JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATES STUDIES

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

(HYDRAULIC ENGINEERING M.Sc. PROGRAM)

MORPHOMETRIC ANALYSIS TO IDENTIFY EROSION PRONE AREAS ON THE UPPER BLUE NILE USING GIS

(CASE STUDY OF DIDESSA AND JEMA SUB-BASIN, ETHIOPIA)

By

Gutema Debelo Dibaba

November, 2015
Jimma, Ethiopia

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Gutema Debelo Dibaba

This thesis is submitted to the School of Graduate Studies of Jimma University; in Partial fulfillment of the requirements for the Degree of Masters of Science in Hydraulic Engineering.

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November, 2015
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Declaration

I, Gutema Debelo, do here by declare to the Senate of Jimma University that this thesis is entirely my original work and all other materials are duly acknowledged. This work has not been submitted and presented for any academic degree award at any other University.

	Signature	Date
By Gutema Debelo	____________	_____________

This Thesis has been submitted for examination with my approval as University supervisor.

Signature: -____________ Date:-_____________

Jimma University

School of Graduate Studies

Certification

This is to certify that the thesis prepared by Gutema Debelo Dibaba, entitled: **Morphometric Analysis to Identify Erosion Prone Areas on the Upper Blue Nile Using GIS: Case Study of Didessa and Jema Sub-Basin,** in partial fulfillment of the requirements for the degree of Master of Science in Hydraulic Engineering compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Basin morphometric analysis is a means of mathematically quantifying different aspects of a drainage basin. In this thesis, morphometric analysis of Didessa and Jema sub basin was done to assess the hydrological characteristics and soil erosion potentials based on the morphological characteristics. The study was carried out using DEM data (30 m by 30m) in GIS environment. The extracted drainage network for both sub basins has 5th order according to Strahler's stream orders. The basic parameter (stream order, stream number, stream length, basin area, basin perimeter and basin length) from GIS software were used for analysis of Linear, areal and relief aspect of Morphometric parameter. The linear parameter (bifurcation ratio, drainage density, stream frequency and drainage texture ratio) and relief aspect parameter (basin relief, relief ratio and ruggedness number) have direct correlation with soil erosion. But the areal parameter (form factor, circularity ratio, elongation ratio and constant channel maintenance) have inverse relationship with soil erosion. The Average of all these parameter for each sub watersheds was calculated to determine the final priority classes and categorized as high (≤ 2.55), medium (2.55 to 3.55) and low (≥ 3.55). Moreover the final priority Map also indicates that; high priority classes of Jema sub watersheds covers larger area of about 7292.57km^2 (49.45%) for both J-3 and J-1, whereas 5099.43km^2 (29.85%) of D-6 from Didessa sub watersheds were vulnerable to soil erosion. This indicates that comparatively; Jema watersheds were more vulnerable to soil erosion than that of Didessa watersheds where phase wise implementation of soil and water conservation measure has to be taken 1st. The Sub-Watershed (J-2 & J-5 from Jema and D-3 & D-4 from Didessa) 2nd priority were needed for reclamation and conservation process. The sub watershed (J-4 from Jema and D-1, D-2 and D-5 from Didessa) have a low risk of land degradation hence it should be given lowest priority in sub-basin conservation practices.

Key Terms: *GIS, Soil erosion, Morphometric analysis, sub watershed Prioritization, Erosion prone area and management.*

Acknowledgement

First of all, I glorify the almighty God for granting and strengthen me to proceed and walk unpaved way to reach this point in life. Next, I would like to express my gratitude to Ethiopian Road Authority for providing such chance to continue my study.

I wish to express my utmost gratitude to my advisor Dr.Ing Kassa Tadele, for his precious encouragement, build-up advice and guidance from the inception of this work to the end. Also, I would like to thank my co-advisor; Mr. Sifan A. Koriche for his willingness to co-advise, criticize, encouragements and motivation during this thesis work. Their critical comments and valuable advices helped me to take this research in the right direction.

I would like also to thank the Ministry of Water, Irrigation and Energy; Department of Hydrology, GIS and Remote Sensing for their cooperation in availing the necessary data. I would like to express my sincere gratitude to Jimma University and Ethiopian Road Authority for their cooperative work that made this research possible through financing.

Special thanks to all my friends, Classmates and others relatives for their encouragement, moral support, true friendship and wonderful social atmosphere.

At last but not least, I would like to extend my deepest gratitude to my dad and mam as well as all family members: Baye, Daamu, Terefa, Mekonnen, Lellisa, Motuma & Tadese for their moral support and belongingness throughout the study; particularly my brother Mekonnen Debelo without his encouragement, advice and care this would not have happened in my life.

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List of Nomenclatures

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

List of Acronyms

ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
BMC	Billion Cubic Meters
DEM	Digital Elevation Model
GERD	Grand Ethiopia Renaissance Dam
GIS	Geographical Information System
Ha	Hectars
Km	Kilometer
M	Million
m	Meter
Mm	Millimeter
MW	Megawatt
RS	Remote Sensing
SWAT	Soil and Water Assessment Tools
WCD	World Commission of Dam

CHAPTER 1

INTRODUCTION

1.1Background

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. 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. 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. Erosion may be exacerbated in the future because of a more vigorous hydrologic cycle as a result of climate change. Due to the diverse topographic characteristics, geology and geomorphology of mountain region have high vulnerability to soil erosion (Das, 2014).

Soil erosion is a worldwide environmental problem that degrades soil productivity and water quality, causes sedimentation, reducing reservoirs storage capacity and life span and increases the probability of floods due to the reduction in carrying capacity of rivers and streams. It is a natural geological phenomenon occurring due to removal of soil particles by water, wind and human activities, transporting them elsewhere depending upon rainfall, topography, vegetation, soil and land-use practices. The land degradation stems from changes in land use, agricultural intensification and intense rainstorms (Sharma and Goyal, 2013)

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 (Zemenfes, 1995). Because of the rugged terrain and, the rates of soil erosion and land degradation are high. Although Ethiopia is one of the fastest growing populations of the world, people cultivate lands that were previously under forest cover to sustain its growing population. But this land use has a tremendous contribution to soil erosion. Soil erosion and loss of agricultural soils is a major Problem in Blue Nile River Basin, Ethiopia (Kidane and Alemu, 2015). The high rate of surface erosion in the basin and the rate of sediment transport in the river system contribute to increased sedimentation problems in the Lake and reservoirs as well as the downstream areas. The catchment is cut by deep ravines in which the major tributaries flow. The primary tributaries of blue Nile in Ethiopia are Beshilo, Jema, Muger, Guder, Fincha'a, Anger, Didessa and Dabus on the left bank and the Chemoga, Timochia, Bir and Beles on the right bank. However; out of those tributaries; this case study will be emphasized to identify most erosion prone areas for Jema river basin at the upstream and Didessa river basin at the downstream.

Erosion of soil in catchment areas and the subsequent deposition in rivers, lakes and reservoirs are of great concern for two reasons. Firstly, rich fertile soil is eroded from the catchment areas. Secondly, there is a reduction in reservoir capacity as well as degradation of downstream water quality. Sediment particles originating from the continuous process of erosion in the catchment area propagated along the river flow. When this flow accumulates into the reservoir the sediment that has been carried with the stream gets settled into the reservoir and reduces its capacity. Reduction of storage capacity of a reservoir beyond a certain limit hampers the purpose of the reservoir for which it was designed (Tamene *et.al*., 2006).

Proper assessment of soil erosion in space and time involve identification of source areas of sediments and the nature of the areas, their variability, and other basin variables indicative of source areas. Soil and water conservation are key issues in watershed management for demarcating the priority watersheds. Therefore, any sediment control management or policy should be directed to those areas that are the major contributors of sediment. Therefore, it becomes essential to locate those critical sediment yielding source areas within a watershed, that need priority attention to improve soil productivity and to prevent further damage from soil erosion (Zhou.Q *et.al*, 2014).

Proper scientific planning and management of these resources requires detail information about morphology and other characteristics. Therefore, geomorphological characteristics of a watershed are commonly used for developing the regional hydrological models for solving various hydrological problems of the inadequate data situations. Now a day's watershed is started to be studied in scientific ways by using different models, Remote Sensing (RS) and Geographical Information System (GIS) Which shows the efficiency of soil erosion rate and mapping erosion prone areas (Das, 2014)

The Application of remote sensing provides a reliable source for the preparation of various thematic layers for morphometric analysis. The digital elevation data is used for generating the elevation model of a landscape to any extent. The resolution of the image may vary with respect to the satellite sensors. The processed Digital Elevation Model (DEM) is used for generating the stream network and other supporting layers (Magesh *et.al.*, 2011; Moharir and Pande, 2014). Geographical information systems (GIS) have been used for assessing various basin parameters, providing flexible environment and powerful tool for determination, interpretation and analysis of spatial information related to river basins. Geology, relief and climate are the primary determinants of a running water ecosystem functioning at the basin scale. Detailed study of morphometric analysis of a basin is great help in understanding the influence of drainage morphometric on landforms and their characteristics (J.Wilson *et.al.*, 2012).

Morphometric analysis of river basin provides a quantitative description of the drainage system, which is an important aspect of the characterization of basins. It is important in any hydrological investigation like assessment of groundwater potential, groundwater management, watershed management and environmental assessment. Various hydrological phenomena is correlated with the physiographic characteristics of a drainage basin such as size, shape, slope of the drainage area, drainage density, size and length of the contributories, etc. The dynamic nature of runoff is controlled by the geomorphologic structure of the catchment area and the induced runoff is very sensitive towards morphometric characteristics of the contributing area. The morphometric analysis is performed through measurement of linear, aerial, relief, gradient of channel network and contributing ground slope of the basin (Rudraiah *et.al.*, 2008; Nag and Chakraborty, 2003). This research describes the process to calculate the various morphometric parameters of Didessa and Jema sub basin using GIS environment.

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, 2014).

The occurrence of natural and anthropogenic extreme phenomena all around the world makes us to pay more attention to their environmental and economic impacts. Soil erosion is one of them and is a growing problem in our country due to increased impact of rapid population growth. Rapid population increase in the upper Blue Nile led to fast land-use changes from natural forest to agricultural land, which resulted in speeding up the soil erosion process. Slope failures of the deep gorges and rugged valley walls which caused land sliding and rock falling is another factor leading to soil erosion in the basin. Soil erosion undesirably increases the sediment load downstream and reduces soil fertility and hence agricultural productivity upstream. Eroded sediment particles are transported away by the flowing water with undesirable downstream sedimentation (Tamene *et.al*., 2006).

The Blue Nile River, which originates from the steep mountains of the Ethiopian Plateau, is the major source of sediment loads in the Nile basin. 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 Nile 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).

Soil erosion is a serious problem for environmental degradation in the mountainous landscape of the highlands of Ethiopia in both its economic costs and the areas affected. The hill slopes are under cultivation without using control measures and appropriate land management practices that result in low productivity, physical and ecological degradation. This part of the land increasingly experiences high pressure for agricultural production. Soil conservation and management practices do not correspond to the activities imposed on these land units. Poor land and water management practices and lack of effective planning and implementation approaches for conservation are responsible for accelerating degradation on agricultural lands and siltation of lakes, dams and reservoirs downstream. Mismanagement of the land is blamed on the land users themselves by assuming lack of their environmental awareness, ignorance or lack of responsibility due to the fact that they cultivate the land for immediate livelihood goals (Desta, 2010).

Proper assessment of soil erosion in space and time involve identification of source areas of sediments and the nature of the areas, their variability, and other basin variables indicative of source areas. Soil and water conservation are key issues in watershed management behind demarcating the priority watersheds. Therefore, any sediment control management or policy should be directed to those areas that are the major contributors of sediment. Therefore, it becomes essential to locate those critical sediment yielding source areas within a (representative) watershed, that need priority attention to improve soil productivity and to prevent further damage from soil erosion. Major factors responsible for soil erosion include rainfall, soil type, and vegetation, topographic and morphological characteristics of the basin. Where there is a lack of data on rainfall and sediment yield, the relative vulnerability of watersheds can be assessed with respect to time independent factors like soil type, topography and morphology. This study is, therefore, undertaken to use Morphometric analysis of the watershed for its ability to predict level of vulnerability of watersheds with respect to time independent topographic, morphometric and soil factors in GIS environment (Das, 2014)

1.3 Objectives

The General objective of this study is to Conduct Morphometric analysis in order to identify and locate erosion prone areas on the upper Blue Nile using GIS environment particularly for Didessa and Jema sub watersheds to recommend Soil conservation measure for management.

The Specific objectives of this study are:-

- ☞ To calculate the Morphometric parameters (linear, areal and relief aspects) for Didessa and Jema sub watersheds.
- ☞ To establish priority rank for identification of erosion prone areas for both sub watersheds based on morphometric analysis result.
- ☞ To locate and compare erosion vulnerable areas of both sub-basins based on the established priority rank.
- ☞ To suggest management practices for erosion vulnerable areas to treat them sequentially in order to reduce soil erosion and sedimentation rate at the downstream.

1.4 Research Questions

Based on the stated objectives, the following questions were used to guide the research process and finally answered from the findings of the study.

1) What are the calculated parameters in Morphometric analysis of sub watersheds?
2) How to establish priority rank for identification of erosion prone areas for Didessa and Jema sub watersheds?
3) Which sub basin area is more vulnerable to soil erosion?
4) What are the Conservation measures to be applied for erosion prone areas of the sub watershed to treat and reduce the impacts of reservoir sedimentation at the downstream?

1.5 Justification/Rationale/motivation

Soil erosion is the major problem causing reservoir Sedimentation, threatening its life as well as the power generating units. However; Hydropower generation plays a significant role for the sustainable economic growth of Ethiopia. The country is endowed with high hydropower potential and there is a plan of generating and exporting power to neighboring countries. So; identification of the most critical erosion prone areas and effective control measure of soil erosion or land use (for agriculture) and land cover change (by deforestation) needs a holistic approach. This requires involvement of all professionals and relevant stakeholders in the water sector including the water users, government and other non-state actors in integrated catchment management. Therefore this research seeks to identify most critical erosion prone areas and then select and adopt best management practices for the priority classes for treating them sequentially in order to reduce reservoir sedimentation rate at the downstream especially for the grand Ethiopian Renaissance Dam.

1.6 Scope

Computation of morphological parameters in GIS environment has proved to be less tedious, fast, and accurate and made best spatial representation of topographic situations. The morphological analysis is a significant tool for understanding the topographic situation and hydrological condition of a catchment area. Morphological 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 known, the watershed can be restored by reducing erosion with the help of watershed management practices like vegetative Contour binding, Sub soiling, Basin listing and Bench terracing, gully control structures, grass waterways, strip mulching and so on. In this study, morphological parameters of the Jema and Didessa basin have been to be derived using GIS Software package for understanding the basin condition with spatial variability in the context of watershed development and management (D.S.Deshmukh *et.al*, 2010).

1.7 Significance of the study

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, 1993). In general, the study will have significant contribution in mitigating erosion problem on time and in a cost effective way. The planning and interventions will be in line with the identified erosion vulnerable sub-watersheds. The soil erosion risk map on the sub-watershed bases will be developed by integrating remote sensing and GIS application. It provides information on Areas that are more prone to soil erosion based on the estimated value of soil loss and multi criteria analysis. It is importance as the database of erosion risk of the sub-watersheds in the development of integrated watershed management to conserve soil erosion and minimize the reservoir sedimentation problem at the downstream of the sub basins project.

