2021-08-19

PERFORMANCE EVALUATION OF GEFERSA STORAGE DAM USING HYDROLOGICAL INDICES AND RUSLE MODEL

ADAMSO, SERBESSA

http://ir.bdu.edu.et/handle/123456789/12488

BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY

SCHOOL OF RESEARCH AND POSTGRADUATE STUDIES

FACULTY OF CIVIL AND WATER RESOURCES ENGINEERING

PERFORMANCE EVALUATION OF GEFERSA STORAGE DAM USING HYDROLOGICAL INDICES AND RUSLE MODEL

BY:

ADAMSO SERBESSA

Bahir Dar, Ethiopia

February 20, 2006

PERFORMANCE EVALUATION OF GEFERSA STORAGE DAM USING HYDROLOGICAL INDICES AND RUSLE MODEL

ADAMSO SERBESSA

A thesis submitted to the school of Research and Graduate Studies of Bahir DarInstitute of Technology, BDU in partial fulfilment of the requirements for the degree ofMasters in Hydraulic Engineering in the Faculty of Civil and Water Resources Engineering.

Advisor: Mekete Dessie (Ph.D.)

Co-Advisor: EnyewTamiru (MSc.)

Bahir Dar, Ethiopia

2021

DECLARATION

I, the undersigned, declare that the thesis comprises my work. In compliance with internationally accepted practices, I have acknowledged and referred to all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the University and can evoke penal action from the sources, which have not been properly cited or acknowledged.

Name of the Student: Adamso Serbessa Signature: ________
Date of submission: 05/02/2021
Place: Bahir Dar

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

Advisor : Mekete Dessie (phD)

Signature: ________

BAHIR DAR UNIVERSITY
BAHIR DAR INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
FACULTY OF CIVIL AND WATER RESOURCES ENGINEERING

Approval of thesis for defense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

Name of Student Adamco Serbessa Signature ____ Date 08/04/2021

As members of the board of examiners, we examined this thesis entitled "Performance Evaluation of Gefersa Storage Dam Using Hyd. Indices & RUSLE" by ____. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Masters of science in " Hydraulic and Water Resources Engineering ".

Board of Examiners

Name of Advisor	Signature	Date
Adam Mekete Dessie (phD)		10/4/2021

Name of External examiner	Signature	Date
Hailu Kende		09/04/2021

Name of Internal Examiner	Signature	Date
Bitew Genet		9/04/21

Name of Chairperson	Signature	Date
Abdu Yimer		10/04/2021

Name of Chair Holder	Signature	Date
Asegdew G (Dr)		

Name of Faculty Dean	Signature	Date
Temesgen Enku Nigussie (PhD) Faculty Dean		

Faculty Stamp

ACKNOWLEDGMENTS

First, thanks to the Almighty God for granting me His limitless care, love, and blessings all along the way. I would like to kindly and very sincerely thank my advisor Dr.Mekete Dessie and AtoEnyewTamiru, for theirnever-ending help, their indefectible encouragements, and their professional guidance from the very beginning of the proposal development up to the final thesis write up.

I gratefully acknowledge all offices such as the Ethiopian Construction Design and Construction Works Corporation, Ministry of Water, Irrigation and Electricity, National Meteorological Services Agency, and the Addis Ababa Water and Sewerage Authority, for the data and priceless comments they gave me.

Finally, yet importantly, my thankfulness goes to my family for their support, individuals, and all friends who have helped me in providing required data on the subject matter of the research work and in encouraging my effort in many aspects.

ABSTRACT

Sediment transport is a global environmental problem that degrades soil productivity, water quality, causes sedimentation of reservoirs and increases the probability of floods. The Gefersa reservoir, one of the sources of surface water supply for the city of Addis Ababa for the past 70 years, has faced several problems. The reservoir supplies an average of 30,000m^3per day with a storage capacity of 6,500,000m^3. This study was conducted in the upper catchment of the Gefersa reservoirwith the objectives of estimating reservoir sedimentation and specific sediment yield of the Gefersa reservoir using the RUSLE model integrated with the GIS environment. The research put together the Revised Universal Soil Loss Equation (RUSLE) model to identify the soil erosion hotspot areas. The findings show that the annual soil loss rate of the upper catchment is about596tons/ha/yr. The study indicated that the sediment yield and specific sediment yield are 0.36 and 214ton/ha/yr respectively. From the results of this study, the researcher concludes that the soil loss from the upper catchment of the reservoir is small which is below the limit as stated by FAO. This is due to the well-conserved catchment and the existence of Gefersadam (III) for sediment trap at upstream of main Gefersa dam (I/II)to prevent the dam from sediment deposition. Albeit that soil erosion is, less it is important to quantify the soil loss at the catchment level to recommend additional sediment trapping techniques for the dam safety.

Key words: Gefersa Reservoir; RUSLE model; IDW; Sediment yield; Ethiopia

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ASCE	American Society of Civil Engineers
GIS	Geographic Information Systems
RUSLE	Revised Universal Soil Loss Equations
TE	Trapp Efficiency
SDR	Sediment Delivery Ratio
C	capacity
I	Inflows
MCM	Million Cubic Metric
UTM	Universal Transfer Mercator
DEM	Digital Elevation Model
AAWSA	Addis Ababa Water and Sewage Authority
FAO	Food and Agricultural Organisation
LULC	Land Use Land Cover
IDW	Inverse Distance Weighted
USDA	United State Department of Agriculture
SSY	Estimating Specific Sediment Yield
R	Rainfall erosivity factor
K	Soil erodibility factor
LS	Slope length and steepness factor
C	Crop management factor
P	Conservation support practice factor
NMA	National metrology agency
SDR	Sediment Delivery Ratio

1.INTRODUCTION

Human-induced environmental change at a global scale is causing a spectacular increase of geomorphic process activity and sediment fluxes in many parts of the world (Turner et al., 1990). In the reservoir, sedimentation is a phenomenon due to which the sediment particles are deposited in the form of bed load and suspended load after separating from their origin (ASCE, 1982). In fluvial hydraulics, sedimentation is an important parameter as it provides a probability of being used as a capacity predicting device in all storage zones due to which the life of a reservoir can be predicted; as there is a unique relationship between capacity and life of a reservoir. To be more explicit, for a given reservoir, sedimentation is dependent on sediment yield, which is defined as the sediment discharge through a river outlet per unit catchment area per unit time (Wei et al., 2017). Soil erosion in the catchment is also an important parameter as the sediment yield depends on it. To reduce the problem corresponding with the number of sediment particles that ultimately deposit into the reservoir after getting eroded from the catchment, attempts have been made to relate the soil erosion, sediment yield, and sedimentation into the reservoir, since these three parameters deal with the life of a reservoir directly or indirectly.

Soil erosion in watersheds and sedimentation in rivers, creek waters, farmlands, and reservoirs are among the main concerns for farmers and relevant managers on both local and global scales (Zounemat-Kermani et al., 2016). The consequences of soil erosion and sediment deposition occur both on and off-site. On-site effects are particularly important on agricultural land where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure, and the decline in organic matter and nutrients result in a reduction of cultivable soil depth and a decline in soil fertility. The net effect is a loss of productivity, which at first, restricts what can be grown and results in increased expenditure on fertilizers, but later may lead to land abandonment (Pimentel et al., 1995, Crosson, 1997).

Off-site problems result from sedimentation downstream, which reduces the capacity of rivers and retention ponds, enhances the risk of flooding and muddy floods, and shortens the design life of reservoirs (Verstraeten and Poesen, 1999). Sediment is also a pollutant in its own right and, through the agro-chemicals adsorbed to it, can increase the levels of nitrogen and phosphorus in water bodies and result in eutrophication (Steegen et al., 2001).

Not surprisingly soil erosion and sediment delivery have become important topics on the agenda of local, national, and international policymakers. This has led to increasing demand for reliable scale soil erosion models to delineate target zones in which conservation measures are likely to be the most effective. Secondly, regional-scale erosion models were requested to predict the geomorphic response of possible conservation measures at the scale of catchments.

Despite the development of a range of physically-based soil erosion and sediment transport equations, sediment yield predictions at a regional scale are at present achieved mainly through simple empirical models that relate the annual sediment delivery by a river to catchment properties, including drainage area, topography, climate and vegetation characteristics (Bazzoffi et al., 1996, Lixian et al., 1996, Verstraeten and Poesen, 2001, Verstraeten et al., 2003).

Reservoirs have the potential for a variety of uses, including water supply for irrigation and domestic use, flood control, and water power, but they are susceptible to filling with sediment due to erosion in the watersheds. Reservoir sedimentation is filling the reservoir with sediment carried into the dam reservoir by streams and the process is a universal phenomenon that has been considered as the most critical environmental hazard of modern time. Many reservoirs can no longer perform their design functions because much of their original active storage volume has been filled by sediment. In Ethiopia, accelerated siltation of reservoirs that are intended to provide irrigation water has resulted in the loss of both the intended services from the reservoirs and of the considerable investments incurred in their construction. The frequent power cuts and rationing-based electric power distribution experienced in the country are also attributed to the loss of storage capacity of hydro-electric power lakes due to erosion.

