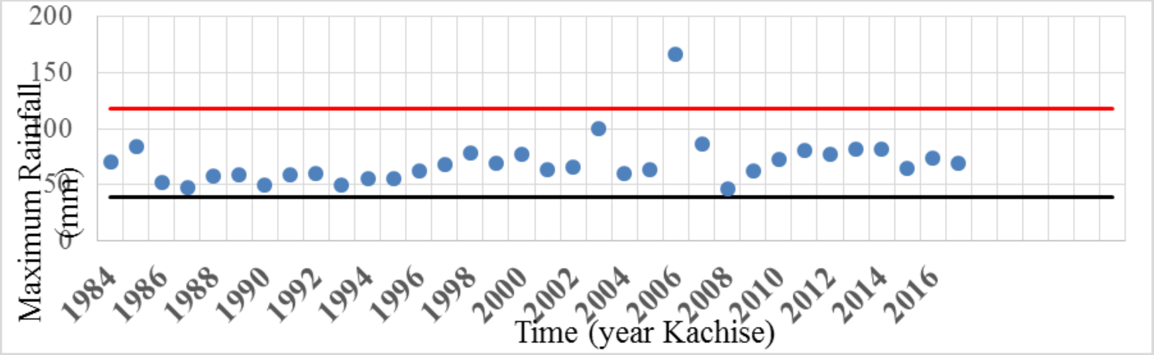
Appendix 3: Outlier data checking and determination








80
60
40
20
0
Maximum Rainfall (mm)
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Time (year Jeldu)


200
150
100
50
0
Maximum Rainfall (mm)
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
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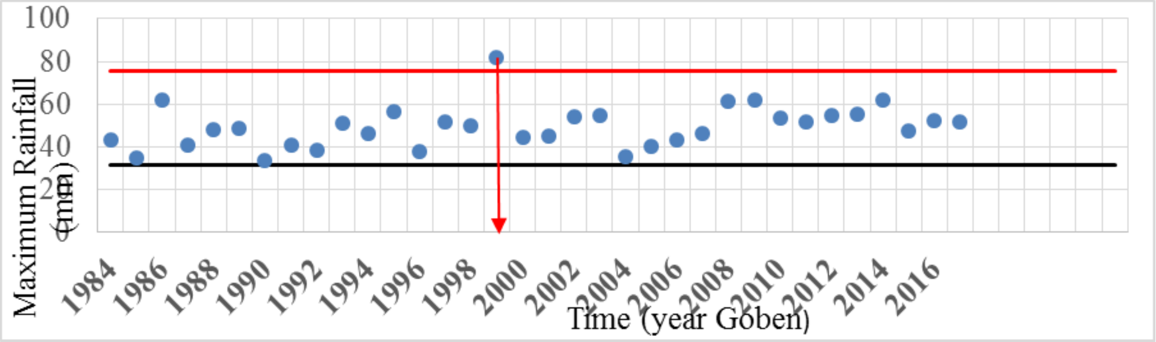
2014
2016
Time (year Kachise)


100
80
60
40
20
0
Maximum Rainfall (mm)
1984
1986
1988
1990
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Time (year Goben)