1.8 Organization of the Thesis

The thesis is organized in five chapters: Chapter 1 corporates an introduction chapter where the background, problem statement, objectives, research question, Justification, scope and significant of the study are discussed. In Chapter 2, Literature review about the concept of soil erosion, previous studies on Morphometric analysis, previous studies on Blue Nile and GIS application. Methodology of the research was carefully arranged in Chapter 3 by describing the study areas, data and software used for sub watershed delineation and characterization, Methods used for Computation of Morphometric parameter and sub watershed prioritization; watershed management . Chapter 4 describes result and discussion of Morphometric analysis that may be (linear, areal and relief), Developing priority rank and compound value for identification of erosion prone areas, as well as Soil conservation measures. Finally, in Chapter 5; conclusions and recommendations are provided.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil erosion in Ethiopia

Soil erosion is a universally accepted environmental problem that threatens man's well-being and his overall development both in its on-site and offsite effects. Soil erosion caused by water and wind is a widespread problem in both rural and urban areas of the world. It is normally a natural process occurring over geological timescales; but where (and when) the natural rate has been significantly increased by anthropogenic activity accelerated soil erosion becomes a process of degradation and thus an identifiable threat to soil. The excessive dependence of the Ethiopian rural population on natural resources, particularly land, as a means of livelihood is underlying cause for degradation of land and other natural resources (Ali, 2014)

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. All physical and economic evidence shows that loss of land resource productivity is an important problem in Ethiopia and with continued population growth the problem is likely to be even more important in the future. Most studies showed soil erosion is severe in the Ethiopian Highland (Awulachew *et.al*, 2008).

According to studies, Ethiopia is described as the most soil erosion affected country in the world with recorded annual soil loss ranging from low 16 tones/ha per year to high of 300 tonnes/ha per year (Assegahegn and Zemadim, 2013) The Blue Nile River, which originates from the steep mountains of the Ethiopian Plateau, is the major source of sediment loads in the Nile basin. 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 Nile basin.

The Blue Nile River Basin is increasingly under human pressure, due to rapidly growing population in Sudan and Ethiopia. This has already resulted in a number of environmental problems caused by the extensive exploitation of territory and resources (Balthazar *et.al*, 2013).

The construction of dams and reservoirs represents a great achievement for the management of the water resource, but at the same time it creates a relevant disturbance to the river ecology and morphology. So; to reduce such disturbances, morphometric analysis to identify critical erosion prone areas are crucial. In addition to that; to select and adopt best management practices for the priority classes of the selected sub-catchment on the upper river basin is responsible for treating them sequentially (Ali, 2014).

In general; Literature review shows many catchment models that include the soil erosion/sedimentation processes on Blue Nile as well as recent research of the morphometric analysis at worldwide. Various researches were done on the Blue Nile using different models. The areas of research include land cover changes, sedimentation, and flow and conditions relating these parameters. Some of them were reviewed as follow.

2.2 Previous Studies on the Blue Nile

According to Erkossa, (2009) Currently, Abbay is one of the least planned and managed sub-basins of the Nile. About two thirds of the area of this densely populated basin fall in the highlands and hence receive fairly high rainfall of 800 to 2,200 mm per year. With its total area of about 200,000 square kilometers (km^2), which is 20% of the countries, land mass and accommodating 25% of the population; the Upper Blue Nile Basin (Abbay) is one of the most important river basins in Ethiopia. About 40% of agricultural products and 45% of the surface water of the country are contributed by this basin. However, the characteristic-intensive biophysical variation, rapid population growth, land degradation, climatic fluctuation and resultant low agricultural productivity and poverty are posing daunting challenges to sustainability of agricultural production systems and reservoir sedimentation in the basin.

Tamene *et.al*, (2006) argued that; 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 (Both the Nile Basin Initiative and the Ethiopian government are developing ambitious plans of water resources projects in the Upper Blue Nile basin, locally called the Abbay basin. Thus, an insight into the soil erosion/sedimentation mechanisms and the mitigation measures plays an indispensable role for the sustainable water resources development in the region.

Ali, (2014) suggested that; Population growth in the upper Blue Nile Basin led to fast land-use changes from natural forest to agricultural land, which resulted in speeding up the soil erosion processes. Soil erosion undesirably reduces soil fertility and hence the agricultural productivity upstream. Eroded sediment is transported to the lower Blue Nile Basin, where sedimentation occurs at many locations. In the reservoirs, sedimentation leads to serious reduction in storage capacity, causing hydropower generation problems and negative impacts on the socio-economic, environmental and ecological system. The Blue Nile River Basin is currently experiencing new developments, both in Ethiopia and Sudan. The Grand Ethiopia Renaissance Dam (GERD) is under construction about 30 km upstream of the Ethiopian-Sudanese border. Recently, the Roseires Dam located 110 km downstream the Ethiopian-Sudanese border has been heightened by 10 m, increasing the storage capacity of the reservoir by additional 3700 million m^3. Some dams are planned in Ethiopia for hydropower production. These developments will strongly affect the water resources and sediment deposition in the lower Blue Nile Basin. Sedimentation in the new reservoirs and in irrigation canals will depend on the operation of these dams, but the only effective solution to reduce the sedimentation problems is reducing the sediment input. This can be achieved by means of erosion control practices in the upper basin. For this, given the vastness of the upper basin, it is important to identify the areas where the largest amounts of sediment are produced.

According to Assegahegn and Zemadim, (2013); Erosion modeling in the upper Blue Nile basin of Mizewa watershed, the model performance test for both calibration and validation indicated that the agreement between measured and simulated result is acceptable. Mizewa is considered as erosion sensitive area as rate of soil loss (40.9 t/ha per year) is more folds of the soil formation rate of the region (11 t/ha per year), stated in many literatures. The surface runoff (335.70 mm or 24%) of the simulated precipitation is high and a very high soil water storage as simulated by the model are responsible for high erosion potential of Mizewa watershed.

Abera, (2014) Assessed the Vulnerability of Micro-Watershed to Soil Erosion in Ribb Watershed Using GIS and Remote Sensing. From the total area of the Watershed which is 1240.12 km^2, 92 km^2 is potential areas for gully development. Thus these micro-watersheds are more vulnerable to erosion compared to the others and they should be prioritized for conservation and other environmental protection activities.

Fetene *et.al*, (2009) Argued that; The Blue Nile region is the main contributor to flood flows of the Nile, with a mean annual discharge of 48.5 km3. The main objective of thesis is to determine sediment yield in the different sub basin of Blue Nile in Ethiopia, sediment load and sediment concentration in the main rivers of the tributaries and in the Abbay River. In addition to this, the aim is to look spatial and temporal variation of sediment yield/ concentration in the basin. Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. The SWAT was successfully calibrated and validated for measured streamflow at Bahir Dar near Kessie and at the border of Sudan for flow gauging stations, and for measured sediment yield at Gilgel Abbay, Addis Zemen and near Kessie gauging stations in the Blue Nile Basin. It was found that the Guder, North Gojam and Jema sub basins are the severely eroded areas with 34% of sediment yield of the Blue Nile coming from these sub basins. Similarly, the Dinder, Beshilo and Rahad sub basins only cover 7% of sediment yield of the basin. The annual average sediment yield is 4.26 t/ha/yr and the total is 91.3 million tonnes for the whole Blue Nile Basin in Ethiopia.

According to G.D. Betrie *et.al*, (2009), Rapid land use change due to intensive agricultural practices in the Ethiopian Highlands, results in increasing rates of soil erosion. This manifested in significant impacts downstream by reducing the storage capacity of reservoirs (e.g., Roseires, Sennar), and high de silting costs of irrigation canals. The paper aims to provide a better understanding of the process at basin scale. The Soil and Water Assessment Tool (SWAT) was used to model soil erosion in the upper catchments of the Blue Nile over the Ethiopian Plateau. The SWAT output forms the input sediment load for SOBEK, a river morphology model. The two models integrated using the principles of the Open Model Interface (Open MI) at the Ethiopia-Sudan border. The Nash-Sutcliffe coefficient was found to be 0.72 and 0.66 for results of SWAT daily sediment calibration and validation, respectively. The SOBEK results also show a good fit of the simulated river flows at Roseires and Sennar reservoirs, both for calibration and validation. The results of the integrated modeling system showed 86 million tonnes/year of sediment load from the Upper Blue Nile, while SOBEK computes on average 19 Mm^3/year of sediment deposition in the Roseires Reservoir. The spatial variability of soil erosion computed with SWAT showed more erosion over the northeastern part of the Upper Blue Nile, followed by the northern part. The overall exercise indicates that the integrated modeling is a promising approach to understand soil erosion, sediment transport, and sediment deposition in the Blue Nile Basin. This will improve the understanding of the upstream-downstream interdependencies, for better land and water management at basin scale.

M. Tenaw and S.B. Awulachew, (2009) assessed, Soil and Water Assessment Tool (SWAT)-Based Runoff and Sediment Yield Modeling for Gumera Watershed in Lake Tana Sub basin. Land degradation is a serious threat in the Gumera watershed which is reflected in the form of soil erosion. Erosion is a major watershed problem causing significant loss of soil fertility and productivity. Increased sediment loads that shorten the useful life of the reservoir, the lives of other water-related structures, and increase the cost of maintenance and sediment remediation are off-site impacts of erosion. To develop effective erosion control plans and to achieve reductions in sedimentation, it is important to quantify the sediment yield and identify areas that are vulnerable to erosion. In recent decades, several simulation models have been developed in order to estimate, quantify, enhance understanding of spatial and temporal variability of erosion, and identify areas which are high contributors of sediment at micro-watershed level and over large areas.

SWAT (Soil and Water Assessment Tool) were used to predict sediment yield, runoff, identify spatial distribution of sediment, and to test the potential of watershed management interventions in reducing sediment load from ‘hot spot’ areas. The tool was calibrated and validated against measured flow and sediment data. Both, calibration and validation results, showed a good match between measured and simulated flow and suspended sediment. The model prediction results indicated that about 72% of the Gumera watershed is erosion potential area with an average annual sediment load ranging from 11 to 22 tonnes/ha/yr exceeding tolerable soil loss rates in the study area. The model was applied to evaluate the potential of filter strips with various widths to reduce sediment production from critical micro-watersheds. The investigation revealed that implementing vegetation filter strips can reduce sediment yield by 58 to 74%.

Shimelis *et.al*, (2009) entitled spatial delineation of Soil erosion Vulnerability in 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.

Wubet *et.al*, (2009); assessed simulation model for water allocation for major activities (existing and planned) in the Abbay Basin using up-to-date water allocation and simulation models. MIKE BASIN model is used to gain an insight into the potential downstream consequences of the development of physical infrastructure and water abstraction in a number of different future development scenarios. Seventeen irrigation projects covering an area of 220,416 hectares (ha) of land have been selected from different gauged catchments of the sub basin in addition to 4,800 megawatt (MW) hydropower projects on the main stream of the study area (Ethiopian part of Blue Nile). From the analysis, the total water extracted for these irrigation projects was estimated to be 1.624 billion cubic meters (BCM) annually. A reduction in the border flow volume as a result of the implementation of these irrigation projects under the reservoir scenario is 3.04% of the estimated mean annual flow of 50.45 BCM. Similarly, from the analysis, the total power generated due to the development of the major hydropower projects on the main stream, having an installed capacity of 4,800 MW, is 18,432 giga watt hours (GWh) per year. This implies, while these interventions provide significant opportunities with respect to interventions and energy generations, their impact on downstream water availability is minimal.

Assefa *et.al*, (2009) assesed Gully formation and upland erosion in Debre-Mewi Watershed in the Gilgil Abay Basin south of Lake Tana. Gully erosion rates were found to be over 500 tonnes/ha/year for the 2008 rainy season when averaged over the contributing watershed. Upland erosion rates were twentyfold less. Gully formation is accelerated when the soils are saturated with water as indicated by water table readings above bottom of the gully. Similarly, upland erosion was accelerated when the fields were close to saturation during the occurrence of a rainfall event. Height of the water table is an important parameter determining the amount of erosion and should, therefore, be included in simulation models.

2.3 Review on morphometric analysis

Morphometric is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms. Morphometric studies in the field of hydrology were first initiated by Horton (1940) and Strahler (1950). Morphological analysis is the systematic description of watershed's geometry and its stream channel system to measure the linear aspects of drainage network, aerial aspects of watershed and relief aspects of channel network. Its parameters directly or indirectly reflect the entire watershed based causative factors affecting runoff and sediment loss. It provides a quantitative description of the basin geometry to understand initial slopes or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of the drainage basin. The morphometric analysis is a significant tool for prioritization of sub-watersheds even without considering the soil map (Biswas *et.al*, 1999).

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, structural control, etc. 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). Drainage patterns refer to spatial relationship among streams or rivers, which may be influenced in their erosion by inequalities of slope, soils, rock resistance, structure and geologic history of a region. (Strahler, 1964; Rama, 2014; P.Dahiphale *et.al*, 2014).

Recently, many researchers and Scholars used remote sensing data and analyzed them on Geographical Information System (GIS) platform to understand the inherent morphometric ingredients of the catchment. Sarma *et.al*, (2013), suggested that, the rapid development of geospatial technology has recently become an effective tool to overcome many problems associated with identification and interpretation of basin morphometric parameters and to design an effective land and water resource plan for the basin area. Although there is no research that was done on morphometric analysis in our country, worldwide Journal articles was reviewed and cited especially Indian Journal of Engineering and technology. Some of the recent research on the morphometric analysis, that was used in these research were reviewed and described as below.

According to Kanth and Hassan, (2012); quantitative analysis of morphometric parameters is found to be of immense utility in watershed prioritization for soil and water conservation and natural resources management at micro level. So carrying out a detailed study of linear and shape parameters of morphometric analysis for all sub watersheds in a Catchment and their prioritization for soil and water resource management is needed. Data of Topographic were utilized to delineate the drainage system, thus to identify precisely water divides using Geographic Information System (GIS). In order to classify the streams, following Strahler's stream ordering scheme was selected due to its simplification. The stream number and stream length of a Catchment is in conformity with the Horton's law of stream numbers and stream lengths. The high value of drainage density indicates that the region is composed of impermeable sub-surface materials, sparse vegetation and high mountainous relief causing higher surface run off, and a higher level of degree of dissection. A high proportion of first order streams (80%) indicate structural breaks, chiefly as, lineaments, and fractures of rocky basement of the watersheds. The prioritization was carried out by assigning ranks to the individual indicators and a compound value parameter (CP) was calculated. Watersheds with highest CP were of low priority while those with lowest CP were of high priority. Thus an index of high, medium and low priority was produced. High priority indicates that the watersheds are susceptible to greater degree of soil erosion and it becomes potential candidates for application of soil conservation measures to preserve the land from further erosion and to alleviate natural hazards.

According to Altaf *et.al*, (2013); Quantitative Morphometry plays a vital role in routing the snowmelt and other hydrological processes. Morphometric analysis of the catchment was carried out using geospatial technique. From the outcome, the high drainage density of sub watersheds indicates more surface runoff. The morphometric analysis also indicates that the area is more prone to weathering due to very-coarse to coarse drainage texture. An immense control of structure on the drainage in some sub watersheds is indicated by their high bifurcation ratios. Circulatory and elongation ratios show that the sub watersheds have elongated to circular shapes. The hydrology of a watershed changes significantly due to the spatial variations of the morphometric parameters, the sub watersheds will therefore also exhibit differential hydrological behavior.

According to Geena and Ballukraya, (2011); Watershed development and management plans are very important for harnessing surface water and groundwater resources. To prepare a comprehensive watershed development plan, it becomes necessary to understand the topography, erosional status and drainage pattern of the area. The morphometric parameters are computed by using Geographic Information system (GIS). GIS was used in evaluation of linear and areal aspects of morphometric parameters. The quantitative analysis of various aspects of river basin drainage network characteristics reveals complex morphometric attributes. The streams of lower order mostly dominate the basin. The development of stream segments in the basin area is more or less affected by rainfall. The erosional processes of fluvial origin have been predominately influenced by the subsurface lithology of the basin.

According to V. Singh and U.C.Singh, (2011); the term morphometry senses the measurements and analysis of form and its properties. The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation, natural resource management at micro level. In context of geomorphology which is science of landforms it is concerned with the various geometrical aspects of the landforms. The basin morphometric parameters such as linear and aerial aspects of the river basin were determined and computed. The parameters considered for analysis are stream length, bifurcation ratio, drainage density, stream frequency, Drainage texture, form factor circularity ratio, elongation ratio, compactness ratio etc.