Sediment deposition in reservoirs is a reflection of catchment erosion and deposition processes, which are controlled by terrain form, soil, surface cover, drainage networks, and rainfall-related environmental attributes (Tamene et al., 2015). Sediment inflow and deposition can affect the function of reservoirs. Therefore, it is of crucial importance to estimate the sedimentation rate and the period before sediment accumulation could interfere with the useful functioning of the reservoir. When designing a reservoir, sufficient sediment storage capacity should be considered so that sediment accumulation will not impair the function of the reservoir during the useful operational life of the project. This will be effective when there is reservoir sedimentation rate data. But watershed sediment yield and reservoir sedimentation rates data for Ethiopia are limited in number (Haregeweyn et al., 2012). The lack of a sufficient local database on sediment yield and adoptable sediment yield models has been a problem for reservoir designers. Therefore,studies are needed to better understand erosion and sedimentation to figure out sedimentation rates and aspects or practices that increase these processes.

1.1 STATEMENT OF PROBLEM

Sediment transport leads to degraded soil productivity causing global problems such as sedimentation in reservoirs. Today, there are many reservoirs that cannot function as designed because much of their storage has been filled with sediment. For a water supply scheme, any loss of live storage increases the risk of supply failure and this is often undesirable. These problems are manifested in the Gefersa reservoir, the main source of water supply for the city of Addis Ababa, due to the rapid change in land use, especially intensive agriculture in the basin. According to some studies which conduct on Gefersa catchment indicates there is a loss of 0.36% of the volume of the main reservoir of 6.23MCM, which constitutes a loss of soil from this basin on average 575 ton / km2 / year, also increasing the cost of treatment due to an increase in turbidity of raw water. Therefore, care must be taken to alleviate this problem.Silting of dam reservoirs is the most challenging problem in Ethiopia due to unsustainable watershed management. Many reservoirs can no longer perform their design functions because much of their original active storage volume has been filled by sediment. Ethiopia suffers a food security problem and an increasing demand for water due to the increase in population growth rate. Consequently, the government of the country has constructedwater-harvesting projects, especially dam projects in many regionsin the last few decades. Gefersa is one of these projects, constructed for alleviating water supply problems. To ensure the effective use of Gefersa Reservoir, appropriate measures haveto be taken to prevent the rapid loss of its storage capacity. Therefore, it is important to maintain the storage capacity of the reservoir and prolong its economic life by taking appropriate measures that could reduce the rate of siltation. This would be possible if we know the quantity of sediment deposition in the reservoir and the spatial distribution of erosion in the upper catchment of the reservoir. Reservoir sedimentation is a severe problem in the managementof water resources development projects in many countries around the world, as it reduces the original capacity of the reservoirs significantly affecting the irrigation, hydropower and drinking water supply, flood control, and recreational activities.

1.2 OBJECTIVE OF THE STUDY

1.2.1 GENERAL OBJECTIVE

Investigate sediment inflow to the Gefersa reservoir and Quantifying the sediment rate in the catchment by using GIS tools and the RUSLE model.

1.2.2 SPECIFIC OBJECTIVE

- To analyse the spatial distribution of soil erosion in the upper catchment of Gefersa Reservoir and to identify erosion risk areas (hot spot areas) to prioritize soil conservation planning.
- To calculate the soil loss rates Using RUSLE
- To estimate reservoir trap efficiency and evaluating reservoir performance

1.3 RESEARCH QUESTIONS

To achieve the objectives, it is better to develop the following research question:

What is the extent of the sedimentation problem in the Gefersa Reservoir?

To what extent, does the soil erosion in the upper catchment affect Gefersa Reservoir?

Where is the erosion hotspot area in the Gefersa watershed?

How much annual sediment inflow in the Gefersa Reservoir?

2. LITERATURE REVIEW

2.1 INTRODUCTION

According to the objectives, the following topics are reviewed in this chapter: a) soil erosion modelling using Geographical Information System (GIS), b) Sediment yield calculation in the reservoir using Revised Universal Soil Loss Equation (RUSLE), and the Sediment Delivery Ratio (SDR).

2. 2. Soil Erosion and Sedimentation

The rapid erosion of soil by wind and water has been a problem ever since the land was first cultivated. The consequences of soil erosion are both on and off-site. Onsite are particularly important on agricultural land where the breakdown of soil structure, redistribution of soil within the field, the loss from a field, and the decline in organic matter and nutrients result in a reduction of cultivable depth and a decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought-prone conditions. The net effect is a loss of productivity, which at first restricts, what can be grown and results in increased expenditure on fertilizers to maintain yield but later threatens food production and lead to land abandonment. Offsite problems result from sedimentation downstream or downwind. The impact of erosional processes can be summarized under three major headings namely a) soil productivity to crops, b) flood hazards and c) the life expectancy of water storage structures. However, the environmental impact of delivered sediment also represents a major concern. Peak rainfall seasons often produce uncontrolled runoff, which may result in floods. However, natural vegetation in high rainfall areas is most adequate to minimize runoff and erosional losses during those periods. Increasing human activities have been reported to disturb the natural hydrologic pattern, thus producing floods. These were previously unknown, increasing the destructiveness of existing floods, inducing water deficit at the locations of the disturbance due to excessive water losses by runoff and evaporation. The term sediment yield is the total sediment outflow from a watershed or drainage basin during a given time. It is the material, which is carried to some point of interest. As it is known, that not all soil loss is delivered to the stream system deposited at various locations in the watershed. Streams transport coarse sediments as bedload, while fine sediment is transported as suspended load. Sources of sediment include soil erosion usually carried as suspended load and material eroded from the stream channel, which is transported as both suspended load and bedload. The major controlling factors for sediment yields are the climate and vegetation, basin size, elevation and relief, rock and soil type, land use, and human activity all of which in turn determine soil erosion rate and stream capacity.

2.3 Soil Erosion Models

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water. The major forces originate from raindrop impact and flowing water. Mechanisms of the soil erosion process, in which water from sheet flow areas run together under certain conditions and forms small rills. The rills make small channels. When the flow is concentrated, it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join to form progressively larger channels, with the flow eventually proceeding to some established streambed. Some of this flow becomes great enough to create gullies. Soil erosion may be unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems. Soil erosion is a natural and inevitable process that can be a serious environmentaland economic problem when it is accelerated by human activities. Soil erosion is the process by which sediment grains are detached, transported, and accumulated in a distant place resulting in exposure to subsurface soil. The consequence of soil erosion occurs both on sites as well as off-site. On-site effects are particularly important on agricultural land where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure, and the decline in organic matter and nutrients result in a reduction of cultivable soil depth and decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought-prone conditions. The net effect is a loss of productivity and results in increased expenditure on fertilizers to maintain yields. Off-site problems resulting from sedimentation downstream, which reduces the capacity of the rivers, enhance the risk of flooding; blocks irrigation canals and reduces the design life of reservoirs. The factors, which influence the rate of erosion, are rainfall, runoff, soil, slope, plant cover, and the presence or absence of conservation measures. Several parametric models have been developed to predict soil erosion at drainage basins, hill slopes, and field levels. With a few exceptions, these models are based on soil type, land use, and land cover, climatic and topographic information Scientific management of soil, water, and vegetation resources on watershed basins is, therefore, very important to arrest erosion and rapid siltation in rivers, and lakes. It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time (Foster and Meyer, 1977; Wischmeier and Smith, 1978; Julien, 1998). Traditional sources of investigation are expensive and time-consuming. GIS-based universal soil loss equation provides a convenient solution for this problem. The Revised Universal Soil Loss Equation (Renard et al., 1997) model, developed to predict water erosion in temperate climates, is easier to adapt to tropical climates than other existing models. RUSLE is an empirically based model, founded on the Universal Soil Loss Equation (Wischmeier and Smith, 1978), but is more diverse and includes databases unavailable when the USLE was developed (Renard et al., 1997). RUSLE is designed for use at the runoff plot or single hillslope scales. The RUSLE model enables prediction of an average annual rate of soil erosion for a site of interest for any number of scenarios involving cropping systems, management techniques, and erosion control practices. Erosion rates of ungauged catchments can also be predicted using RUSLE by using knowledge of the catchment characteristics and local hydro-climatic conditions (Garde and Kathyari, 1990). The results from erosion pre-diction are compared to estimated soil-loss tolerance (T) values for the area in question, which denotes the maximum rate of soil erosion that can occur and still permit crop productivity to be sustained economically. An infinite number of slope lengths exist in a field. In RUSLE, erosion can be calculated for several slope lengths and the results averaged according to the area represented by each slope length to obtain an erosion rate for a field. Results from representative fields can be combined to estimate erosion rates for an entire watershed. RUSLE computes the average annual erosion expected on hillslopes by multiplying several factors together: rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and support practice (P). The values of these factors are determined from field and laboratory experiments (Renard et al., 1997). This method is widely used to estimate soil erosion loss and risk, which provides a guideline for the development of conservation plans and controlling erosion under different land-cover conditions, such as croplands, rangelands, and disturbed forest lands (Mil-ward and Mersey 1999).

Further voluminous data gathered with the help of remote sensing techniques are efficiently handled and utilized with the help of GIS. In the present study, GIS has been extensively used for the preparation of soil erosion models as stated in Shin, G.J. (1999).Soil may be deemed, as one of the most important resources available as it services the many needs of human living. Brady (1984) justifies this statement by connecting the historical correlation between human settlements within the context of fertile soils such as the river floodplain. Traditional sources of investigation are expensive and time-consuming. Several studies have indicated that remote sensing data and Geographic Information Systems (GIS) can be used as a first stage input to identify and map the degraded land. In Ethiopian highlands, the productivity of cultivated land was reduced through soil erosion. This problem occurs through both anthropogenic and natural activities, such as poor land-use practices, storm storms, particularly inadequate management systems, soil protection measures, and steep slopes. As a result, the phenomenon causes land degradation problems in the highlands ofEthiopia (Menale*et al.*, 2011). Spatial information exploration is a new approach that can identify, analyse, and manage complex watersheds and catchment areas. Today, GIS is a good alternative tool for better decision support in the implementation, planning, and management of land and water resources. GIS is important for viewing, processing, manipulating, and storing geo-databases. The Multi-Criteria Assessment (MCA), an instrument for improving GIS, could help users to improve their decision-making processes. To explore a range of alternatives in terms of goal conflicts and multiple criteria, the MCE technique is used (Voogd, 1983).