Also Rama, (2014) argued that; an attempt has been made to study and characterize the drainage morphometry and its influence on hydrology. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data were used for preparing Digital Elevation Model (DEM) and slope maps. Geographical information system (GIS) was used in evaluation of linear, areal and relief aspects of morphometric parameters. The lower order streams are mostly dominating the basin. The higher mean Bifurcation ratio of sub watersheds indicates that the drainage pattern is influenced marginally by geological structures i.e. absence of structural control. Shorter Length of overland flow indicates that short flow- paths, with steep ground slopes, reflecting the areas associated with more run-offs and less infiltration and long flow-paths and gentle ground slopes, which reflects areas of less surface run-offs and more infiltration. Bifurcation ratio indicates absence of any significant structural control on the development of the drainage. Relief ratio indicates that the discharge capabilities and groundwater potential of the sub watersheds. Also such studies are very useful for planning in construction of rainwater harvesting structures and watershed management.

In the same manner according to C.B. Pande and K. Moharir, (2015); a morphometric analysis of basin carried out using geo-processing techniques in GIS are found relevant for the extraction of river basin and its drainage networks. The extracted drainage network was classified according to Strahler's system of classification. Most of the time; terrain exhibits dendritic to sub-dendritic drainage pattern. The remote sensing data or DEM data coupled with geo-processing techniques prove to be a competent tool used in morphometric analysis and evaluation of linear, slope, areal and relief aspects of morphometric parameters.

The combined outcomes have established the topographical and even recent developmental situations in basin. It will also change the setup of the region. It therefore needs to analyze high level parameters of drainage and environment for suitable planning and management of water resource developmental plan and land resource development plan. The slope variation is chiefly controlled by the local geology and erosion cycles. The morphometric parameters of the stream have been analyzed and calculated by applying standard methods and techniques of different scholars and researchers like Horton (1945), Miller (1953), and Strahler (1964). GIS based on analysis of all morphometric parameters and the erosional development of the area by the streams has been progressed and studies are very useful for planning of rainwater harvesting and watershed management.

Hajam *et.al*, (2013) argued that; morphometric analysis of the drainage basin and channel network play an important role in understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural antecedents of the catchment. Morphometric analysis of a drainage basin expresses fully the state of dynamic balance that has been attained due to dealings between matter and energy. Morphometric analysis carried out using Geographical Information System (GIS) techniques to assess the geo-hydrological characteristics of river basin and an attempt has been made to identify the ground water potential zones through geo-morphometric specs. The morphometric parameter discusses about linear, areal and relief aspects. The development of stream segments in the basin area is affected by rainfall; groundwater discharge and snow melt over. The total number and length of stream segments is maximum in first order streams and decreases as the stream order increases. The bifurcation ratio (Rb) between different successive orders varies revealing the geo-structural control. The shape parameters (R_C, Re and Rf) used to indicate the basin shape that may be elongated or circular shape and in association with some areal (Dd, Dt etc.) and relief parameters shows discharge of runoff, permeability of subsoil condition, infiltration capacity and groundwater resource potential of the sub watersheds. Therefore; morphometric analysis based on GIS technique is a competent tool for geo-hydrological studies for identifying and planning the ground water potential zones and watershed management.

Also Vishal T.*et.al*, (2013) argued that; The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation, and natural resources management at micro level. The dendritic type of drainage system indicates the homogeneity in texture. The drainage density and stream frequency values are an indication of rainfall intensity. Low drainage densities are often associated with widely spaced streams due to the presence of less resistant materials. The low drainage density is also indicative of relatively long overland flow of surface water, high permeability of soil, dense vegetation cover and low relief. The law of lower the order higher the number of streams is implied throughout the catchment. The total length of stream segments is maximum in first order streams and decreases as the stream order increases. The study has shown that the catchment is in conformity with the Horton's law of stream numbers and law of stream lengths.

2.4 GIS Application for Morphometric analysis

Availability of natural resources, i.e., land and water is decreasing day by day, due to growing population pressure. So, planning and management of these natural resources is the need of the hour. Proper scientific planning and management of these resources requires detail information about morphology and other characteristics. Therefore, geomorphological characteristics of a watershed are commonly used for developing the regional hydrological models for solving various hydrological problems of the inadequate data situations. Applications of geographical information system (GIS) techniques are much efficient, time-saving 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 potential and application to prioritize Sub watershed based on morphometric parameters (Amani.M and Safaviyan.A, 2015)**.**

The morphological analysis is a significant tool for understanding the topographic situation and hydrological condition of a catchment area. Morphological 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 known, the watershed can be restored by reducing erosion with the help of watershed management practices (D.S. Deshmukh *et.al*, 2010).

2.5 Watershed Management and Conservation measures

Watersheds in their natural state are subject to continuous processes of change erosion, sedimentation, flooding, and change in water quality. The problem of watershed degradation is that these processes of change are accelerated and their negative impacts become more pronounced. For example, soil erosion is a natural process, but it can be accelerated by overgrazing, deforestation, the expansion of road networks, and inadequate soil and moisture conservation measures on cultivated lands. The more rapid erosion quickly reduces the depth of fertile topsoil, creates gullies in the land, and causes sedimentation of streams.

However; managing the water and other natural resources is an effective and efficient way to sustain the local economy and environmental health. Almost every activity on the land has the potential to affect the quality and quantity of water in our waterways. Watershed management helps to reduce soil erosion, reservoir sedimentation, flood damage, decrease the loss of green space, and improve water quality. Soil Conservation is a combination of the appropriate land use and management practices that promote the productivity and sustainable use of soils and in the process minimizes soil erosion and other form of land degradation. Soil and water conservation practices are the primary step for watershed management. The Conservation practices for management can be divided into two main categories as in-situ and ex-situ management. The in-situ managements are Land and water conservation practices, made within agricultural fields like construction of contour bunds, Stripping, terraces building, and agro forestry or furrow practice and other soil-moisture conservation practices. These practices protect land degradation, improve soil health, and increase soil-moisture availability and groundwater recharge. Moreover, construction of check dam, farm pond, gully control structures, pits excavation across the stream channel is known as ex-situ management. Ex-situ watershed management practices reduce peak discharge in order to reclaim gully formation and harvest substantial amount of runoff, which increases groundwater recharge and irrigation potential in watersheds.

CHAPTER 3

METHODOLOGY

3.1 Description of study Area

The Upper Blue Nile River basin has a total area of 184, 560 km^2. The Ethiopian Plateau has been deeply incised by the Blue Nile River and its tributaries, with a general slope to the northwest direction. The elevation ranges from 500 m at Sudan border to 4230 m at the top of highlands. The Didessa and Dabus tributaries, draining the south-western part of the basin contribute about one third of the total flow (Sutcliffe, J., and Parks, Y., 1999). The basin is characterized by mean maximum and minimum temperatures of 11 °c and 18 °c respectively. The dominant soil types are Alisols and leptosols 21%, followed by Nitosoils 16%, Vertisols 15% and Cambisols 9% (Betrie G.D *et.al*, 2011)

Didessa is a great river that originates from the tropical rainforest mountains of Gomma and Guma area, where Gabba and Gojeb rivers come from, and drains big rivers of the Jimma, Illubabor and Wolega areas. It is one of tributaries of Blue Nile flowing in a northwestern direction to its confluence where the course of the Abay has curved to its southern most point before turning northwards at a geographical coordinates of about 9°57′-0°00′N and 35°41′-37°15′ E latitude and longitude respectively in western part of Ethiopia. The Didessa's drainage area is about 17,085km^2, covering portions of the Benishangul-Gumuz region and the West Wolega zones of the Oromia region. Its tributaries include Doggaja, Malka-hidda, Enareya, Dabana, Alet, Wama, and the Angar rivers; it joins with the Blue Nile downstream of the river. The size of the river Didessa at its mouth is comparable to that of the Baro River, and it constitutes about 13% of the Nile. The historical Oromo name of the river that flows from Wolagga areas to the Sudan is called Mormor, and it is this river that actually forms the core of the Blue Nile (Blundell, 1906; Tesfahunegn.G.B, 2014; Jidda, 2014).

Jema drains parts of the Semien Shewa Zones of the Amhara and Oromia regions of Wanchet and Salale areas and passes close to Fiche town to merge with the Blue Nile. It is one of a river in central Ethiopia that was located in Amara region about 180 km north of Addis Ababa at the central coordinates of 39^o 3′ 6″ East 10^o 11′57″North and a tributary of the Abay (or Blue Nile) on its right side. The Upper Jema flows through steep, deep canyons cut first through volcanic rock and then through the Cretaceous sandstone with Jurassic limestone at the bottom. The bottoms the valleys comprise gently sloping land, and the rivers have created gravel flood-plains of varying width. It has a drainage area of about 14,748km^2 and the altitude at the Jema river-crossing is 1,300 m, and 2,000 m at the top of the gorge. There is an Old Portuguese bridge on this river and this river contributes 5% of the Nile (Blundell, 1906; Tesfahunegn.G.B, 2014; Jidda, 2014).

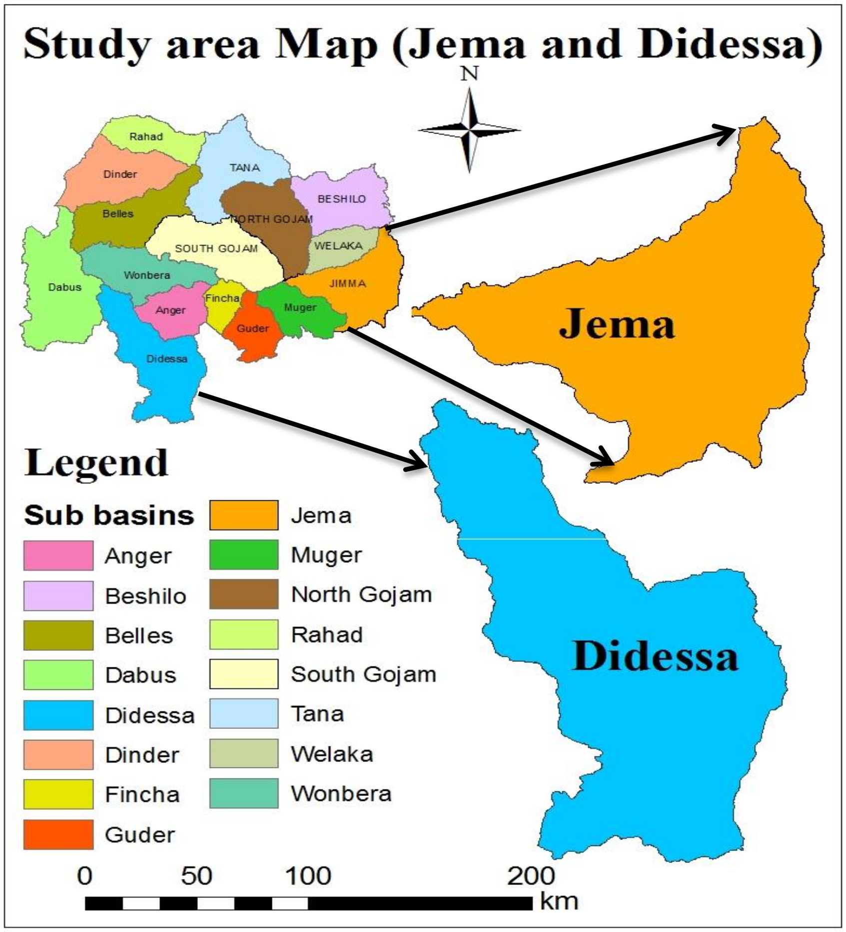

Figure 3. 1: Showing study areas Map of Both Didessa and Jema

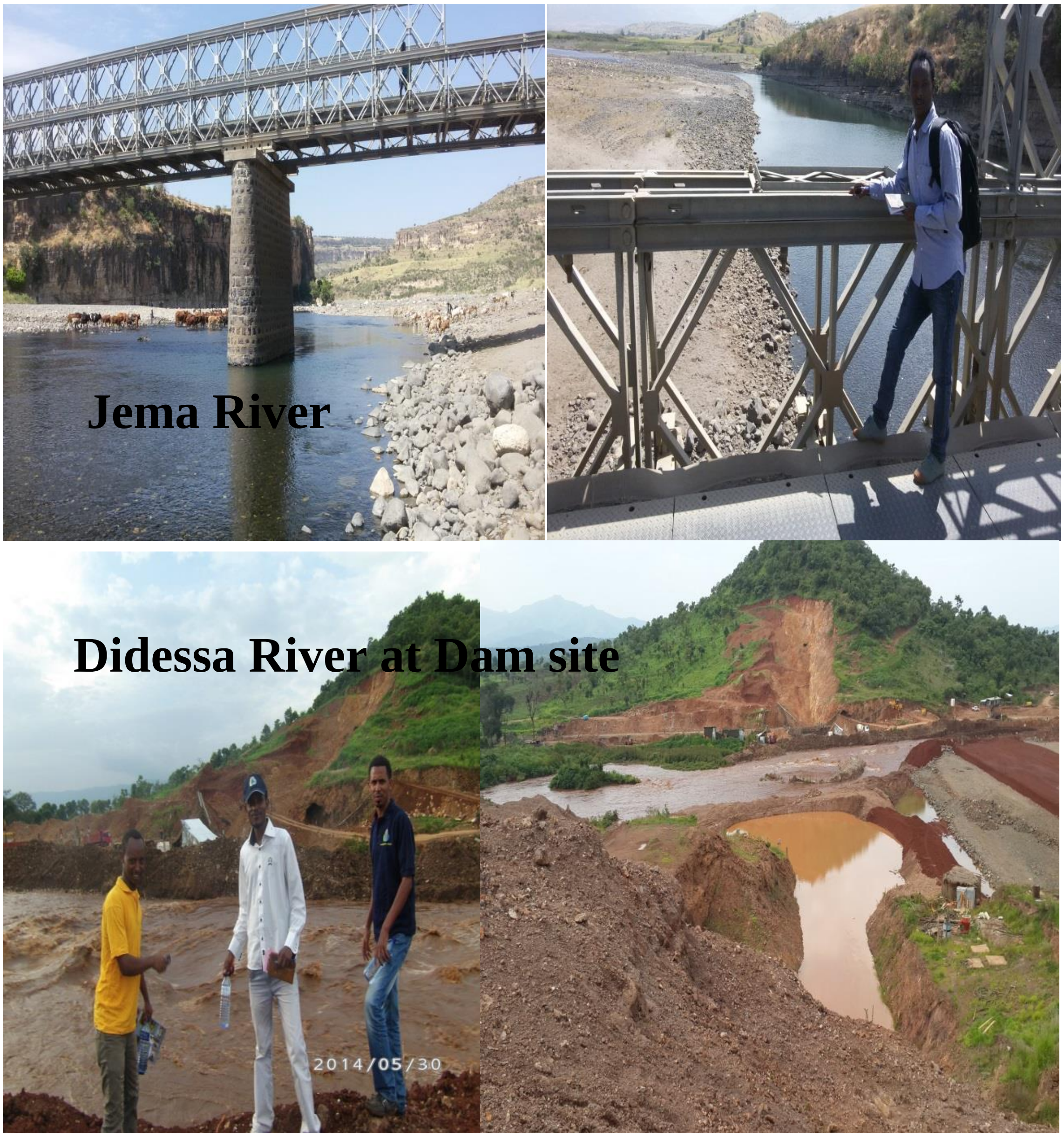

Figure 3. 2: Study Area (Didessa & Jema Sub-basin)

3.2 Data and Software used for Analysis Tool

This thesis work was basically based on morphometric analysis of Didessa and Jema sub- basin to prioritize and locate erosion prone areas of the watershed for conservation plan development. To assess the morphometric conditions, DEM data (30m by 30m resolution) obtained from Ministry of Water, Mineral and Energy were used. 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 SWAT software. Inlet and outlet are defined to demarcate the sub-watershed. Arc GIS Version 9.3 and Arc SWAT software was used for creating, managing and generation of different layer and maps. The Microsoft excel was used for mathematical calculation.

Geographic Information System (GIS) technology has been used as a tool for analysis. GIS has emerged as a powerful tool for handling spatial and non-spatial geo-referenced data for preparation and visualization of input and output, and for interaction with models. There is considerable potential for the use of GIS technology as an aid to the soil erosion inventory with reference to soil erosion modeling and erosion risk assessment. GIS can be used to scale up to regional levels and to quantify the differences in soil loss estimates produced by different scales of soil mapping used as a data layer in the model. The integrated use of remote sensing and GIS could help to assess quantitative soil loss at various scales and also to identify areas that are at potential risk of soil erosion. Spatial modeling involves the use of GIS for representation of the conceptual model and performance of simple mathematical computations on the stored GIS object attributes for displaying the results spatially (Bhaware, 2006).

It is still often used mostly just to make maps and can do much more. Using GIS databases, more up-to-date information can be obtained or information that was unavailable before will be estimated and complex analyses performed. This information can result in a better understanding of a place, can help to make the best choices, or prepare for future events and conditions. This tools can most commonly analyses geographic information easily such as:- Mapping where things are, Mapping the maximum and minimum values, Mapping density, Finding what is inside (intersection analysis), Finding what is nearby (proximity analysis), Mapping change (overlay analysis) and etc.

The main reason for using a GIS is that the erosion process varies spatially, so that cell sizes should be used allowing spatial variation to be taken into account. The Different authors also reported that the amount of data necessary for a great amount of cells is required for an accurate representation of the watershed. Since it is not practicable to input data manually, GIS can be used to gather and access databases (Avanzi.J.C, 2013).

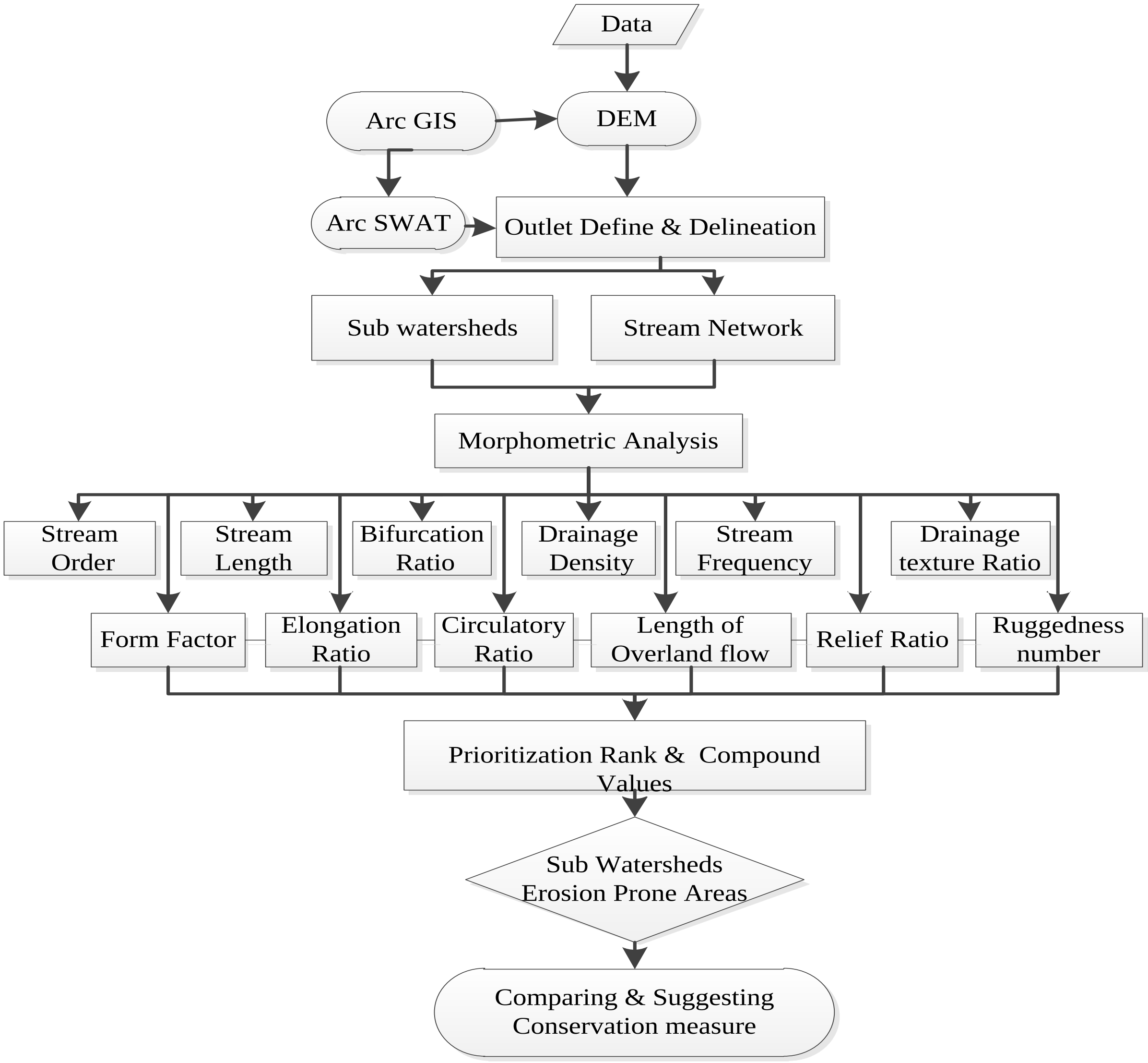

Figure3. 3: Flow Chart showing the work frames

3.3 Hydrologic Modeling for Watershed Characterization using GIS

Hydrologic modeling in GIS environment focuses on hydrology for flow modeling and watershed delineation. This Arc GIS environment was operating with raster data sets of the surface shape to determine the water flow across it. The hydrologic analysis extension in ArcGIS provides a method to describe the physical characteristics of a surface using a Digital Elevation Model (DEM) as input, it is possible to delineate a drainage system and then quantify the characteristics of that system. The tools in the extension let you determine, for any location in a grid, the upslope area contributing to that point and the downslope path of water flow. An understanding of the shape of the Earth's surface is useful for many fields such as regional watershed planning, agriculture and forestry. These fields require an understanding of how water flows across an area, and how changes in that area may affect that flow (Merwade, 2012; Graham.A and Sheehan.D, 2014).

Therefore for hydrological model analysis determining the behavior of where the water comes from and where it is going is important for morphometric characterization through watersheds delineation. Delineation was explained as creating a boundary that represents the contributing area for a particular control point or outlet that was Used to define boundaries of the study area, and/or to divide the study area into sub-areas. Watershed Delineation is part of the process known as watershed segmentation, i.e., dividing the watershed into discrete land and channel segments to analyze watershed behavior. It is required for basin modeling and watershed characterization report (D.Tarboton and M. Piasecki, 2015; B. Parmenter and J.Melcher, 2010). So this thesis was done to characterize and investigate what is going on in one portion of the study area versus another.

3.4 Computation of Morphometric Parameter

Both Didessa and Jema sub-watersheds and the associated Stream networks were delineated. The basic parameter considered as the geometric characteristics (area and perimeter of the basin, length and number of streams) were automatically obtained from GIS software by direct measurements. Those geometric characteristic were used as input for morphometric analysis. To do so, Methods of different researchers and Scholars like Strahler's, Horton's, Miller's, Schumm's and so on were employed to assess the fluvial characteristics of the watersheds (Panhalkar *et.al*, 2012).

In Morphometric analysis, we have to assume in three aspects *i.e.*, linear aspect, aerial aspect and relief aspect. Linear aspect is further divided into stream Order (U), stream length (Lu), stream length ratio (Rl) and bifurcation ratio (Rb). Similarly Aerial aspect divided into drainage density (Dd), Drainage Texture ratio(Dt), stream frequency (Fs), form factor (Rf), circularity ratio (Rc), elongation ratio (Re) and length overland flow (Lof). Relief aspect is also divided into Basin relief (Bh), ruggedness number (Rn) and Relief ratio (Rh). The formula for computation of the morphometric parameters was discussed in detail of the next table 3.1.

Table3. 1 : Methods for Computation of Morphometric Parameters

S. no	**Morphometric Parameter**	**Methods /Formulas**	**References**
		Linear Aspects	
1	Stream Order (U)	Hierarchical rank	(Strahler, 1964)
2	Total Stream Length (Lu)	Lu= L1+ L2+…Ln, Length of the stream of each order	(Horton, 1945)
3	Mean Stream Length(Lsm)	Lsm= Lu/Nu Where, Lsm= Mean stream length, Lu= Total stream length of Order u, Nu= Total number of stream segment of order u	(Strahler, 1964)
4	Bifurcation ratio (Rb)	Rb= Nu/Nu+1 Where, Rb= Bifurcation Ratio, Nu= Total number of stream segment of order u Nu+1= Number of stream segment of next higher order	(Schumm, 1956)
5	Mean Bifurcation ratio (Rbm)	Rbm= average of bifurcation ratio of all orders	(Strahler, 1964)
		Areal Aspects	
1	Basin length (Lb)	L_b= 1.312*$A^{0.568}$ Where,L_b= length of basin (km) A= area of Basin (km^2)	(K.Nookaratnam *et.al*, 2005)
2	Drainage Density (Dd)	Dd= Lu/A Where, Dd= Drainage density Lu= Total stream length of all order, A= Area of the basin.	(Horton, 1945)

3	Stream Frequency (Fs)	Fs= Nu/A Where, Nu= Total number of stream of all order ,A= Area of the basin(km^2)	(Horton, 1945)
4	Drainage texture ratio (Dt)	Dt= Nu/P, Where, Nu= Total number of stream of all order order , P= Perimeter (km)	(Smith, 1950)
5	Form Factor (Rf)	Rf= A/Lb^2 Where, Rf= Form factor A= area of the basin (km^2), L_b^2= Square of the basin length	(Horton, 1945)
6	Circulatory Ratio (Rc)	Rc= $4\pi A/P^2$, Where, Rc= Circularity ratio A= Area of the basin (km^2) P = Perimeter (km)	(Miller, 1953)
7	Elongation Ratio (Re)	Re= $(2/Lb)*(A/\pi)^{0.5}$, Where, Re= Elongation Ratio, Lb= length of basin (km), A= Area of the basin (km^2)	(Schumm, 1956)
9	Constant of channel maintenance (C)	C = $1/D_d$ where C = Constant of channel Maintenance, D_d = Drainage density	(Schumm, 1956)
10	Length of Overland flow (Lof)	Lof = $1/ 2D_d$, where D_d = Drainage density	(Horton, 1945)
Relief Aspects			
1	Basin Relief(Bh)	Bh = Max. - Min. elevation of sub watershed	(Schumm, 1956)
2	Relief ratio (Rh)	Rh= Bh/ Lb	(Schumm, 1956)
3	Ruggedness number (Rn)	Rn= Bh* Dd	(Schumm, 1956)
4	Relative relief (Rr)	Rr = Bh/P	(Schumm, 1956)

3.5 Ranking of sub Watershed based on Morphometric Analysis Result

In Morphometric analysis, each morphometric characteristic is considered as a single parameter and knowledge based priority rank were assigned as per morphometric result by considering its role in soil erosion. For linear aspect, high weightage has been given for high values. The highest value of each of the first four morphometric parameters (i.e., bifurcation ratio, drainage density, stream frequency and Drainage texture ratio) for each sub watersheds was given a rating of 1, the next highest value was given as rating of 2, and so on as the morphometric parameters generally shows positive co-relation with soil erosion.

Conversely, the aerial aspects were assigned low weightage for high values of form factor, circularity ratio elongation ratio, length of overland flow and compactness constant. the lowest value was given a rating of 1, the next lowest value was given a rating of 2, and so on as the areal aspect parameters generally shows negative co-relation with soil erosion (Das, 2014; Panhalkar *et.al*, 2012).

3.6 Determination of Average Ranking and Final Priority

After assigning ranking based on every single parameter, rated values for each watershed were averaged to arrive at a composite value. Based on the average value of these parameters, the sub watershed having the least value of composite rating is assigned the highest priority denoted by 1; the sub watershed with next highest value of composite rating is assigned a priority denoted by number 2, and so on. The sub watershed that got the highest value of composite number is assigned the last priority number. Lastly, the final priority classifications were given into three major classes i.e. High priority, Medium priority and Low priority. The high priority of the sub watersheds indicates most vulnerable areas to soil erosion that needs to give great attention for reclamation process and action plan for soil conservation (Das, 2014).

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Watershed Delineation

Basically there are two Methods of Watershed Delineations named as Manual watershed delineation and Automatic watershed delineation methods.

4.1.1 Manual watershed delineation

Manual watershed Delineation method allows user to define the entire area contributing to flow at an outlet based on knowledge of topography. It requires underlying data of Shape file or grid DEM for accuracy from existing watershed boundaries and stream layers. Watershed delineations were done by drawing watersheds by clicking on the map using mouse.

4.1.2 Automatic watershed delineation

Automatic watershed Delineation methods were also named as DEM Based or grid based approach. The Automatic (DEM based) delineation Creates GIS layers required for setting up model in which Water flows downhill and Boundaries were created automatically by computer. Features of Stream burning option was used to ensure that flow is forced to those cells that correspond to the true locations of stream networks and solves some of the problems with inaccuracies of elevation data. Stream definition determines drainage area required to form the beginning of a streams, size and number of sub watersheds.

Also it is possible to edit manually the outlet of watersheds used to specify desired outlet locations for sub watersheds delineation. The Sub-watersheds were used for watershed analysis and watershed characterization reports. Therefore this thesis was done by Automatic watershed delineation method by using Arc SWAT for both Didessa and Jema sub basins. Furthermore, other hydrological parameters in GIS like Fill operation for Identifying and filling sinks in the DEM, Calculating and creating the flow direction map, Calculating and creating flow accumulation map, creating stream network map from the flow accumulation grid and creating stream order raster from the stream network raster map were obtained using Arc GIS. Though Arc SWAT cannot display the raster map, it uses them as an input.

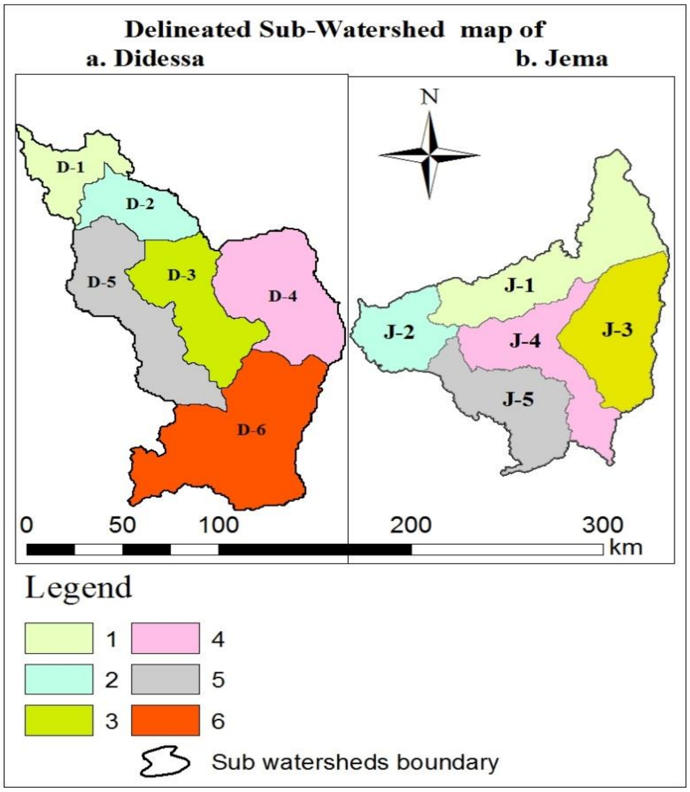

Figure 4. 1: Delineated sub watershed of Didessa and Jema Sub basin

The entire area of Didessa and Jema sub basins were divided into six and five sub-watersheds respectively. These sub-Watersheds were taken up for prioritization based on morphometric analysis. Drainage network is a significant indicator of the process of landform development in a geographical unit. (Horton, R.E, 1932,1945); stated that a drainage basin as an ideal unit for understanding the geo-morphological and hydrological processes and for evaluating the runoff pattern of the streams. Therefore, for the prioritization of each sub watersheds, morphometric analysis of Didessa and Jema were done using the Physical meaning of various morphometric parameters in three aspects (linear aspect, aerial aspect and relief aspect) as indicated in respective descriptions.