2.4 PREVIOUS STUDIES ON GEFERSA RESERVOIR

Sedimentation is an important issue for the Gefersa dam as it directly influences the reservoir capacities and satisfaction of the water demand. Several topographic surveys or bathymetric surveys of the Gefersa reservoirs have been carried out in 1955,1964,1979 and 1998 and have concerned Gefersa I/II (all studies) and Gefersa III(1998 study).

The 1955 topographic survey was made by USAOM. In 1964, Lahmeyer made a survey, which gives interesting results. Following the 1964 survey, the Gefersa III dam was built as a sediment trap upstream of the old Gefersa I/II dam (1966).Lahmeyer assessment indicates that the 1964 sedimentation, based on the 1955 lake level, amounted to about 380,000m^3. This siltation is mainly located at the bottom of the reservoir since 90% of deposits are below 2596m. They found that 214,000m^{3}were deposited from 1939 to 1955 and 160,000m^3 from 1956 to 1964. Besides, there are 289,282m^3 were deposit from 1966 to 1979. The loss of capacity between 1979 and 1998 is about 420,000 m^3 (at elevation 121 i.e. the present sill elevation).

2.5 RESERVOIR SEDIMENTATION PROBLEMS AND SEDIMENTATION RATE IN THE WORLD

Reservoir sedimentation is a worldwide problem and considered a salient enemy. It has tremendous economic and environmental impacts. The gradual loss of reservoir capacity reduces the effective life of dams. For each year up to 1% of the world's reservoir capacity is lost by sedimentation (Howard, 2000). A World Bank study by Mahmood (1987) illustrated that the average useful life of existing reservoirs in all countries of the world decreased from 100 to 22 years. The annual cost for promoting the removal of the sediment is estimated at US$ 6 billion.

Sedimentation continues to be one of the most important threats to river eco-systems around the world. A study was done on the world's 145 major rivers with consistent long-term sediment records and the results show that about 50% of the rivers have statistically a significantly downward flow trend due to sedimentation (Walling & Fang, 2003). Sumi & Hirose (2009) reported that the global reservoir gross storage capacity is about 6000 km3 and annual reservoir sedimentation rates are about 31 km^3 (0.52 %). This suggests that at this sedimentation rate, the global reservoir storage capacity will be reduced to 50% by the year 2100. Reservoir sedimentation, therefore, is filling with the reservoir behind a dam with sediment carried into the reservoir by streams. The flow of water from the catchment upstream of a reservoir is capable of eroding the catchment area and of depositing material either upstream of the reservoir, or in the still water of the reservoir. The nature of the material in the catchment area and the slope of the catchment area and the inlet streams are a factor, as is the nature of the ground cover. The deposition of sediment will automatically reduce the water storing capacity of the reservoir, and if the process of deposition continues longer, a stage is likely to reach when the whole reservoir may get silted up and become useless (Garg, 2009).

There are several direct and indirect causes of degradation in this particular catchment leading to rapid siltation of the dam (Chihombori et al., 2013). Among the direct causes of overgrazing, excessive wood cutting, improper soil and water management, land disturbance, and cropping lands that are too erodible. Indirect causes including the increase in human and livestock populations, refusal to believe that a problem exists, absence of environmental awareness, lack of knowledge on how to control and prevent land degradation, government policies, and greed. Improper soil and water management and cropping are the most important causes in this particular catchment (Chihombori et al., 2013).

Similar studies elsewhere have also been conducted with similar results. Shiyang Reservoir in China had its capacity reduced after 43% of woodland areas within its catchment were turned into agricultural land (Mavima et al., 2011). In Ghana, a similar study to assess the impact of land-use changes on the Burekese catchment was conducted and the results showed a loss in reservoir storage capacity of 45% due to siltation over six years. The causes for the silting up of the reservoir were attributed to deforestation, population growth, and lack of proper education of the communities in catchment management (Mavima et al., 2011).

The impoundment of water behind a dam causes the velocity of the water to drop. Sediment carried by the river is dropped in the still water at the head of the lake. Below the dam, the river water flows from the clear water directly behind the dam (Ehigiator et al., 2017). Because the river no longer carries any sediment, the erosive potential of the river is increased. Erosion of the channel and banks of the river below the dam will ensue. Even further, downstream, sediment deprivation affects shoreline processes and the biological productivity of coastal regions (David, 2017).

Sediment accumulation in reservoirs reduces their storage capacity and limits their useful life if it is not controlled in some manner. When a dam is built across a stream, the flow cross-section progressively increases, and the flow velocity decrease towards the dam.

This leads to a decrease in sediment transport capacity, causing deposition of sediments, first in the backwaters created by the reservoir and then in the reservoir. Coarse particles are deposited first, and silt and clay particles are deposited in the deep portion of the reservoir in the vicinity of the dam. Sediment deposition continues to reduce the useful active and dead storage capacity of the reservoir so much. Sedimentation also affects the surface area of the reservoir, by reducing water depth and favoring the development of aquatic growth (Raghunath, 2006).

2.6 SEDIMENT YIELD & RESERVOIR SEDIMENTATION IN ETHIOPIA

The extent of degradation in general and soil erosion, in particular, is threatening Ethiopian high lands. Because of population pressure and poor agricultural system very fragile and steep slopes as steep as 60% have been under cultivation. Apart from several damages caused by erosion, the siltation of the reservoir is a crucial problem in Ethiopia. This problem could be seen in different regions of the country. Many dams constructed for irrigation and domestic purposes are being silted up while they were under construction (Amare, 2005).

Reservoir sedimentation and there resulting loss of storage affects water availability and reservoir operation schedules in Ethiopia. This interfering problem forces researchers being to emphasize matters of sedimentation. Due to this, some reservoir sediment surveys of existing Ethiopian reservoirs and lakes have been carried out in recent years on different reservoirs by different researchers. Tamene (2005) in the Tigray region northern part of Ethiopia was studying reservoir siltation and sediment rate on 11 small reservoirs. For his assessment of reservoir siltation sediment-pit analysis and bathymetric survey methods of quantifying sediment deposition in reservoirs were applied. For his study, he found that the annual average rate of capacity loss varies from 0.1 to 7.4% due to differences in environmental variables of catchments. In addition to this, his result showed most of the reservoirs filled with sediment within less than 50% of their projected service time. For instance, with 11 reservoirs three reservoirs have lost over 40% of their live storage capacity within 25% of their expected service time. These reservoirs have also lost 100% of their dead storage in less than a quarter of their expected service time. Mulugeta (2013) in southern Ethiopia was studying the impact of sedimentation on the hydrological status of Lake Hawassa with bathymetry survey methods using echo sounder for depth measurement by 500m x 500m grid spaces. in his study, the annual reduction in storage capacity of Lake Hawassa due to siltation is about 0.08% and the specific sediment yield is estimated to be 9.67 m^3/ha/year.

In northern Ethiopia, a study was conducted by Aynekulu et al. (2009) on the volume of sediment deposited in two small dams, Filiglig and Grashito. The result indicates that the volume of sediment deposition in reservoirs was 13,856m^3 and 23,974m^3 for Filiglig and Grashito reservoirs, respectively. The annual rate of sedimentation of Filiglig and Grashito reservoirs were found to be 6,928m^3yr-1 and 11,987m^3yr-1, respectively.

Moges, M. M., et al. 2018 report a study conducted in 2018 on an investigation of reservoir sedimentation and its implication to the watershed in the cases of two small reservoirs (Shina and Selamko) in south Gondar in Amhara regional state in Ethiopia. The study findings showed that the depth sonar surveys and GIS analysis suggested a projected lifetime of 7 years for the Shina reservoir, compared to a projected lifetime of 22 years for the Selamko reservoir. As described in the report, it also indicated the annual average sedimentation rate for both reservoirs was greater than the global average of 1% (1.67% for Shina reservoir; 2.295% for Selamko reservoir). The specific sediment yield is relatively larger for both watersheds (2,499 and 4,333.6ton-km-2year-1for Shina and Selamko, respectively) indicating the watersheds are degraded by greater than the global average.

The highlands of the Amhara region suffer from accelerated soil erosion and overall land degradation, which resulted in considerable areas of cropland unable to provide reasonable crop yield. Estimates show that 1.1 billion tons of soil (58%ot the nation's total loss) are lost from the region each year (Zeleke and Hurni, 2001). About 42% of the estimated soil loss is from only 10% of the region, which is classified as a very high erosion hazard category. These areas are locating in the highlands of North and South Gondar, East, and West Gojjam, North and South Wollo, North Shoa, and Waghamra zones. In terms of the extent of impacts, Gojjam, Awi, and surrounding areas of Lake Tana are the most critical areas where the erosion hazard is very severe. These areas are known as surplus producing areas at both regional and national levels (Admasu, 2005). In his investigation of dams in the Amhara region argued that sedimentation in small dams was serious and needed further research. He was further argued that human activities and lack of soil conservation practice in catchment areas contribute to soil erosion and silting up of many small dams in the region and other parts of Ethiopia.