4.2 Linear Aspect

4.2.1 Stream order

The initial work of morphometric analysis of drainage basin is started by demonstrating stream orders. A number of parameters have been developed to represent drainage pattern. Stream order by Strahler (1964) method is used to analyze the drainage pattern of the area. Strahler has been followed because of its simplicity, where the smallest, un-branched fingertip streams are designated as 1st order, the confluence of two 1st order channels give a channels segments of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. 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 paper, the whole drainage in both watersheds was disseminated in five orders.

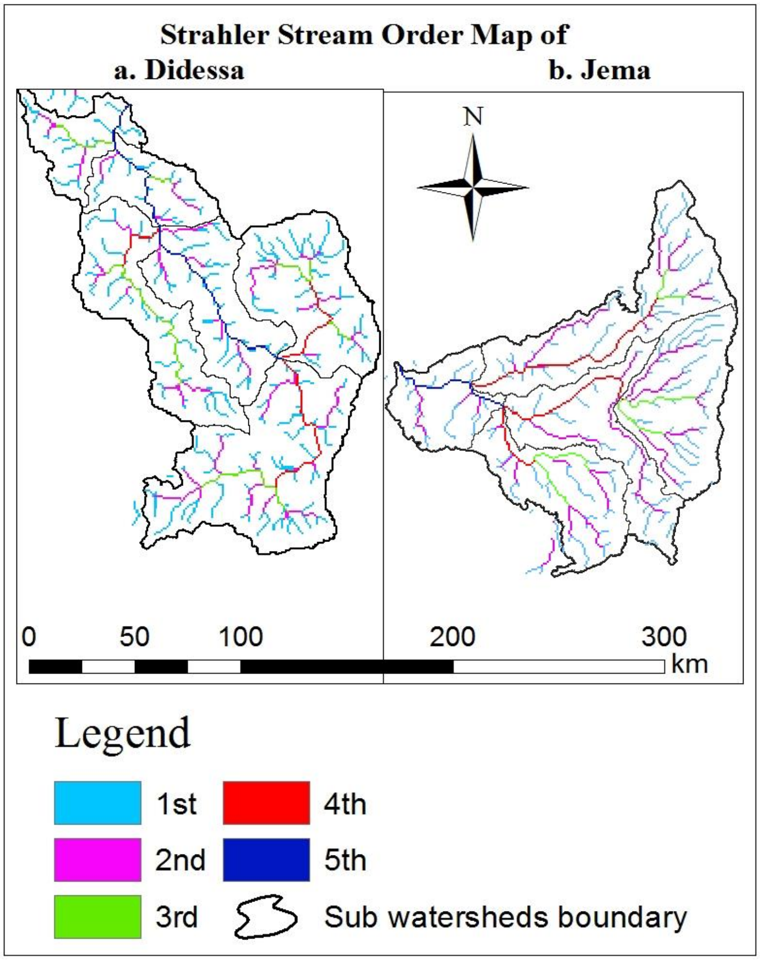

Figure 4. 2: Strahler Stream order map for both Didessa and Jema sub basin

In all 534 streams were identified for Didessa watershed, of which 276 are 1st order,125 are 2nd order, 48 are 3rd order, 42 are 4th order and 43 are 5th order. Whereas 319 streams were identified for Jema watershed, of which 156 are 1st order, 84 are 2nd order, 21 are 3rd order, 44 are 4th order and 14 are 5th order. The calculated result matched with Strahler, which described that the total number of streams gradually decreases as the stream order increases.

4.2.2 Stream number

Stream number is the number of stream segments of various orders in watersheds. Each segment of the stream was numbered starting from the first order to the maximum order present in each of the sub-basins. After numbering, the drainage-network elements are assigned their order numbers, the segments of each order are counted to yield the number Nu of segments of the given order U (Horton, 1945). The total stream number of all order for each sub watershed of Didessa and Jema were expressed in Table 4.1. The maximum and minimum number of stream number were 178 (D-6), 100(J-1) and 33(D-1), 48(J-4) respectively for both Didessa and Jema sub watersheds. 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.

Table 4. 1: Stream number of both Didessa and Jema sub basin

Sub basin		**Stream Number (Nu) of all order**					**Total**
		1st	**2nd**	**3rd**	**4th**	**5th**	
Didessa Sub watersheds	D-1	15	7	7	-	4	**33**
	D-2	23	7	2	-	12	**44**
	D-3	55	20	1	-	24	**100**
	D-4	53	23	7	9	1	**93**
	D-5	40	18	18	9	1	**86**
	D-6	90	50	13	24	1	**178**
Jema Sub watersheds	J-1	46	23	5	26	-	**100**
	J-2	29	10	-	-	14	**53**
	J-3	30	19	11	1	-	**61**
	J-4	22	15	-	11	-	**48**
	J-5	29	17	5	6	-	**57**

4.2.3 Total Stream length and Mean stream length

Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. It is an indicator of the area contribution to the watershed, steepness of the drainage watershed as well as the degree of drainage. The numbers of streams of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. Total stream length is the sum of all lengths of all the stream order. Total stream length divided by the number of stream segments of that order gives the mean steam length for that order Strahler, (1964).

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 Didessa and Jema sub watershed were presented in Table 4.2 and 4.3 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. 2: Total stream length of both Didessa and Jema Sub basin

Sub basin		**Stream Length(Lu) of all order (km)**					**Total(km)**
		1st	**2nd**	**3rd**	**4th**	**5th**	
Didessa Sub watersheds	D-1	99.00	34.74	34.10	-	20.70	188.54
	D-2	73.96	49.76	13.45	-	56.93	194.1
	D-3	173.13	96.45	0.92	-	93.08	363.58
	D-4	254.88	95.16	45.18	57.13	4.06	456.41
	D-5	201.38	66.28	90.05	31.72	5.91	395.34
	D-6	361.30	197.22	57.79	88.87	4.06	709.24
Total		**1163.65**	**539.61**	**241.49**	**177.72**	**184.74**	**2307.21**
Jema Sub watersheds	J-1	234.41	145.93	31.97	120.66	-	532.97
	J-2	129.26	37.82	-	-	65.60	232.68
	J-3	251.80	146.15	97.72	2.21	-	497.88
	J-4	117.81	137.67	-	79.19	-	334.67
	J-5	148.68	110.45	68.82	40.56	-	368.51
Total		**881.96**	**578.02**	**198.51**	**242.62**	**65.60**	**1966.71**

The table reveals that, generally, the total length of stream segments is maximum in 1st order stream and decreases as stream order increases.

The sum of mean stream lengths of first, second, third, fourth and fifth order streams (Table 4.3) also indicates that, the second order streams are longer than the higher order streams for both Didessa and Jema watershed. 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. 3: Mean Stream Length of both Didessa and Jema sub basin

Sub basin		**Mean Stream Length of all order (km)**				
		1st	**2nd**	**3rd**	**4th**	**5th**
Didessa Sub watersheds	D-1	6.60	4.96	4.87	-	5.18
	D-2	3.22	7.11	6.73	-	4.74
	D-3	3.15	4.82	0.92	-	3.88
	D-4	4.81	4.14	6.45	6.35	4.06
	D-5	5.03	3.68	5.00	3.52	5.91
	D-6	4.01	3.94	4.45	3.70	4.06
Total		**26.81**	**28.65**	**28.42**	**13.57**	**27.83**
Jema Sub watersheds	J-1	5.10	6.34	6.39	4.64	-
	J-2	4.46	3.78	-	-	4.69
	J-3	8.39	7.69	8.88	2.21	-
	J-4	5.35	9.18	-	7.20	-
	J-5	5.13	6.50	13.76	6.76	-
Total		**28.43**	**33.49**	**29.03**	**20.81**	**4.69**

4.2.4 Stream Length Ratio

The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and has an important relationship with surface flow and discharge (Horton, 1945). The Stream length ratio varies at the basin and sub-watershed levels. The values of the mean R_L vary from 0.19 (D-3) to 2.21 (D-2) for Didessa sub-watersheds and from 0.25 (J-3) to 2.12(J-5). These variations of RL values between streams of different order in the basin reveal that there are variations in slope and topography.

4.2.5 Bifurcation Ratio

Bifurcation ratio is related to the branching pattern of a drainage network and may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order Schumm, (1956). It is also defined as the universal value for maturely dissected drainage basins Rao and Babu, (1995). According to Strahler, (1957); 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 Didessa sub basin varies from 1.57 to 11.38 and it was from 1.47 to 4.77 for Jema sub basin.

Table 4. 4: Bifurcation Ratio of both Didessa and Jema sub basin

Sub basin		**Bifurcation Ratio(Rb)**					**Mean Rb**
		1st	**2nd**	**3rd**	**4th**	**5th**	
Didessa Sub watersheds	D-1	2.14	1.00	-	-	-	**1.57**
	D-2	3.29	3.50	-	-	-	**3.39**
	D-3	2.75	20.00	-	-	-	**11.38**
	D-4	2.30	3.29	0.78	9.00	-	**3.84**
	D-5	2.22	1.00	2.00	9.00	-	**3.56**
	D-6	1.80	3.85	0.54	24.00	-	**7.55**
Jema Sub watersheds	J-1	2.00	4.60	0.19	-	-	**2.26**
	J-2	4.46	3.78	-	-	4.69	**2.90**
	J-3	1.58	1.73	11.00	-	-	**4.77**
	J-4	1.47	-	-	-	-	**1.47**
	J-5	1.71	3.40	0.83	-	-	**1.98**

The analysis result showed that the mean Bifurcation ratio of both Didessa and Jema 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 Rb, whereas a circular basin is likely to have a low Rb.

4.3 Aerial Aspects

Various hydrologic phenomena such as size, shape, slope of drainage area, drainage density, size and length of the contributories can be correlated with the physiographic characteristics of the watershed. Areal aspects of a watershed of given order is defined as the total area projected upon a horizontal plane, contributing overland flow to the channel segment of the given order including all tributaries of lower order. The watershed shape has a significant effect on stream discharge characteristics. For example; an elongated watershed having a high bifurcation ratio can be expected to have alternated flood discharge. But on the other hand, a round or circular watershed with a low bifurcation ratio may have a sharp flood discharge. The shape of a watershed has a profound influence on the runoff and sediment transport process. The shape of the drainage watershed also governs the rate at which water enters the stream (Rama, 2014). For analysis of areal aspects, knowing the geometric parameter of basins like Area of a basin, Basin perimeter and basin length were the important parameters in quantitative geomorphology (K.Nookaratnam *et.al*, 2005; D.S. Deshmukh *et.al*, 2010).

Basin Area: The area of the basin is defined as the total area projected upon a horizontal plane. It is probably the single most important basin parameter for hydrologic design. It reflects volume of water that can be generated from the rainfall. Thus drainage area is required as an input to models ranging from simple linear prediction equations to complex computer models. It is expressed in km^2.

Basin perimeter: Basin perimeter is the length of the basin boundary. It is expressed in km.

Maximum length of basin: Maximum length of watershed is the distance between basin outlet and farthest point in the basin. The basin length determines the shape of the basin. High basin length indicates elongated basin. It is expressed in ‘km’.

Table 4.5 Basic Parameter for analysis of areal aspect for Didessa and Jema sub watershed

Sub Basin		**Area (A)km^2 (From Arc SWAT)**	**perimeter (P)km (From Arc SWAT)**	**Basin length(Lb)km, Lb =1.312*$A^{0.568}$**
Didessa Sub watersheds	D-1	1389.24	317.10	79.99
	D-2	1439.66	258.72	81.63
	D-3	2718.43	375.42	117.12
	D-4	3266.04	353.46	129.99
	D-5	3171.28	476.04	127.83
	D-6	5099.43	530.34	167.42
Jema Sub watersheds	J-1	4037.69	659.46	146.63
	J-2	1737	309.90	90.81
	J-3	3254.88	398.76	129.73
	J-4	2967.74	618.78	123.10
	J-5	2749.46	513.48	117.88

Therefore; Areal Aspect deals with the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes all tributaries of lower order. Their quantitative expressions for each sub watershed were characterized by drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow. The detail calculation results were expressed as below for both Didessa and Jema sub watershed.

4.3.1 Drainage Density

Drainage density is one of the other elements of drainage analysis which provides a better quantitative expression to the dissection and analysis of land forms, although a function of climate, lithology, structures and relief history of the region and can ultimately be used as an indirect indicator to explain those variables, as well as the morphogenesis of landform. Drainage density is defined as the total length of streams of all orders to total drainage area. The drainage density, which is expressed as km/km^2, indicates the closeness of spacing of channels, thus provides quantitative measure of the average length of the overland flow. Low drainage density generally results in the areas of highly resistant or permeable sub-soil material, dense vegetation and low relief. High drainage density is the result of weak or impermeable sub-surface material, sparse vegetation and mountainous relief. Low density leads to coarse drainage texture while high drainage density leads to fine drainage texture. The low value of drainage density influences greater infiltration. In the areas of higher drainage density the infiltration is less and surface runoff is more. The drainage density can also indirectly indicate groundwater potential of an area, due to its surface runoff and permeability Rama, (2014); Nag and Chakraborty, (2003). Drainage densities of Didessa sub-watersheds were varied from 0.125 to 0.139 and that of Jema sub-watersheds were from 0.113 to 0.153.

Table 4. 5: Drainage densities of Didessa and Jema sub-watersheds

Sub basin	**Drainage density; $Dd = \sum Lu/A$**					
Didessa	**D-1**	**D-2**	**D-3**	**D-4**	**D-5**	**D-6**
	0.136	0.135	0.134	0.140	0.125	0.139
Jema	**J-1**	**J-2**	**J-3**	**J-4**	**J-5**	
	0.142	0.134	0.153	0.113	0.134	

The reclassified drainage density map of both sub basins also indicates that, the sub watersheds D-4, D-6 and J-3 shows high drainage density may be due to the presence of impermeable sub surface material, sparse vegetation and high relief. The sub watersheds D-5 and J-4 fall under Low Drainage density that indicates the region has highly permeable subsoil and dense vegetation cover. Whereas the remaining sub watersheds fall under medium drainage density indicate that presence of moderate permeability of sub surface material. But, individually the, the higher value of Dd (0.153) of Jema sub-watershed indicates that Jema sub-watershed has less impermeable subsurface material, sparse vegetation, mountainous relief and coarser drainage texture compared to that of Didessa sub-watershed.

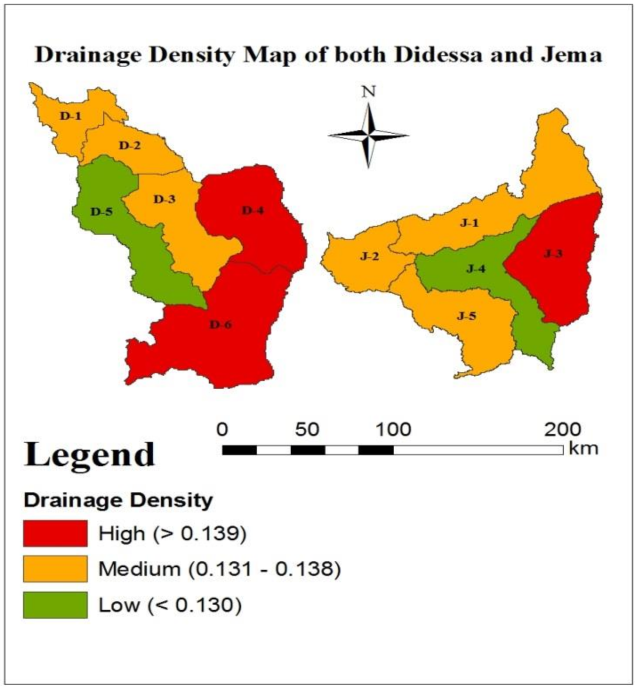

Figure 4. 3: Reclassified Drainage Density Map for Didessa and Jema sub watersheds

4.3.2 Stream frequency/Drainage frequency

Stream frequency or channel frequency is a number of stream segments per unit area. The stream frequency mainly depends on the lithology of the basin and reflects the texture of the drainage network. The stream frequency values of the of the study area were varying from 0.024 to 0.037 for Didessa sub watershed and it also varying from 0.016 to 0.031 for Jema sub watershed.

Table 4. 6: Stream Frequency of Didessa and Jema sub-watersheds

Sub basin	**Stream frequency; $Fs = \sum Nu/A$**					
Didessa	**D-1**	**D-2**	**D-3**	**D-4**	**D-5**	**D-6**
	0.024	0.031	0.037	0.028	0.035	0.027
Jema	**J-1**	**J-2**	**J-3**	**J-4**	**J-5**	
	0.025	0.031	0.019	0.016	0.021	

From the reclassified Stream frequency map, High value of stream frequency is related to impermeable sub-surface material, sparse vegetation, high relief conditions and low infiltration capacity (P.Dahiphale *et.al*, 2014). Stream frequency map of both sub basins indicates that, the sub watersheds D-3 shows high drainage density that has impermeable sub surface material and low infiltration. Larger areas of the sub watersheds fall under Low Stream frequency that indicates the region has highly permeable subsoil and dense vegetation cover. Whereas the remaining sub watersheds fall under medium stream frequency indicate that presence of moderate permeability of sub surface material.

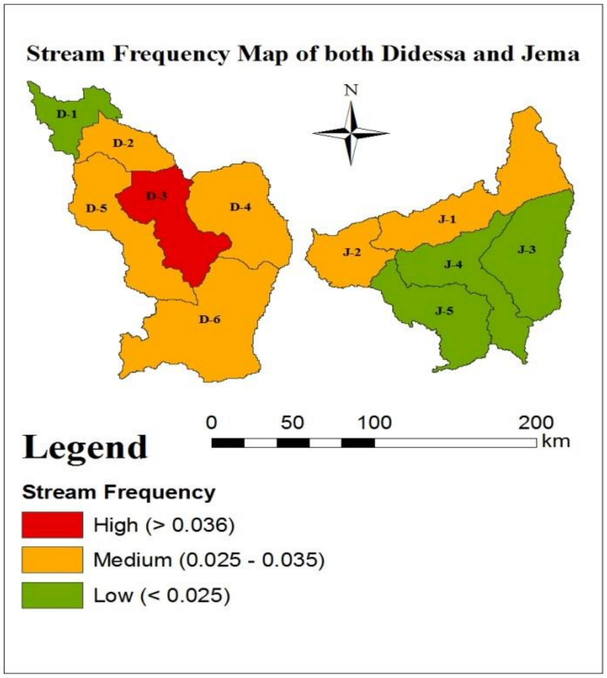

Figure 4. 4:- Stream Frequency Map of both Didessa and Jema Sub watersheds

The drainage Density and Stream frequency were the most useful criterion for the morphometric classification of drainage basins that certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin. The value of stream frequency indicate that the watershed show positive correlation with increasing stream population with respect to increasing drainage density.

4.3.3 Drainage Texture ratio

Drainage Texture ratio is an important factor in drainage morphometric analysis and is dependent on the underlying lithology, infiltration capacity of the material below the earth’s surface and relief aspects of the terrain. It is expressed as the ratio between total streams number and perimeter of the basin (Smith, 1950). Drainage texture ratio of study area was varying from 0.104 to 0.336 for Didessa and from 0.078 to 0.171for Jema sub watershed. The high texture ratio of indicates high runoff and low infiltration capacity.

Table 4. 7: Drainage Texture ratio of Didessa and Jema sub-watersheds

Sub basin	**Drainage Texture ratio; $Dt = \sum Nu/P$**					
Didessa	**D-1**	**D-2**	**D-3**	**D-4**	**D-5**	**D-6**
	0.104	0.170	0.266	0.263	0.181	0.336
Jema	**J-1**	**J-2**	**J-3**	**J-4**	**J-5**	
	0.152	0.171	0.153	0.078	0.111	

4.3.4 Form Factor

Form factor is defined as the ratio of the basin area to the square of the basin length. It is dimensionless property and is use as a quantitative expression of the shape of basin form. The form factor value should be always less than 0.7854 (the value corresponding to a perfectly circular basin). This factor indicates the flow intensity of a basin of a defined area. Smaller the value of the form factor, more elongated will be the watershed. The basins with high form factors have high peak flows of shorter duration, whereas elongated sub watersheds with low form factors have lower peak flow of longer duration indicating elongated shape and suggesting flat hydrograph peak for longer duration. Flood flows of such elongated basins are easier to manage than those of the circular basin. The high Form Factor (Rf) indicates that they have developed into quite circular to rectangular shape (Altaf *et.al*, 2013). Form Factor (Rf) values of whole sub basin and sub-watershed of the Didessa and Jema vary from 0.182 to 0.217 and 0.188 to 0.211 respectively. Which indicate low form factor for both basin, that they were sub-circular and elongated in shape.

Table 4. 8: Form factor of Didessa and Jema sub-watersheds

Sub basin	Form factor; $Rf = A/Lb^2$					
Didessa	**D-1**	**D-2**	**D-3**	**D-4**	**D-5**	**D-6**
	0.217	0.216	0.198	0.193	0.194	0.182
Jema	**J-1**	**J-2**	**J-3**	**J-4**	**J-5**	
	0.188	0.211	0.193	0.196	0.198	

Although the values were varied from one place of sub watersheds to another, they can't have equal flow intensity. Therefore they can be reclassified and mapped as below to indicate rate of soil erosion. Thus its low value indicates high soil erosion.

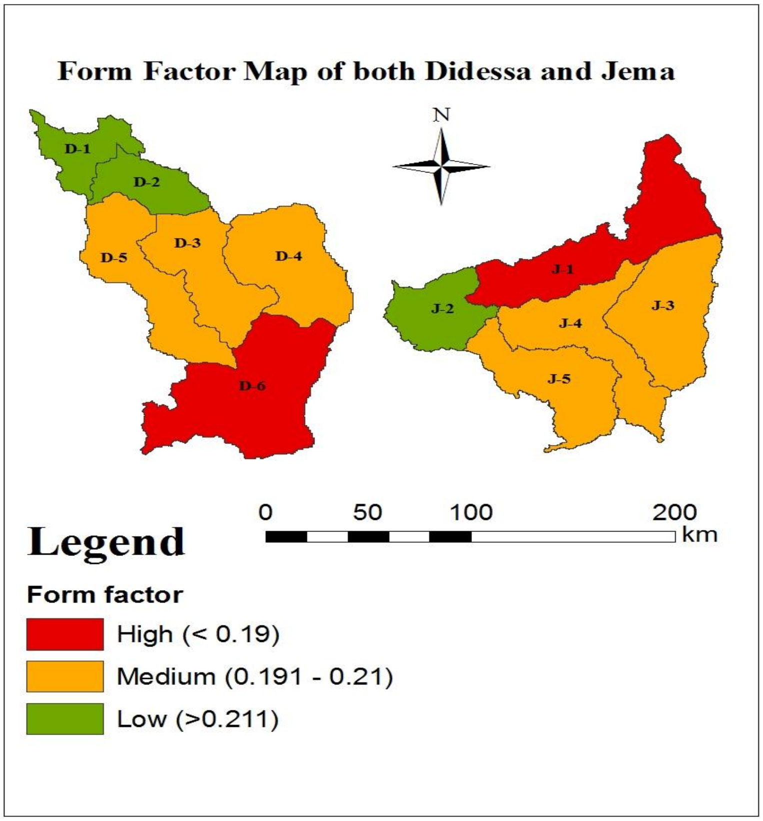

Figure 4. 5: Form factor Map of both Didessa and Jema Sub watersheds

4.3.5 Circulatory ratio

Circularity Ratio is the ratio of the area of the basin to the area of a circle having the same circumferences as the perimeter of the basin (Miller, 1953).The value of circularity ratio vary from 0(in a line) to 1.0(for circular shape). Higher the value of the Circularity Ratio (Rc), the more circular shape of the basin and vice-versa. The value of R_C is influenced by length and frequency of streams, geological structure, land use/land cover, climate, relief and slope of the basin. Its values approaching one indicates that the basin shapes are like circular and as a result, it gets scope for uniform infiltration and takes long time to reach excess water at basin outlet. Greater the value more is the circularity ratio. It is the significant ratio which indicates the stage of dissection in the study region. Its low, medium and high values are correlated with youth, mature and old stage of the life cycle of the tributary of the watershed of the region. Miller (1953) described that the Rc value of 0.4 and below indicates basin is elongated and values greater than 0.75 indicate circular basin. Rc values in 0.4-0.75 indicate intermediate shape of basin. Therefore, the Rc values of the study areas varying from 0.174 to 0.329 in case of Didessa sub watershed and it also varying from 0.117 to 0.257 in case of Jema sub watershed. These values indicate that low circulatory ratio for both the sub basins and they were elongated in shape.

Table 4. 9: Circulatory ratio of Didessa and Jema sub-watersheds

Sub basin	**Circulatory ratio;** $\boldsymbol{Rc = 4\pi * A/P^{\wedge}2}$					
Didessa	**D-1**	**D-2**	**D-3**	**D-4**	**D-5**	**D-6**
	0.174	0.270	0.242	0.329	0.176	0.228
Jema	**J-1**	**J-2**	**J-3**	**J-4**	**J-5**	
	0.117	0.227	0.257	0.097	0.131	

Although the values were varied from one place of sub watersheds to another, they can't have equal stage of dissection. Therefore they can be reclassified and mapped as below to indicate low, medium and high values correlated with youth, mature and old stage of the life cycle of the tributary of the watershed of the study region. Similarly; its low value indicates high soil erosion.

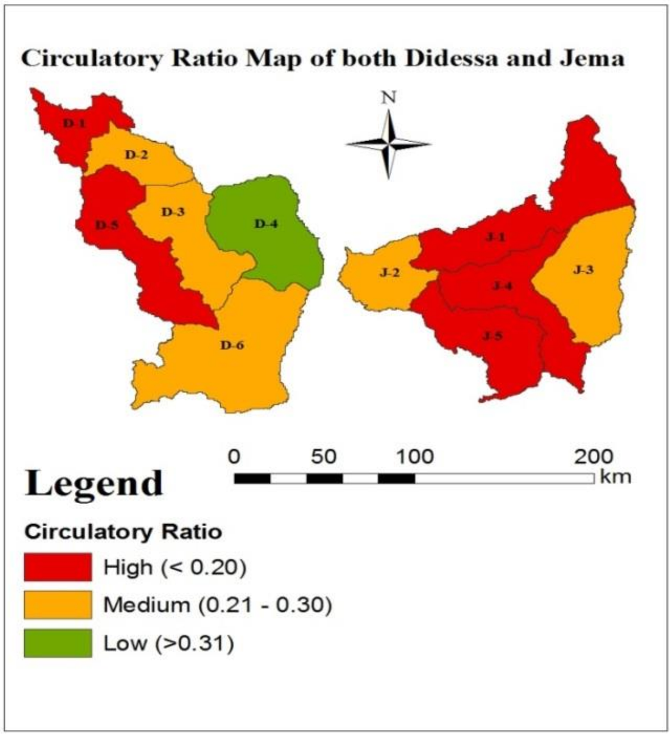

Figure 4. 6: Circulatory Ratio Maps of Didessa and Jema Sub watersheds

4.3.6 Elongation Ratio

Elongation ratio is the ratio between the diameters of a circle with the same area of that of the basin to the maximum length of the basin. The value of Re varies from 0(in highly elongated shape) to unity i.e. 1.0(in the circular shape) over a wide variety of climatic and geological environments. Thus higher value of the elongation ratio more circular shape of the basin and vice-versa. The circular basin is more efficient in run-off discharge than an elongated basin (Singh, S and Singh, M.C, 1997). If the Re value is close to 1.0 are typical regions of very low relief and gentle slope. These Re values can be grouped into three categories, namely, circular (> 0.9), oval (0.9 - 0.7) and less elongated (<0.7). Narendra and Rao, (2006) suggested that, If the value is very low, it indicates high relief and steep slope.

Table 4. 10: Elongation ratio of Didessa and Jema sub-watersheds

Sub basin	**Elongation ratio; Re $= \frac{2}{Lb} * \left(\frac{A}{\pi}\right)^{0.5}$**					
Didessa	**D-1**	**D-2**	**D-3**	**D-4**	**D-5**	**D-6**
	0.526	0.525	0.496	0.502	0.497	0.481
Jema	**J-1**	**J-2**	**J-3**	**J-4**	**J-5**	
	0.489	0.518	0.496	0.499	0.502	

From the analysis result, it was found that, both Didessa and Jema sub-watershed have low Re less than 0.7, which indicates that sub watersheds were elongated with high relief and steep slope. The run off discharge from the elongated basin shape were less efficient than circular shape. That means elongated basin shape contributes high soil erosion.

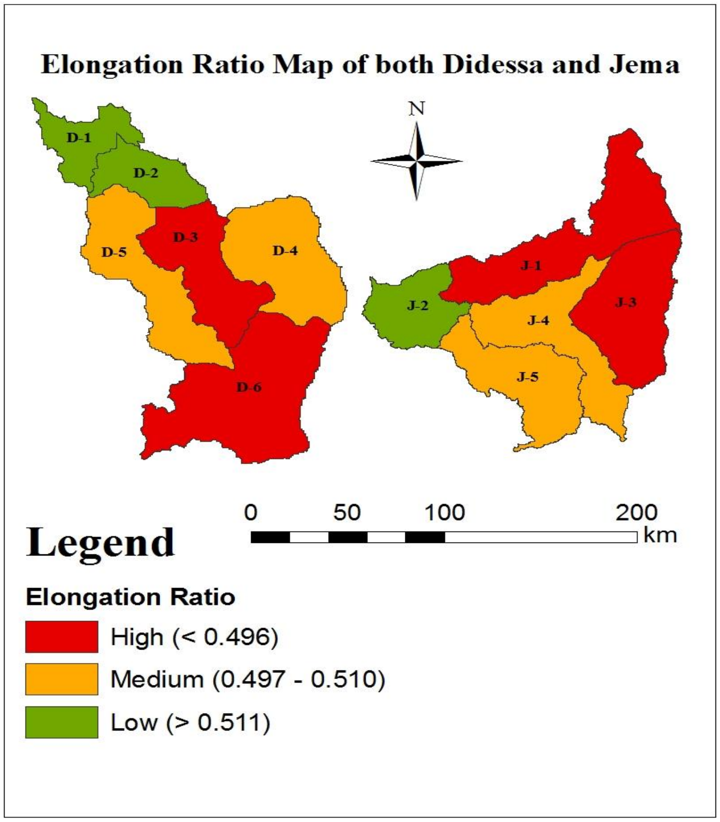

Figure 4. 7: Elongation Ratio map for both Didessa and Jema Sub watersheds

4.3.7 Length of overland flow

The Length of Overland Flow is the length of water over the ground surface before it gets concentrated into definite stream channel. Horton's used this term to refer to the length of the runoff the rainwater on the ground surface before it is localized into definite channels. Since this length of overland flow, at an average, is about half the distance between the stream channels, Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density. The length of overland flow is a measure of erodibility and it is also one of the most important independent variables affecting hydrologic and physiographic development of watershed drainage. This factor is related inversely to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree. The shorter the length of overland flow, the quicker the surface runoff from the streams Kumar *et.al,* (2011).