Shiferaw (2019) pointed out that the Abrajit reservoir in east Gojjam, Amhara region, Ethiopia; is adversely severed by sedimentation due to soil erosion from the watershed area. A bathymetric survey using echo-sounding (Garmin GPSMAP421s) was conducted and a topo map of reservoir data was used for estimation of the sediment volume. For estimating sediment volume from a bathymetric survey and top map data, ArcGIS 10.5 version and Golden surfer 16 latest version were used. The triangular interconnected network (TIN) map was developed for both the initial and measured elevation data using ArcGIS. The deposited sediment volume was estimated by subtracting the TIN map of the initial bed level from the Tin map of the measured bed level. For estimation of annual sediment load contributed from the watershed RUSLE model was conducted. The result of the study revealed that to date, 343,700m^3 volume of sediment was accumulated in the reservoir that reduces 20% of the total reservoir capacity. From the sediment model, annually a total of 28,641.68 m sediment is coming from the watershed to the reservoir that contributed 1.66% of annual reservoir volume reduction. From the comparison of remaining reservoir storage and annual sediment load, the reservoir will not serve more than 12 years. The measured current storage capacity for the Abrajit dam was 1,388,870m^3. The estimated sediment delivery ratio (SDR) for the Abrajitreservoir and its watershed was found to be 96 %. The estimated specific sediment yield (SSY) was found to be 4733.387ton-km^{-2}y^{-1}.

2.7 CAUSES OF SEDIMENTATION

Soil erosion is the major cause of reservoir sedimentation and subsequent sedimentation of reservoirs is a complex process dependent upon many natural and anthropogenic factors. The causes are classified into two concerning factors, namely; Natural Causesand Anthropogenic Causes.

2.7.1 Natural Causes

Geomorphology: In a geological sense, geomorphology is the configuration of the land surface, and it includes the location, size, and shape of such physical features as hills, ridges, valleys, streams, and lakes. Topographic maps show these features.

Hydrology: Hydrology is the science relating to the water of the earth, its distribution, and its phenomena. To be successful, a dam and reservoir project must have an adequate and continuous supply of water suitable for the theory intended uses of the reservoir. Hydrologic information and investigation will be required in varying degrees, depending upon the size of the project. The annual rainfall, the ratio of watershed area to reservoir area, and the volume of the stream of the year must be known.

Hydrogeology: Hydrogeology to determine whether groundwater would contribute to the reservoir or whether the reservoir would lose water to the groundwater system is also essential. The reservoir yield also must be known so that commitments for water will not exceed the quantity of water available.

Geology: It has been said that the construction of a dam and reservoir causes more interferences with natural conditions than does any other civil engineering operation.

Knowledge of the geological situation is essential as a basis for sound engineering, especially in the investigation of dam and reservoir sites, for an error in geological interpretation or the failure to discover some relatively minor geologic detail may be costly and sometimes hazardous.

Soil Characteristics: The type of soil and its properties such as porosity and permeability can cause or lead to erosion within and around the reservoir.

2.7.2 Anthropogenic Causes

Tillage practices: Wrong tillage practices can cause loose soil thereby leading to washing away of topsoil.

Overgrazing: Too much grazing of vegetation by animals can lead to exposure of the soil in an area thereby causing erosion.

Mining and logging: Mining activities can lead to erosion due to wearing off of the surface through surveys and excavation as well. Logging is the cutting, on-site processing, and loading of trees or logs on trucks. It is a process of cutting trees, processing them, and moving them to a location for transport.

2.8. FACTORS THAT AFFECT EROSION AND SEDIMENTATION

The rate and volume of erosion and hence sedimentation can be affected by the following factors.

2.8.1 Catchment size

In Northern Ethiopia, the size of the catchment was one main factor contributing to sediment loads in the reservoirs. The smaller the catchment the greater the chances of suspended load being carried by the flood to reach the reservoir in a relatively shorter distance without settling somewhere in the watershed (Aynekulu et al., 2006). This results in sediment load rapidly filling up the dead storage zone, therefore, reducing the useful life of reservoirs.

2.8.2 Vegetal apron in a catchment

If the catchment area is covered with vegetation like grass, plants, forest area, the soils are held together by a network of roots, which underlies the forest floor. These results reduced the eroding and sediment transport power of runoff. Thus, catchment vegetation affects sediment transport into the rivers and reservoirs.

2.8.3 Topography of catchment area

Although the sediment source can often be localized to the highly erodible hill slopes such as heavily used agricultural fields in the headwater catchments, the transport and storage processes in the reservoir, is not well understood (Muller, 2007). Steep and long slopes develop a high velocity of flow, which will cause more erosion thereby making the river carry a subsequent amount of sediments. Eventually, the sediment will be deposited into reservoirs where the river would be flowing into the reservoir. In Ethiopia, cultivation on steep slopes without applying conservation practice coupled with deforestation case high erosion and has led to the sedimentation of reservoirs (Barber, 1984).

2.8.4 Population increases

Rapid population growth led to fast land-use changes from forest to agricultural land. These changes together with the steep slope topography and inappropriate land-use practices can result in severe soil erosion in the catchment. Eroded sediment particles are then transported away by water. Nizamsagar in India is one of the heavily silted reservoirs constructed in 1931 with live storage of 841 million m3 but according to the echo sounding technique done in 1965, it was found out that about 61% of live storage has been lost (Bowonder et al., 1985). This was attributed to an increase in population density within the catchment, which had increased from 116 to 174 per km2. This along with intensive agricultural activities and cattle grazing in soils susceptible to erosion has led to severe erosion, which then results in sedimentation of reservoirs (Bowonder et al., 1985).

2.8.5 Agricultural practices

Cultivation of crops makes the soil loose and runoff will carry a lot of sediment into the river, which will be subsequently carried into the reservoirs. According to Hill (1999), land use and land cover change in Africa is currently accelerating and causing widespread sedimentation problems in many river catchments. In Ethiopia, continuous cultivation and loss of vegetation cover aggravated soil erosion in the watershed (Amare, 2005). Monitoring such changes is important for coordinated actions at the national and international levels in the integrated catchment as well as basin management to minimize the onsite and _site impact.

2.8.6 Reservoir sedimentation Management Methods

Reservoir sedimentation affects the long-term sustainability of dams. Sediment deposition in reservoirs causes mainly loss of water storage capacity, risk of blockage of intake structures, sediment entrainment in power intakes, and turbines. Sedimentation reduces the flood absorption capacity of reservoirs thus increasing risks of dam overtopping during flood events. Therefore, systematic and thorough consideration of technical, social, environmental, and economic factors should be made to address reservoir sedimentation and prolong the useful life of reservoirs.

2.8.6.1 Reducing sediment inflow to the reservoir

This sediment management method simply means land and catchment management in the upstream watershed of a reservoir. Structural measures and vegetative measures are basic soil conservation measures that are commonly taken to reduce sediment load entering the reservoir. Structural measures include structural terraces, flood interception and diversion works, channel protection and stabilization works, bank protection works, check dams, and silt trapping dams. Vegetative measures include growing soil and water conservation forests and reforestation.

2.8.6.2 Reduction of sediment deposition in the reservoir

Reduction of sediment deposition in reservoirs is conducted by facilitating sediment-laden flows to pass through reservoirs, as quickly as possible, before deposition of sediment. It is one of the most effective and economic ways to preserve storage capacity. The most commonly used methods of sediment deposition reduction are sediment routing. Sediment routing is the method to use reservoir hydraulics and/or geometry to pass the incoming sediment to minimize deposition.

Sediment routing techniques can be done in two main ways: one is sediment pass through: this is where the incoming sediment is discharged through deep sluice mainly during high sediment concentration season in the river. The second way is sediment bypass: is the technique in which the incoming sediment is diverted from the main storage area upstream to the reservoir area. After sediment, routing water from less sediment carrying flow starts to store. Sediment bypass partially preserves the natural sediment transport process in the river.

2.8.6.3 Removing deposited sediment

This method involves the elimination of sediment after it has settled in the reservoir. Flushing is a common method of removing sediment deposits. Sediment flushing involves reservoir drawdown by opening lower level gates to create flow capable of eroding and transporting the deposited sediment through the outlet. Unlike sediment routing which attempts to prevent deposition of sediment during the flood, flushing uses draw downed water to erode the sediment after it has been deposited. It is suitable where the annual runoff volume is large when compared to the reservoir capacity. Due to this removal of deposited sediment, using flushing is not much effective for small reservoirs especially reservoirs having low inflow, because flushing requires draw downing or emptying the reservoir.

2.9RESERVOIR TRAP EFFICIENCY

Reservoir trap efficiency is defined as the ratio of deposited sediment to total sediment inflow for a given period within the reservoir’s economic life and it is influenced by many factors but primarily dependent upon the sediment fall velocity, flow rate through the reservoir, and reservoir operation (Ahmed and Ismail, 2008). Particle fall velocity is influenced by factors such as particle size and shape, water viscosity, and chemical composition of the water (Chalachew, 2007). The main factors influencing trap efficiency can be categorized as hydraulic characteristics of the reservoir and sediment characteristics. Hydraulic characteristics of the reservoir such as the capacity inflow ratio, reservoir shape, type of outlet, and reservoir operation affect the trap efficiency of a reservoir (Musa et al., 2005). Thus, estimation of trap efficiency of a reservoir becomes an important parameter in estimating the useful life of a reservoir. Many empirical relationships (Brown, 1943, Brune, 1953) and their modifications (Gill, 1979, Heinemann and Dvorak, 1963) are available in the literature for estimating the trap efficiency (TE) of reservoirs. These relationships take into account the common parameters like the capacity of reservoirs, the annual inflow, and the catchment area of the reservoir. Brune’s and Churchill's empirical relationships have been widely used and found to provide reasonable estimates for long term release and trapping efficiency. Both methods are based on reservoir capacity to inflow ratio (C/I) and neither method specifically considers the effect of sediment characteristics (Verstraeten and Poesen, 2000) have stated that although the use of the Churchill curves may give a better prediction of TE compare to Brune curves, but it is very difficult to obtain the input data for calculating the sedimentation index forthe Churchill curve.