Table 4. 11: Length of Overland Flow of Didessa and Jema sub-watersheds

Sub basin	**Length of Overland Flow; $\mathrm{Lof} = 1/2\mathrm{Dd}$**					
Didessa	**D-1**	**D-2**	**D-3**	**D-4**	**D-5**	**D-6**
	3.684	3.710	3.738	3.578	4.011	3.595
Jema	**J-1**	**J-2**	**J-3**	**J-4**	**J-5**	
	3.524	3.733	3.269	4.434	3.731	

Higher the values of Length of overland flow, lower will be the relief and lower the values higher will be the relief with steep ground slopes, reflecting the areas associated with more run-offs and less infiltration. The value of length of overland flow for Didessa sub watershed varying from 3.578 to 4.011 and also varying from 3.269 to 4.434 for Jema sub watershed. These results indicate that relatively quicker surface runoff was occurred from Jema sub watershed compared with Didessa sub watershed.

Moreover the reclassified Length of over land flow map also shows that sub watersheds having low value of Lof (<3.6) contributes high soil erosion because of quicker surface run-off and less infiltration occurrence from stream. This indicates the regions have high relief and steep slope. Whereas Lof >4.01 are considered as areas contributing low soil erosion.

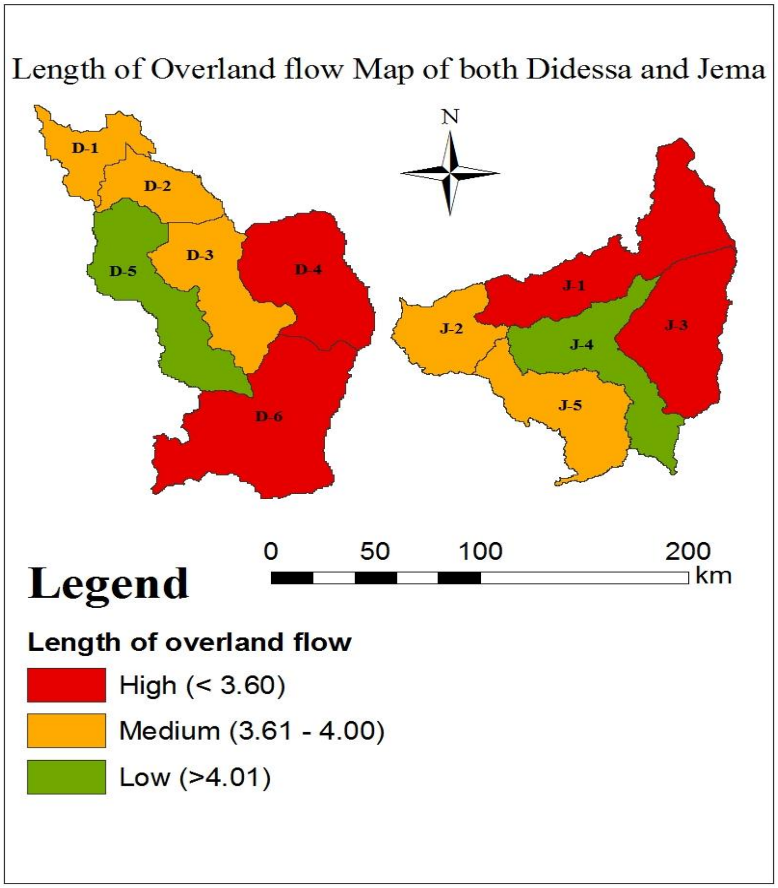

Figure 4. 8: Length of overland flow Map of Didessa and Jema Sub watersheds

4.3.8 Constant channel maintenance

Constant channel maintenance is defined as the area of the basin surface needed to sustain a unit length of a stream channel and is expressed by inverse of drainage density that means, constant of channel maintenance is the reciprocal of the 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 constant indicates the number of km^2 of basin surface required to develop and sustain a channel 1km long. The constant of channel maintenance indicates the relative size of landform units in a drainage basin Strahler, (1957). For Didessa and Jema sub watersheds the C value varying from of 7.156 to 8.021 and 6.537 to 8.868 respectively.

Table 4. 12: Constant channel maintenance of Didessa and Jema sub-watersheds

Sub basin	**Constant channel maintenance;** $\mathbf{C} = \frac{\mathbf{1}}{\mathbf{Dd}}$					
Didessa	**D-1**	**D-2**	**D-3**	**D-4**	**D-5**	**D-6**
	7.368	7.421	7.477	7.156	8.021	7.190
Jema	**J-1**	**J-2**	**J-3**	**J-4**	**J-5**	
	7.047	7.465	6.537	8.868	7.461	

The reclassified map also indicates that, the lower value of C of both Didessa and Jema sub 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.

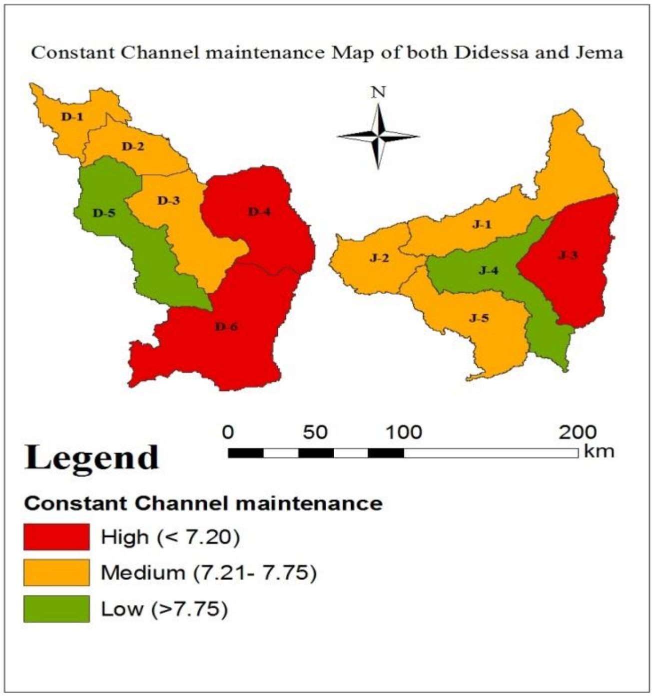

Figure 4. 9: Constant channel maintenance Map of Didessa and Jema sub watersheds

4.4 Relief Aspect

Relief aspects of drainage basin relate to the three dimensional features of the basin involving area, volume and altitude of vertical dimension of landforms wherein different morphometric methods are used to analyses terrain characteristics. The relief aspects include Basin relief (Bh), relief ratio (Rh), ruggedness number and relative relief. Description and analysis results of the terms were given below (Schumm, 1956; D.S. Deshmukh *et.al*, 2010).

4.4.1 Basin Relief

Basin relief (Bh) is the maximum vertical distance between the lowest and highest elevation in a basin. This is an important factor in understanding the denudational characteristics of a basin. It is also known as total relief and expressed in 'km'. The maximum and minimum height of Didessa watershed is 2946 m and 875 m respectively, whereas in Jema watershed, it varies from 3803m and 1086m respectively. Therefore, the basin reliefs of both Didessa and Jema watersheds were 2.07km and 2.72km respectively. The higher value of Basin relief of Jema watershed shows that it has lower infiltration and higher runoff than Didessa watershed.

Table 4. 13: Relief Aspect Analysis Result for Didessa Sub watershed

Sub watersheds	**P(km)**	**Lb (km)**	**Dd**	**Elevation(m)**		**Relief aspects**			
				Max	**Min**	**Bh(km) = Max-Min**	$Rh = \frac{Bh}{Lb}$	$Rr = Bh/P$	$Rn = Bh * Dd$
D-1	317.10	79.99	0.136	2151	875	1.276	0.016	0.0040	0.17
D-2	258.72	81.63	0.135	2130	922	1.208	0.015	0.0047	0.16
D-3	375.42	117.12	0.134	2549	1179	1.37	0.012	0.0036	0.18
D-4	353.46	129.99	0.140	2946	1322	1.624	0.012	0.0046	0.23
D-5	476.04	127.83	0.125	2398	1165	1.233	0.010	0.0026	0.15
D-6	530.34	167.42	0.139	2889	1322	1.567	0.009	0.0030	0.22

Table 4.14: Relief Aspect Analysis Result for Jema Sub watershed

Sub watershed	**P (km)**	**Lb (km)**	**Dd**	**Elevation(m)**		**Relief aspects**			
				Max	**Min**	**Bh(km) = Max-Min**	$Rh = \frac{Bh}{Lb}$	$Rr = \frac{Bh}{P}$	$Rn = Bh * Dd$
J-1	659.5	146.63	0.132	3803	1158	2.645	0.0180	0.0040	0.349
J-2	309.9	90.81	0.134	3467	1086	2.381	0.0262	0.0077	0.319
J-3	398.8	129.73	0.153	3686	1558	2.128	0.0164	0.0053	0.326
J-4	618.8	123.10	0.113	3550	1222	2.328	0.0189	0.0038	0.263
J-5	513.5	117.88	0.134	3287	1222	2.065	0.0175	0.0040	0.277

4.4.2 Relief ratio

Relief ratio is the total relief of the basin divided by the maximum length of the watershed. It measures the overall steepness of a drainage basin 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. Rh normally increases with decreasing drainage area and size of a given drainage basin. 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 4.13 and 4.14 above), the relief ratio of Didessa Sub watershed were varying from 0.009 to 0.016 and from 0.016 to 0.0262 for Jema sub watershed. Higher Rh value (0.0262) indicates more hilly regions in Jema sub-watershed which results in lower infiltration and greater discharge compared to that of Didessa sub-watershed. On the other hand, knowing this value helps for Rain water harvesting and watershed management plan.

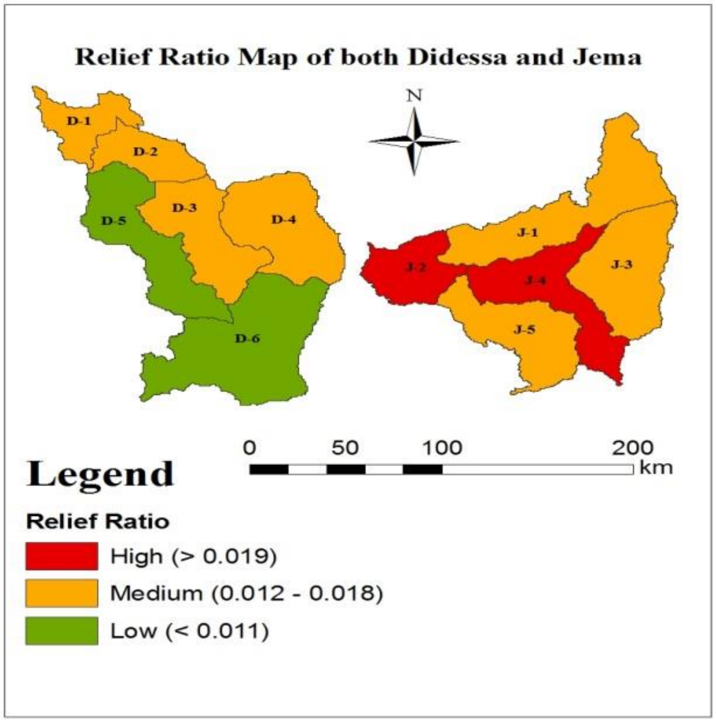

Figure 4. 10: Relief Ratio Map of both Didessa and Jema Sub watersheds

4.4.3 Ruggedness number

Ruggedness number is defined as the product of the maximum basin relief and its drainage density. It provides an idea of overall roughness of a 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 present study, the ruggedness number is minimum in case of Didessa (from 0.015 to 0.22) and maximum in Jema sub watershed (from 0.277 to 0.349) as seen in Table 4.13 and 4.14 above. This indicates that Didessa sub watersheds were least susceptible to erosion and Jema sub watersheds were most susceptible among all the sub watersheds of the study area.

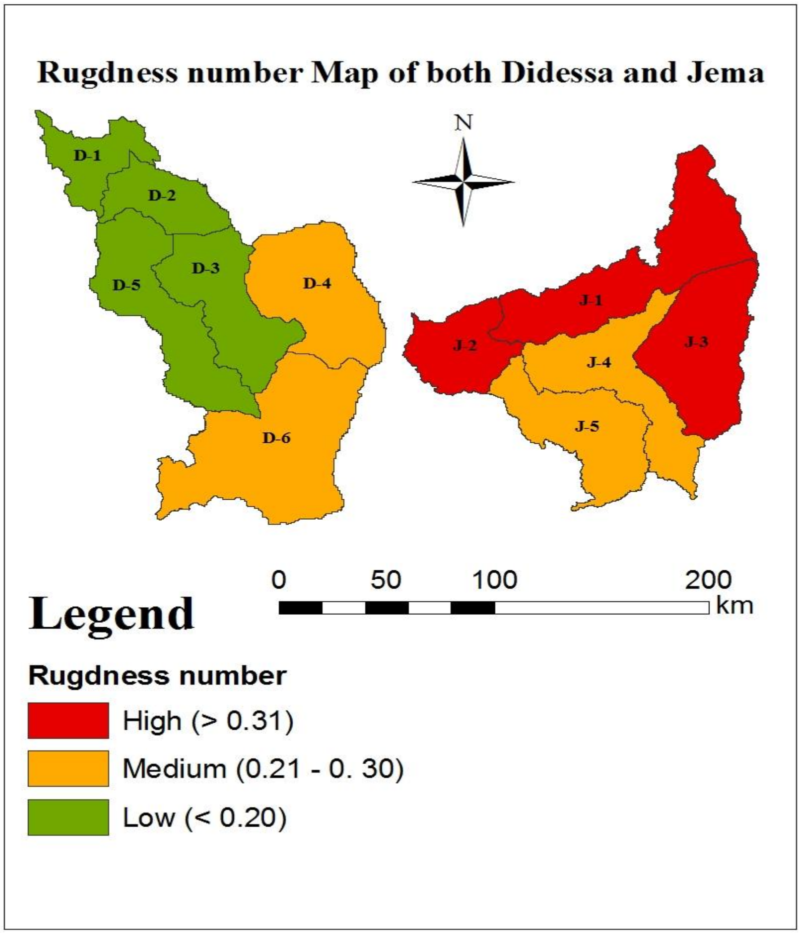

Figure 4. 11: Ruggedness number map of Didessa and Jema sub watersheds

4.4.4 Relative relief

Relative relief termed as ‘amplitude of available relief’ or ‘local relief’ is defined as the difference in height between the highest and the lowest points (height) 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 Didessa sub watersheds were found to be vary from 0.0026 to 0.0047(Table 4.13 above) and also vary from 0.0038 to 0.0077(Table 4.14 above) incase for Jema sub watersheds.

The Summary of All the morphometric analysis results for both sub basins were tabulated in Table 4.15 and 4.16 respectively.