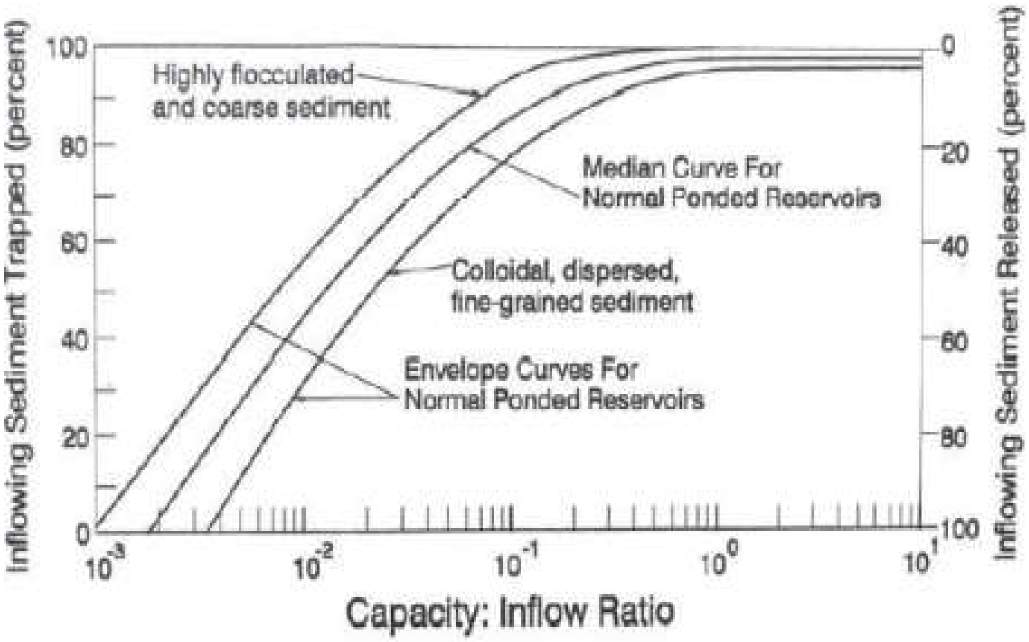

Figure 1. Brune curve (Brune, G. M., 1953)

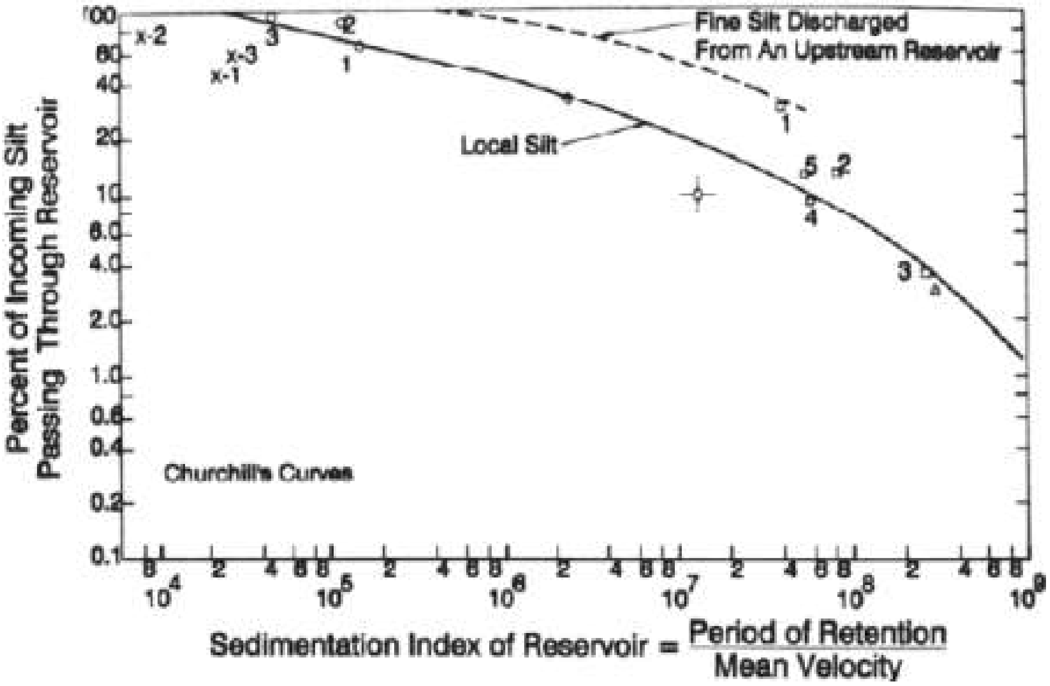

Figure 2 Churchill curve (Churchill, M. 1958)

These relationships take into account the common parameters like the capacity of reservoirs, annual inflow, and the catchment area of the reservoir. Brune's and Churchill's empirical relationships have been widely used and found to provide reasonable estimates for long term release and trapping efficiency. Both methods are based on reservoir capacity to inflow ratio (C/I) and neither method specifically considers the effect of sediment characteristics. (Verstraeten and Poesen, 2000) have stated that although the use of the Churchill curves may give a better prediction of TE compare to Brune curves, but it is very difficult to obtain the input data for calculating the sedimentation index for the Churchill curve (figure 2). The relationship proposed by (Brune, 1953) (figure 1), is considered to be more accurate than that of (Brown, 1943) (figure 3) if the annual inflow rate is known. Very few studies have been reported in the literature on reservoir sedimentation and most of them are based on analytical methods. In general, the amount of sediment accumulated in a reservoir is expressed as a percentage of the inflow sediment quantity, which is called sediment Trap Efficiency (TE).

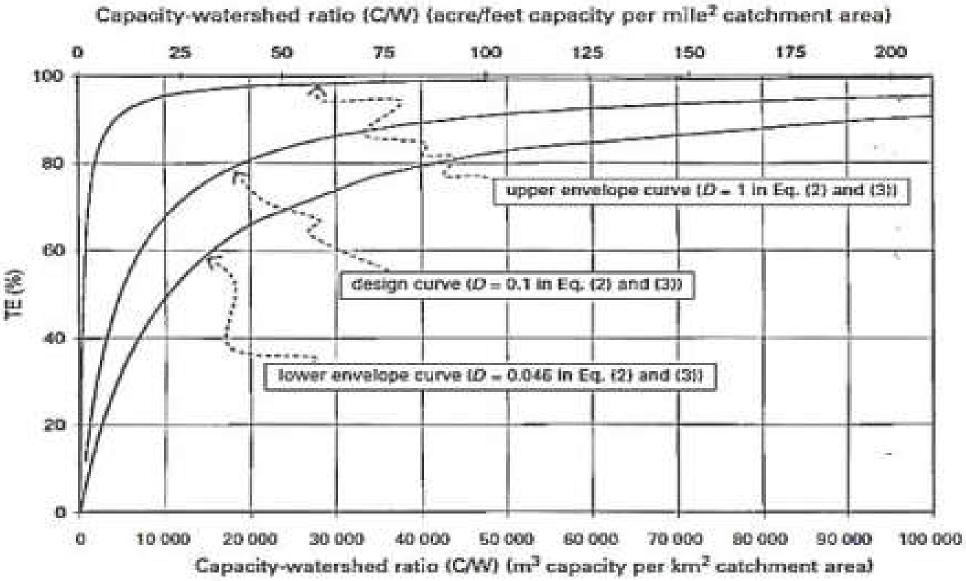

Figure 3. Brown's curve

The relationship can also be expressed as (equation 1):

$$TE = 100\left(1 - \frac{1}{1 + 0.0021D * \frac{C}{A}}\right) \text{.......... ....} 1$$

Where, C = reservoir storage capacity expressed in m^3; and A = catchment area expressed in km^2. D is a coefficient whose values range from 0.046 to 1, with a mean value of 0.1.Here, Brown (1943) has also considered the capacity (C) and watershed area (A) of the reservoir when a more significant number of parameters affect the reservoir sedimentation.

3. METHODOLOGY

3.1 Area Description

Gefersa reservoir is located 18 km west of Addis Ababa in West Shewa Zone, within Oromiya Region. Addis Ababa Water and Sewage Authority (AAWSA) has administrative control of the area. The reservoir is in a shallow basin about 10 km wide, stretching between the Wechacha and Entoto mountains with a catchment area of 5,551ha in the Awash basin. The location of the study area is as shown in Fig. 4. Coordinate of the Gefersa catchment is 38° 37' 13.291" E and 9° 5' 25.700" N which covers a total area of 5551Ha.

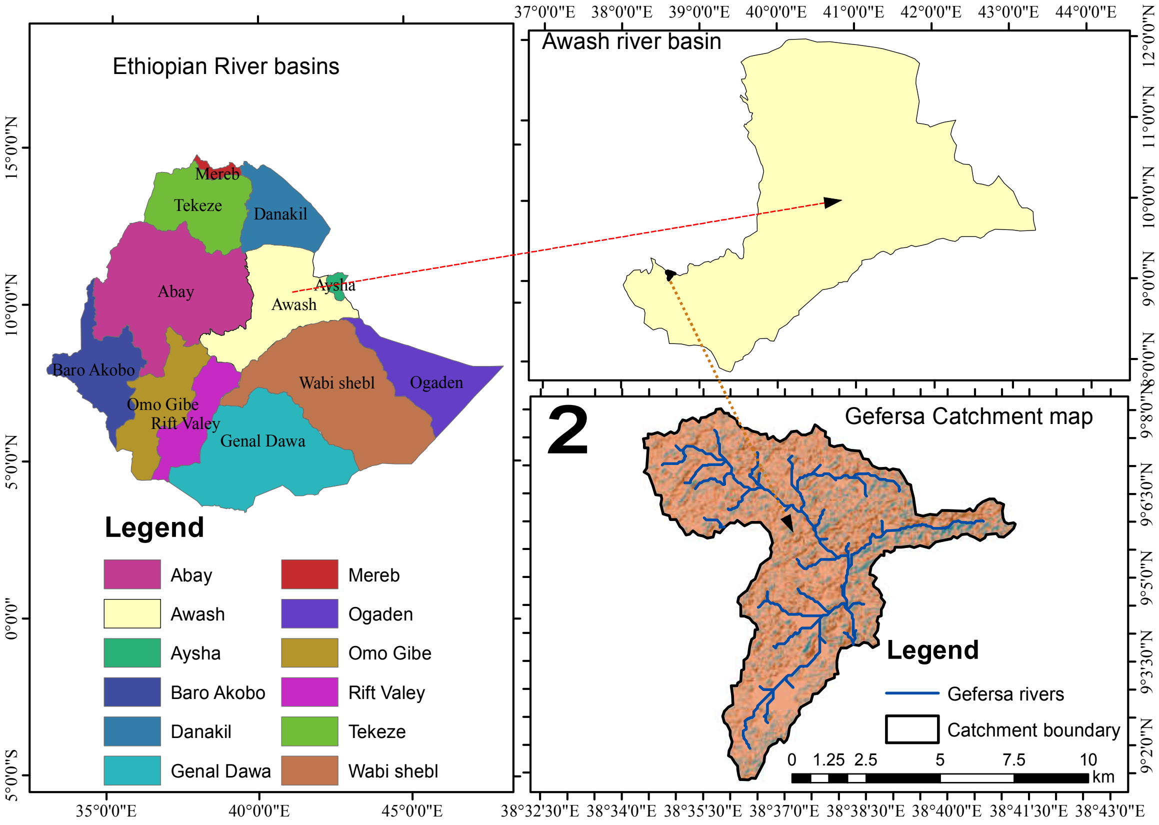

Figure 4. Location map of the study area

3.2 INPUT DATA

The RUSLE model was applied to analyse the mean annual soil loss, which requires land use/land cover map, rainfall, slope length/steepness, soil types and properties, and management practices, and the parameters of this method can be easily estimated andintegrated with GIS for better analysis. It is the best available model that can be used at the watershed or basin-wide levels. Input values were obtained from the digital elevation model (DEM), land use/land cover (LU/LC) maps from a satellite image, and soil and rainfall data which were then integrated with the RUSLE model. This model is more efficient for a small area, e.g., watershed level, because it does not have the capability for routing sediment through channels.

3.2.1 DEM and Slope of Study area

DEM data is the most important dataset for every slope generation project. It is defined as the raster data containing an array of pixels or cells having an elevation value of every point in a given area at a particular resolution. For this study, 30x30m resolution of DEM data was downloaded from SRTM (Shuttle Radar Topographic Mission) and it has been projected on coordinate system WGS_1984_UTM, Zone_37N. The DEM as shown in Fig 5a is used to delineate watersheds and analysis the networks of drainage and streams pattern of terrain. The slope map of the study area was prepared from DEM processing using ArcGIS 10.3. A slope ranging from 0–48.71 % as shown in figure 5b, characterizes the watershed. The slope is the most important terrain characteristic and plays a vital role in soil erosion and soil loss estimation, which is loading to the reservoir from the upper catchment. The altitude of the catchment area ranges from 2,543 to 2,958 m-AMSL. The major physiographic units in this area are gentle rolling; gentle sloping, moderately steep/ hills as shown in table 1.

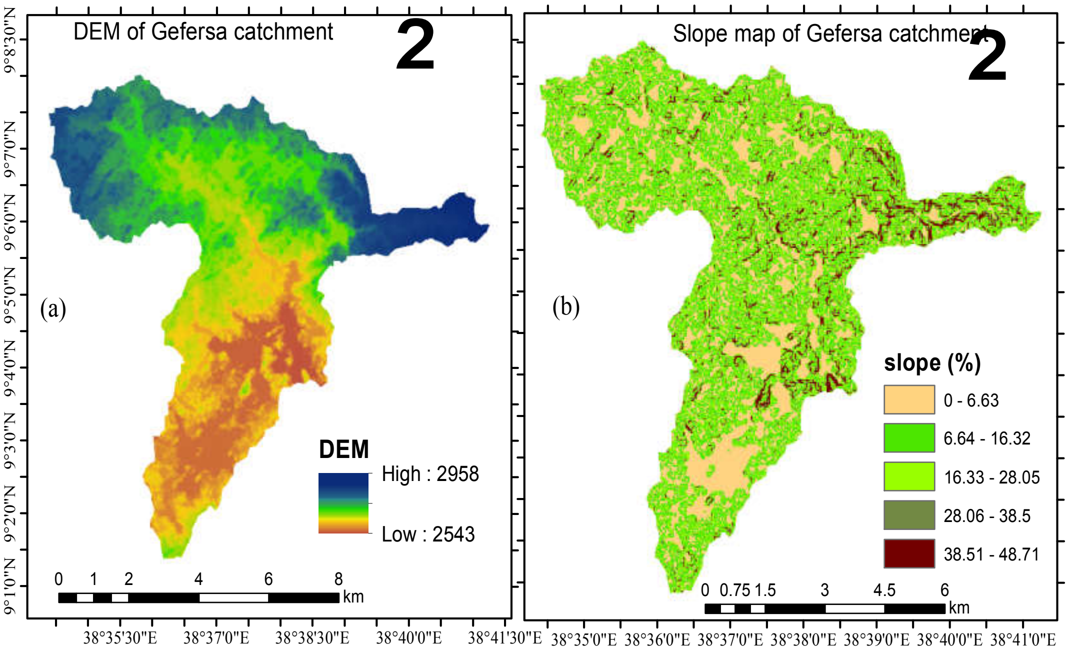

Figure 5. (a) DEM and (b) Slope maps of the study area

Table 1. Watershed slope characterization based on FAO classification

no	Slope (%)	description	Area (ha)	Coverage (%)
1	0 - 6.63	Flat/gentle	1725.4	31.08
2	6.64 - 16.32	Gently sloping	1865.76	33.61
3	16.33 - 28.05	Gently rolling	1313.36	23.66
4	28.06 - 38.5	Moderately steep	523.2	9.42
5	38.51 - 48.71	Steep/Hilly	123.72	2.23

3.2.2 Climate

The Gefersa catchment is located in a relatively high rainfall area with an annual rainfall of around 1,200 to 1,300 mm. There are two seasonal patterns in the region of Addis Ababa. Theweather is relatively cool in the wet season of July to September when the main rainfalls, whilethe rainless season of October to June has warmer temperatures. Various spatial interpolation techniques have already been employed in related fields. Such techniques can be divided into geographical statistics and non-geographical statistics. Examples include nearest neighbour (NN), Thiessen polygons, splines and local trend surfaces, global polynomial (GP), local polynomial (LP), trend surface analysis (TSA), radial basic function (RBF), inverse distance weighting (IDW), and geographically weighted regression proposed by Fotheringham et al. 2002. Through IDW, the spatial rainfall field can be obtained when data over a whole catchment are interpolated. When using such method, the results were proven satisfactory as the stimulated data at individual sites preserved properties which mimicked the observed statistics at an acceptable level for practical purposes. The main impact of climate variability on soil erosion globally indicates as shown in Fig. 6.

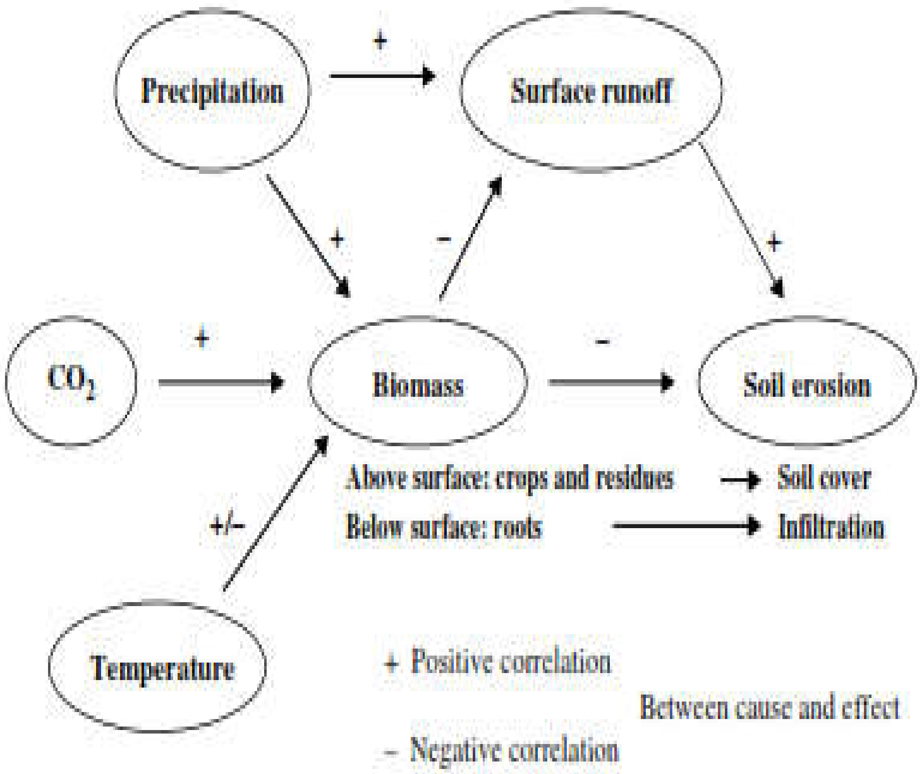

Fig. 6 Main pathways of selected climatic factors on surface runo and soil erosion (Klik, A. and Eitzinger, J., 2010)

The rainfall data were obtained from the National metrology Agency (NMA). There were four namely Tseday, Kotebe, Holleta, and Menageshasuba meteorological stations located inside and outside the Gefersa watershed where highly influencing the catchment area. The daily rainfall data of those stations are used in the model. The rainfall data for stations was available from 1987 to 2017 (Table 2). In order to assimilate some characteristics of spatially varying rainfall, the inverse distance method is themost advantageous for interpolations using spatially dense networks. The monthly values were converted to mean annual rainfall and interpolated using the ordinary IDW method for the entire watershed. Then, the R factor map was determined.