Table 4. 15: Summery of Morphometric Analysis result for Didessa sub watersheds

Sub water sheds	Mean Rb	Dd	Fs	Dt	Rh	Rn	Rf	Rc	Re	Lof	C
D-1	1.57	0.136	0.024	0.104	0.016	0.173	0.217	0.174	0.526	3.684	7.368
D-2	3.39	0.135	0.031	0.170	0.015	0.163	0.216	0.270	0.525	3.710	7.421
D-3	11.38	0.134	0.037	0.266	0.012	0.183	0.198	0.242	0.496	3.738	7.477
D-4	3.84	0.140	0.028	0.263	0.012	0.227	0.193	0.329	0.502	3.578	7.156
D-5	3.56	0.125	0.035	0.181	0.010	0.154	0.194	0.176	0.497	4.011	8.021
D-6	7.55	0.139	0.027	0.336	0.009	0.218	0.182	0.228	0.481	3.595	7.190

Table 4. 16: Summery of Morphometric Analysis result for Jema sub watersheds

Sub Water sheds	Mean Rb	Dd	Fs	Dt	Rh	Rn	Rf	Rc	Re	Lof	C
J-1	2.26	0.142	0.025	0.152	0.018	0.375	0.188	0.117	0.489	3.524	7.047
J-2	2.90	0.134	0.031	0.171	0.0262	0.319	0.211	0.227	0.518	3.733	7.465
J-3	4.77	0.153	0.019	0.153	0.0164	0.326	0.193	0.257	0.496	3.269	6.537
J-4	1.47	0.113	0.016	0.078	0.0189	0.263	0.196	0.097	0.499	4.434	8.868
J-5	1.98	0.134	0.021	0.111	0.0175	0.277	0.198	0.131	0.502	3.731	7.461

4.5 Developing Prioritization Rank and Compound Value

4.5.1 Prioritization Rank of Sub Watersheds

Based on the Morphometric analysis result, priority ranks were developed for each sub watershed to know the patterns of soil erosion potential. Moreover, for each sub watersheds, the higher value of the linear morphometric parameter such as bifurcation ratio, drainage density, stream frequency, Drainage texture ratio and etc. were much more susceptible for soil erosion. Therefore, the higher value were rated as rank 1, second highest value was rated as rank second and so on. Conversely, Areal aspect parameters like elongation ratio, form factor and circulatory ratio have inverse relationship with soil erosion. Hence, lower value of that shape parameter is an indication of higher risk of erodibility. As per the analysis, ranks were given to each parameter.

4.5.2 Compound Value parameter

The ranking values of all the parameters were added to assign Compound values or final weightage. The compound values parameter for all Didessa and Jema 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 watersheds were 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.

Table 4. 17: Compound values for priority classes

Compound Values	**Prioritization Classes**
≤ 2.55	High Priority
2.55 – 3.55	Medium Priority
≥3.55	Low Priority

High Priority: 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 run off. These 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: watersheds falling in medium priority classes consist of moderate slopes, relatively moderate values of linear and shape parameters. These 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: 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 for all sub watersheds were done and shown in Table 4.18 and 19 for both Didessa and Jema sub watersheds respectively.

Table 4. 18: Compound Values and Prioritization rank of Didessa Sub watersheds

Sub Water sheds	**Mean Rb**	**Dd**	**Fs**	**Dt**	**Rh**	**Rn**	**Rf**	**Rc**	**Re**	**Lof**	**C**	**Compound values**	**Rate of Soil erosion**
D-1	6	3	6	6	1	4	6	1	6	3	3	4.09	Low
D-2	5	4	3	5	2	5	5	5	5	4	4	4.27	Low
D-3	1	5	1	2	4	3	4	4	2	5	5	3.27	Medium
D-4	3	1	4	3	3	1	2	6	4	1	1	2.64	Medium
D-5	4	6	2	4	5	6	3	2	3	6	6	4.27	Low
D-6	2	2	5	1	6	2	1	3	1	2	2	2.45	High

Table 4. 19: Compound Values and Prioritizations of Jema Sub watersheds

Sub Water sheds	Mean Rb	Dd	Fs	Dt	Rh	Rn	Rf	Rc	Re	Lof	C	Compound values	Rate of Soil erosion
J-1	3	2	2	3	3	1	1	2	1	2	4	2.55	High
J-2	2	4	1	1	1	3	5	4	5	4	3	2.82	Medium
J-3	1	1	4	2	5	2	2	5	2	1	1	2.36	High
J-4	5	5	5	5	2	5	3	1	3	5	5	4.00	Low
J-5	4	3	3	4	4	4	4	3	4	3	2	3.27	Medium

The analysis result reveals that, From Jema Sub basin, the sub-watershed J-3 with a compound parameter value of 2.36 received the highest priority rank. Also Sub-watershed J-1 having a compound parameter value of 2.55 received the next high priority classes. Similarly for Didessa sub-basin, the sub-watershed D-6 with a compound parameter value of 2.45 received the highest priority classes. These Highest priority indicates the greater degree of erosion susceptibility in the particular sub watershed and it becomes potential Candidate area for applying soil conservation measures.

Similarly, the sub Watersheds falling in Medium priority classes (J-2 & J-5 from Jema and D-3 & D-4 from Didessa) indicates relatively moderate soil erosion zone and consist of moderate slopes, moderate values of morphometric analysis result.

Finally, sub watersheds falling under low priority classes (J-4 from Jema and D-1, D-2 and D-5 from Didessa) consist of lower slopes, very low values of linear and 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.

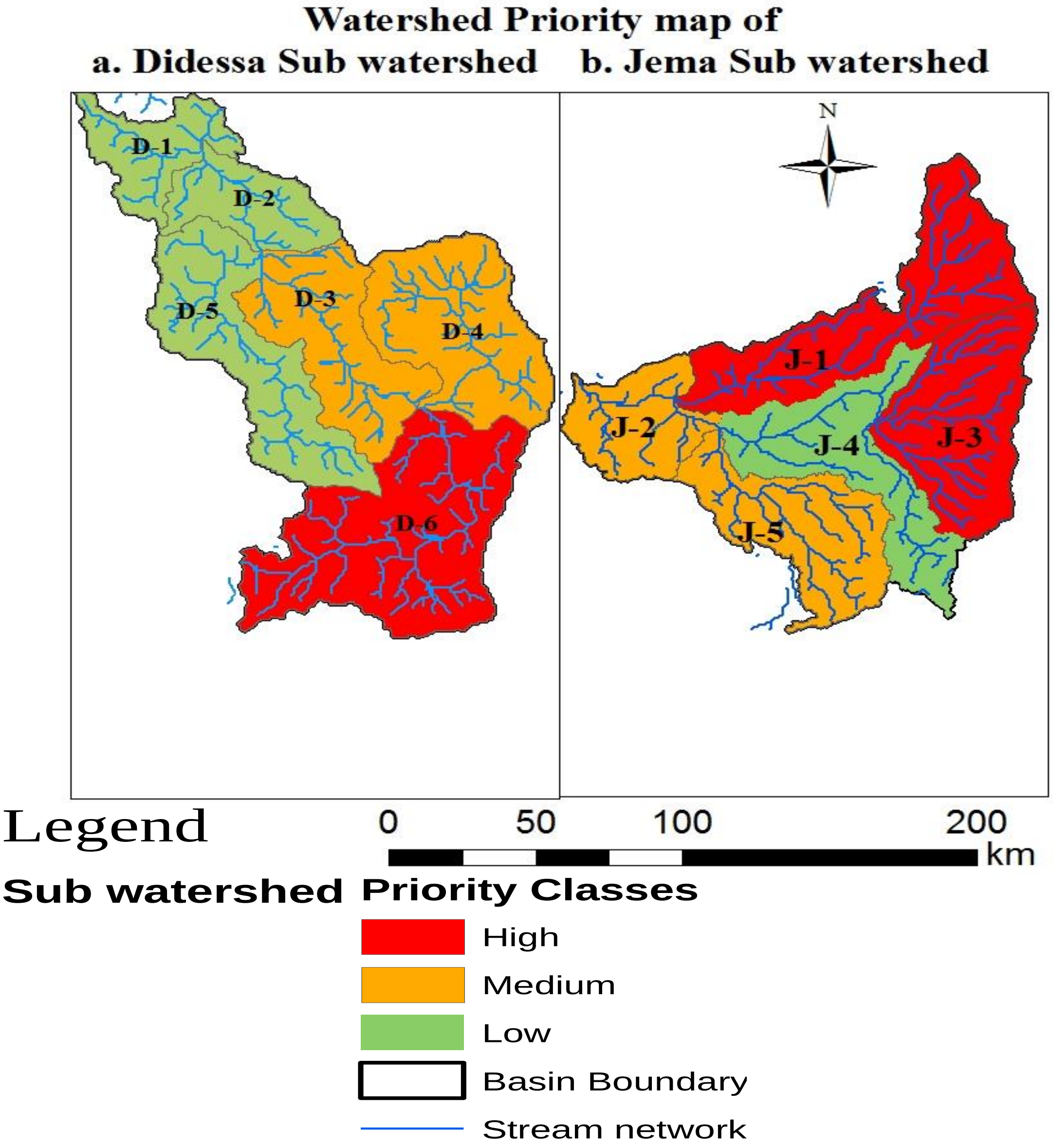

Figure 4. 12: Prioritized Rank of Didessa and Jema Sub Watershed

Moreover the final priority Map also indicates that; high priority classes of Jema sub watersheds covers larger area of about 7292.57km^2 for both J-3 and J-1, whereas 5099.43km^2 of D-6 from Didessa sub watersheds. This shows that about 49.45% of the total areas of Jema watersheds were vulnerable to soil erosion. However about 29.85% of the total areas were vulnerable to soil erosion in case of Didessa watersheds. This indicates that comparatively; Jema watersheds were more vulnerable to soil erosion than that of Didessa watersheds.

4.6 Conservation measures for management

Although managing the whole watershed at once is very difficult, the final priority ranks of sub watersheds guides for phase wise implementation plan for management. The Conservation practices for management can be divided into two main categories as in-situ and ex-situ management depending on their erosion potential or priority classes. The sub watersheds falling in high soil erosion potential needs immediate attention for soil conservation measures. Thus both in-situ and ex-situ management were recommended. Whereas ex-situ management were recommended for sub watersheds falling in low and medium soil erosion potential.

The in-situ managements are Land and water conservation practices, made within agricultural fields like construction of contour bunds, contour ploughing, terraces building, and agro forestry or furrow practice and other soil-moisture conservation practices. These practices protect land degradation, increase soil-moisture availability and groundwater recharge. Moreover, at the outside of the agricultural field, construction of check dam, farm pond, gully control structures, grass waterways and pits excavation across the stream channel is known as ex-situ management. Ex-situ watershed management practices reduce peak discharge in order to reclaim gully formation and harvest substantial amount of runoff, which increases groundwater recharge and irrigation potential in watersheds. Therefore, for sub watersheds J-3 and J-1 from Jema and D-6 from Didessa both conservation measures will be applied sequentially. These indicate that, the sub watershed was in sparse vegetation, high relief and steep slope, that it shows lower infiltration and higher runoff than all other sub watershed of the basin. Similarly; in-situ management were recommended for the sub Watersheds falling in Medium priority classes (J-2 & J-5 from Jema and D-3 & D-4 from Didessa) indicates relatively moderate soil erosion zone and consist of moderate slopes, moderate values of linear and shape parameters. Also, for sub watersheds falling under low priority classes (J-4 from Jema and D-1, D-2 and D-5 from Didessa) 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. Therefore; Erosion control is essential to maintain the productivity of the land as well as to control sedimentation and pollution of streams and lakes. Since erosion is a natural process, it cannot be prevented. But it can be reduced to a maximum acceptable level or soil loss tolerance.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This thesis work was basically based on Hydrology of Watershed characterization for morphometric analysis of Didessa and Jema sub basin 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 evaluated and analyzed morphometric parameters such as area, length, stream pattern, flow direction, and perimeters all these are reflect the shape and topography of the given watershed. Overall thesis was summarized as follow

- The numbers of streams of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software.
- The linear, areal and relief aspects of morphometric parameters were analyzed.
- High mean Bifurcation ratio of Didessa sub watersheds indicates absence of any significant structural control on the development of the drainage.
- Higher value of Drainage density 0.153(J-3) of Jema sub-watershed indicates that sparse vegetation and mountainous relief, low infiltration capacity and high soil erosion compared to that of Didessa sub-watershed.
- The value of stream frequency indicate that the watershed show positive correlation with increasing stream population with respect to increasing drainage density.
- For both sub basins, the value of form factor, circulatory ratio and elongation ratio suggests that all watersheds were elongated in shape. But relatively Jema sub watersheds were more elongated than that of Didessa sub watersheds that have high relief, steep slope and produce high discharge of runoff.
- The lower value of constant channel maintenance in Jema sub watersheds indicates that very low-resistance soils, sparse vegetation, relatively higher run off and lower permeability while the Didessa sub watershed was associated with resistance soils, dense vegetation and comparably plain terrain.

- the higher values of relief ratio and ruggedness number in case of Jema sub watersheds indicates more hilly regions in Jema sub-watershed which results in greater discharge capabilities and lower infiltration rate compared to that of Didessa sub-watershed.
- In general priority ranks were developed for each sub watershed based on the value of Morphometric analysis result, to know the patterns of soil erosion potential.
- The higher values of linear and relief aspects were rated as 1st rank, second highest value was rated as 2nd rank and so on. Whereas the inverse is true in case of for Areal aspect parameters.
- Again combination of the whole morphometric analysis result using average compound values were developed and classified as High, medium and low to locate erosion pruned areas.
- As per analysis result, the sub-watershed J-3 and J-1 from Jema and D-6 from Didessa with a compound parameter value of 2.36, 2.55 and 2.45 respectively received the highest priority classes. This indicates existence of high soil erosion zone.
- Similarly, the sub Watersheds falling in Medium priority classes (J-2 & J-5 from Jema and D-3 & D-4 from Didessa) indicates relatively moderate soil erosion zone.
- Sub watershed falling under low priority classes (J-4 from Jema and D-1, D-2 and D-5 from Didessa) indicates low soil erosion.
- In general about 49.45% and 29.85% of the total areas of Jema and Didessa watersheds were vulnerable to soil erosion. This indicates that comparatively; Jema watersheds were more vulnerable to soil erosion than that of Didessa watersheds.
- Both in-situ and ex-situ management will be recommended for the most vulnerable areas of the sub watersheds to take up soil conservation measures on the field as well as at an areas of gully formation to protect the topsoil loss, Land degradation and downstream reservoir sedimentation.
- Finally, for sub watersheds falling under medium and low priority classes, In-situ managements or agronomical measures such as Contour farming, Mulching practices, Strip cropping and Mixed cropping to protect the sheet and rill erosion were recommended.

5.2 Recommendation

This research demonstrates the usefulness of GIS technique for morphometric analysis and prioritization of the Didessa and Jema sub watersheds. The morphometric analyses of different watersheds show their relative characteristics with respect to hydrologic response of the watershed. Although it was very difficult to take the whole area of watersheds at once for applying conservation measure, prioritizing each of the sub watersheds were very important. Based on the average compound value the priority criteria have decided as High Priority, Medium priority and low priority. The sub watershed having lowest average compound value belongs to high priority and those the watershed having highest average compound value belongs to low priority.

In this regard this research reveals that Sub watersheds number J-3 and J-1 from Jema and D-6 from Didessa have high vulnerability to soil erosion and hence these three sub-watersheds will need to give a highest priority for conservation of soil and water resources compared to medium and low ranking sub-watersheds. The Sub-Watershed number (J-2 & J-5 from Jema and D-3 & D-4 from Didessa) will need to give second priority for reclamation and conservation process. The sub watershed number (J-4 from Jema and D-1, D-2 and D-5 from Didessa) have a low risk of land degradation hence it should be given lowest priority in sub-basin conservation practices. Furthermore, as from the analysis result table, the larger areas of Jema Sub basin were more vulnerable to soil erosion potential relative to Didessa Sub basin watersheds. On the other hand; this study also validates; larger areas of the Ethiopian highlands were more vulnerable to soil erosion than the lowlands. Therefore, Suitable soil erosion control measures are required in those watersheds to preserve the land from further erosion.

In general, if soil erosion control measure for watershed management will be applied to those sub watersheds, soil erosion from the highland areas and reservoir sedimentation at the downstream will be reduced, the rain water will be harvested and the ground water will be recharged. So, these studies are very useful for watersheds and catchment management program on the upstream of the sub basin to reduce the impacts of reservoir sedimentation problems at the downstream of the Blue Nile basin like the great Ethiopian renaissance dam. Finally I would like to say that, it is better if such like research was done on the other sub basins of Ethiopia for Soil and water recourses planning and management program for development.

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