Table 2. Influencing metrological stations

No	station	mean annual RF(mm)
1	Tseday	552.20
2	Kotebe	846.05
3	Holletta	838.59
4	MenageshaSubba	745.61

(**Source:** Ethiopian National Methodological Agency)

3.2.3 Soil of the study catchment

The soil map of the Gefersa Catchment was extracted from the Awash basin soil map. Shapefile was converted into a grid format using Arc GIS 10.3. The soil data needed for the physical and chemical characteristics of the soil both play a large role in determining the movement of water within the study area. According to the soil distribution map prepared by the Ethiopian Ministry of Water and Energy for the Awash basin, five different types of soil were identified in the study area; Vertic cambisols, Orthicsolonchaks, Eutric nitisols, Chromic vertisols, Chromic luvisols, of which, Vertic cambisols cover most of the study area.

The catchment has principally five soil classes and the area covered by each soil type is indicated in (Table 3) and presented in Figure 4a, lowland extensions of the catchment are dominated by Eutricvertisols while chromic Luvisols dominate the highland areas of the catchment. The catchment is characterized by five soil types as indicated in Table 3 and Fig 9a. The catchment has principally five soil classes. Luvisols followed by Leptisols (Table 3) mostly dominate vast areas of the catchment. As presented in Figure 5a, lowland extensions of the catchment are dominated by Vertic cambisols while chromicvertisols dominate the highland areas of the catchment. The second and the third soil types of the catchment are vertisols which are heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens inmost years. While Nitisols are deep, well-drained, red tropical soils with diffuse horizonboundaries and a subsurface horizon with at least 30 percent clay and in a moist state, shinyaggregate faces (IUSS Working Group WRB, 2015).

Table 3. Soil Gefersa catchment

No	Major soil types	Area (ha)	Area (%)
1	Vertic cambisols	2877.18	51.83
2	Orthicsolonchaks	554.98	10.00
3	Eutric nitisols	709.61	12.78
4	Chromic vertisols	1339.05	24.12
5	Chromic luvisols	70.36	1.27

3.2.5 Land use Land cover types

The close association between soil erosion and changes in land use and even land cover deserves special mention. The human use of land gives rise to land use which varies with the purpose it serves, whether it be food production, provision of shelter, recreation, extraction ofnatural resources, etc. In the developing countries, due to population pressure on land, there is a continuous need to extract the maximum output from the available resources. Thus, the impact ofland degradation can be much worse than in other countries and adversely affect even the landcover of the region (Roy and Roy, 2010). Land cover refers to the naturally existing cover on theland surface in the form of water bodies, vegetation, bare soil, and the like (Ellis and Pontius, 2007). Since food production can only come from agricultural land, the cultivated area needs to increase.However, since the total geographical area cannot be practically enlarged, environmentally sensitive land areas are often seen to be brought under cultivation. Together with this, the existing land cover is bound to change, such as through the clearing of forests. Thus, land-use changes are initiated leading to degradation of the quality of the land.The detail of satellite data is presented in Table 4. The imagery was processed using ArcGIS10.3 and ERDAS IMAGE14 software. Spatial distribution and specific land use parameters were required for RUSLE modeling.In the study area, 8 major land use/ land cover types have been identified asshown in Table 4 and Fig. 7b. The land use land cover is the spatial data used for soil loss estimation and to identify the erosion hotspot areas in the upper catchment of the dam and it's also important to estimate how the natural resources in the study area were affected by the streamflow and loading sediments to the reservoirs. This was done by integrating the RUSLE model with GIS tools. From the classification of the land use land cover: cropland, grassland, and forest land cover 38.204%, 27.688%, and 25.328% respectively from the whole area coverages as indicated in Table 4 and Fig. 7a and 7b.

Table 4. Details of land use land cover categories

No	**Land cover types**	**Area (ha)**	**Area (%)**
1	Forest land	1406	25.328
2	Annual Cropland	2120.8	38.204
3	Bare Soil	2.2	0.040
4	Closed Grassland	1537	27.688
5	Closed Shrubland	155.2	2.796
6	Settlement	181	3.261
7	Water Body	135	2.432
8	Wetland	14	0.252

(**Source:** ERDAS 2014 classification results)

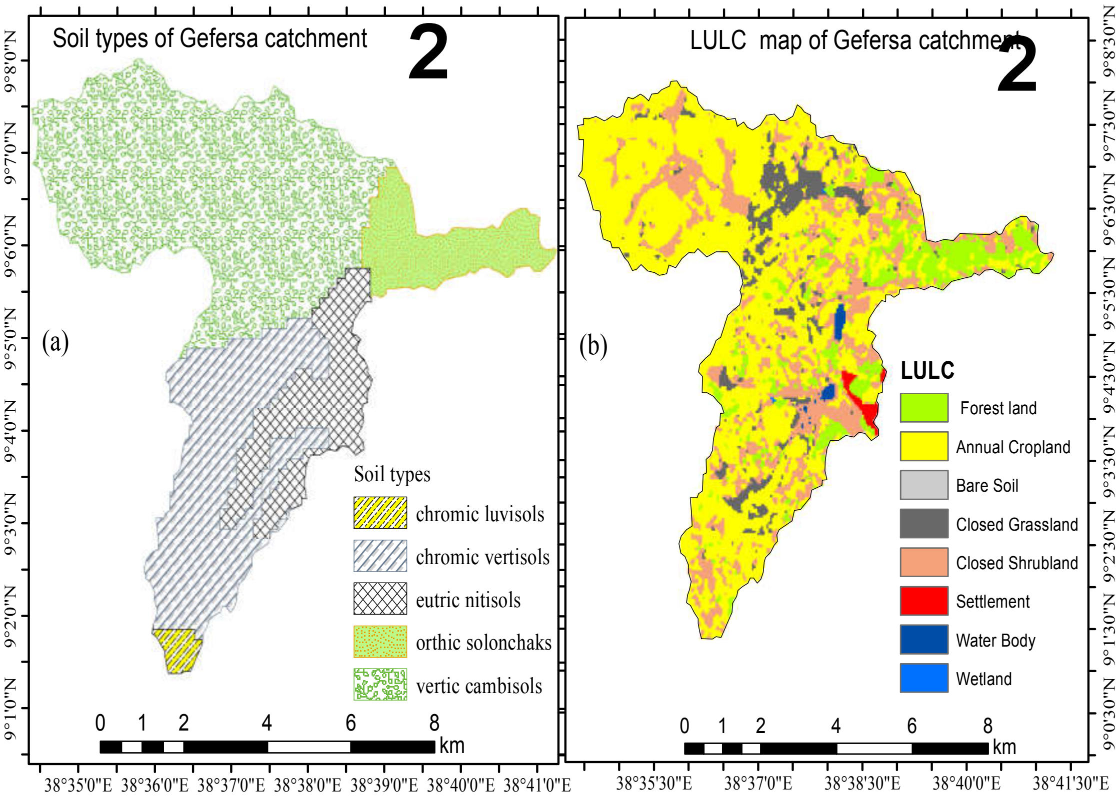

Figure 7. (a) Soil types and (b) LULC of Gefersa catchment

3.2.6 Data collection

The data sources used for the study are Climate, Soil, DEM, Satellite Image,and related data acquisition are shown in (Table 5).

Table 5. Data source and Description

No	Data types	Description	Use	Sources
1	Rainfall Data	Mean Annual Rainfall	Erosivity factor (R-factor) calculation	National Meteorological Agency
2	Soil	Digital soil map	Soil erodibility (K-factor) calculation	MoIE
3	DEM	SRTM 20m resolution	Slope and LS factor Generation	http://earthexplore.usgs.gov
4	Satellite Image	Sentinel 2A (30m Resolution)	Land cover classification and C-factor generation	http://earthexplore.usgs.gov
5	Field data	Ground control points, Observation	P-factor generation	Own sources

3.8 SOIL LOSS ANALYSIS

Revised Universal soil loss equation (RUSLE) in a raster GIS environment was employed in assessing the soil erosion risk and mapping. RUSLE is developed as an equation of the main factors controlling soil erosion, i.e., climate, soil characteristics, topography, land cover, and land management practice. Soil loss rate at watershed level is determined by the interplay of physical, hydrological, and land management practices. Therefore, the Revised Universal Soil Loss Equation (RUSLE) modelling was used for soil erosion assessment, because RUSLE is used to compute long-time average soil losses from sheet and rill erosion. Priority areas in a watershed for conservation measures can be identified by considering physical hazards like drought, soil erosion, sedimentation, and excessive percolation under irrigation (Khan et al., 2001, Tripathi et al., 2003). In this study, identification of erosion risk areas to prioritize the watersheds for conservation measures planning was done based on soil loss rate using revised universal soil loss model (RUSLE), which was developed by Renard et al., 1997; the annual soil loss rate was calculated by a cell-by-cell multiplication of the raster map of the six erosion factor(Cover, C factor; Rainfall Erosivity, R factor; Soil Erodibility factor, K; slope steepness- length factor, LS; and Conservation practice P, factor). This model is used to quantify the soil loss in the upper catchment of the Gefersa dam to prevent the dam from sediment deposition to improve the performance of the dam for long period.

According to Renard et al., (1991), USDA-ARS, (1980), the form of the Revised Universal Soil Loss Equation (RUSLE) is expressed by the formula:

$$A= R \times K \times LS \times C \times P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2)$$

Where: A is the mean annual soil 1 yr^{-1}); K is erodibility index (tons ha and steepness (S) factor (dimensionless) C is the land between 0-1), and P is the management practice factor. Individual files was built for each factor in the RUSLE and combined by cell grid modelling procedures in a GIS software environment to predict soil loss in the watershed (figure 8).As indicated in the conceptual framework diagram (figure. 8) all factors estimated based on the recommendation of different scholars and Hurni (1985a).

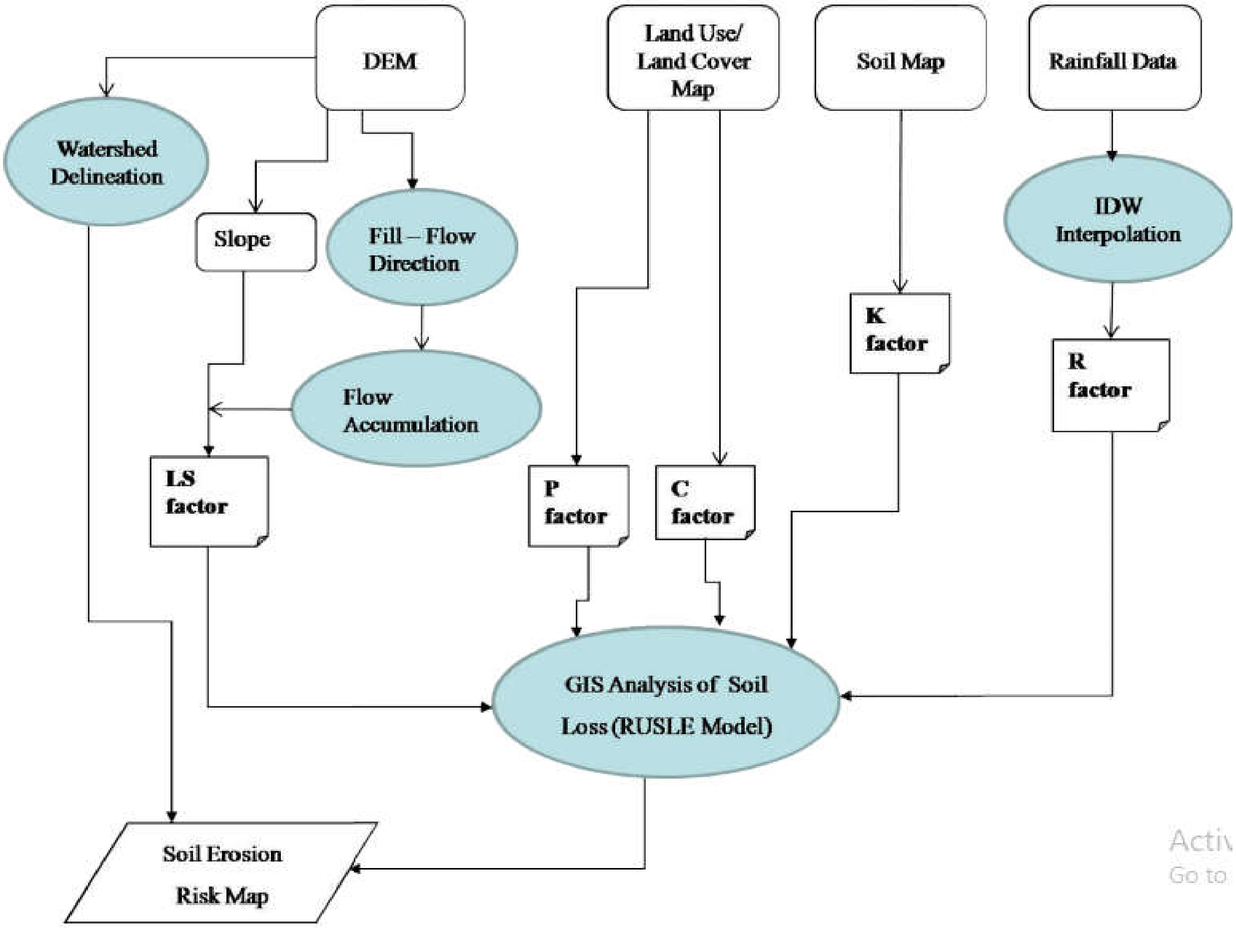

Figure 8: Flow Chart of General Methodology for RUSLE model

3.8.1 Parameter estimation for RUSLE model

3.8.1.1 Rainfall Erosivity Factor (R)

The rainfall factor, an index unit, is a measure of the erosive force of a specific rainfall. In this particular study, the R factor was estimated by taking the average of RF from four neighbouring stations, which affects the Gefersa catchment. The R-value was calculated based on the equation given by Hurni (1985) which is derived from spatial regression analysis (Hellden, 1987) for Ethiopian conditions. The equation is highly preferred for the Ethiopian case since rainfall intensity data, which is used to derive rainfall kinetic energy, is not available for Ethiopian conditions and the equation is based on the easily available mean annual rainfall (P).

$$R= -8.12+ (0.562\times P)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

Where; R is the erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1}), P is the mean annual rainfall in mm. The inverse distance weight of the spatial interpolation technique in GIS software was used for assessing the spatial variability in the rainfall. Then R-value was calculated from the rainfall map using the 'Raster calculator' tool. The raster rainfall data of the study area was then converted to an erosivity map of the study area using the regression equation.

3.8.1.2 Soil Erodibility Factor (K)

The erodibility of soil is an expression of its inherent resistance to particle detachment and transport by rainfall. It is determined by the cohesive force between the soil particles and may vary depending on the presence or absence of plant cover, the soil's water content, and the development of its structure (Wischmeier& Smith, 1978). The Soil Erodibility (K-factor) refers to the liability of the soil to "suffer" erosion due to the forces causing detachment and transport of soil particles (Hellden, 1987). For Ethiopian conditions, an attempt was made to classify the soil types of the study area based on their color by referring to the FAO soil database. K-values reflect the rate of soil loss per rainfall-runoff erosivity (R) index.This factor is used to quantify soil resistivity to transport by shear stress on ground flow and raindrops. Based on the recommendation of different scholars (Animka et al. 2013; Wischmeier& Smith 1978) and kinds of literature the researcher reclassifying the soil of the study area and assigned k-values based on the colors of the soils (Table 6).

Table 6. K-values based on colours

No	Soil color	Name/class	K values [metric tons ha^{-1} MJ^{-1} mm^{-1}]
1	Brown	Chronic Luvisols/ HaplicLuvisols/ Urban etc…	0.2
2	Yelow	Eutric Fluvisols/ Eutric Leptosols, eutric nitosols	0.3
4	Block	Eutric Vertisols, vertic cambisols etc…	0.15
6	Red	haplic Nitisols, Alisols, orthic solonas,etc...	0.25
8	Blue	Water	0

(Source: Wischmeier and Smith, 1978**)**

3.8.1.3 Slope Length-Steepness (LS) Factor

The Slope length-steepness (LS) factor is the combinedfactor that indicates the effect of slope length and slope steepness on soil loss. The effect of topography on soil erosion is accounted for by the LS factor in RUSLE, which combines the effects of slope length factor (L) and steepness factor (S). The LS-factor is derived from slope and flow accumulation. Slope and flow accumulation were generated from 20 m x 20 m resolution DEM using ArcGIS 10.3. Then the LS factor was estimated with the following equation using a raster calculator in which is proposed by (Gizachew, 2015). The LS-factor of the study area has been generated from DEM using the following steps in the GIS environment:

1) Filling of sinks of DEM of the study area;
2) Generation of S-factor using filled-in DEM as an input;
3) Generation of flow direction by using filled DEM as an input.
4) Computing flow accumulation raster using flow direction raster as an input;
5) Generating the slope of the study area in degree
6) Calculating LS-factor by using flow accumulation slope raster as an input.

The output LS-factor raster map of the Gefersa catchment is shown in Figure 13.As revealed by Moore & Wilson (1992) LS factor is an important parameter in RUSLE to measure the sediment transport capacity of the flow. It is important to consider the upslope contributing area to estimate the LS-factor for the spatial distribution of soil erosion in a given catchment area (Moore & Burch 1986a, 1986b; Mitas&Mi-Tarasova 1996; Simms et al. 2003). Hence, this study used the following advanced method of calculating the LS-factor in the ArcGIS environment (Equation 3).

$$LS = Power(Flowaccumulation * \frac{Cell\,size}{22.13}, 0.4) * Power(\frac{\sin(slope(\%))}{0.09}, 1.4) * 1.4 ------------(4)$$

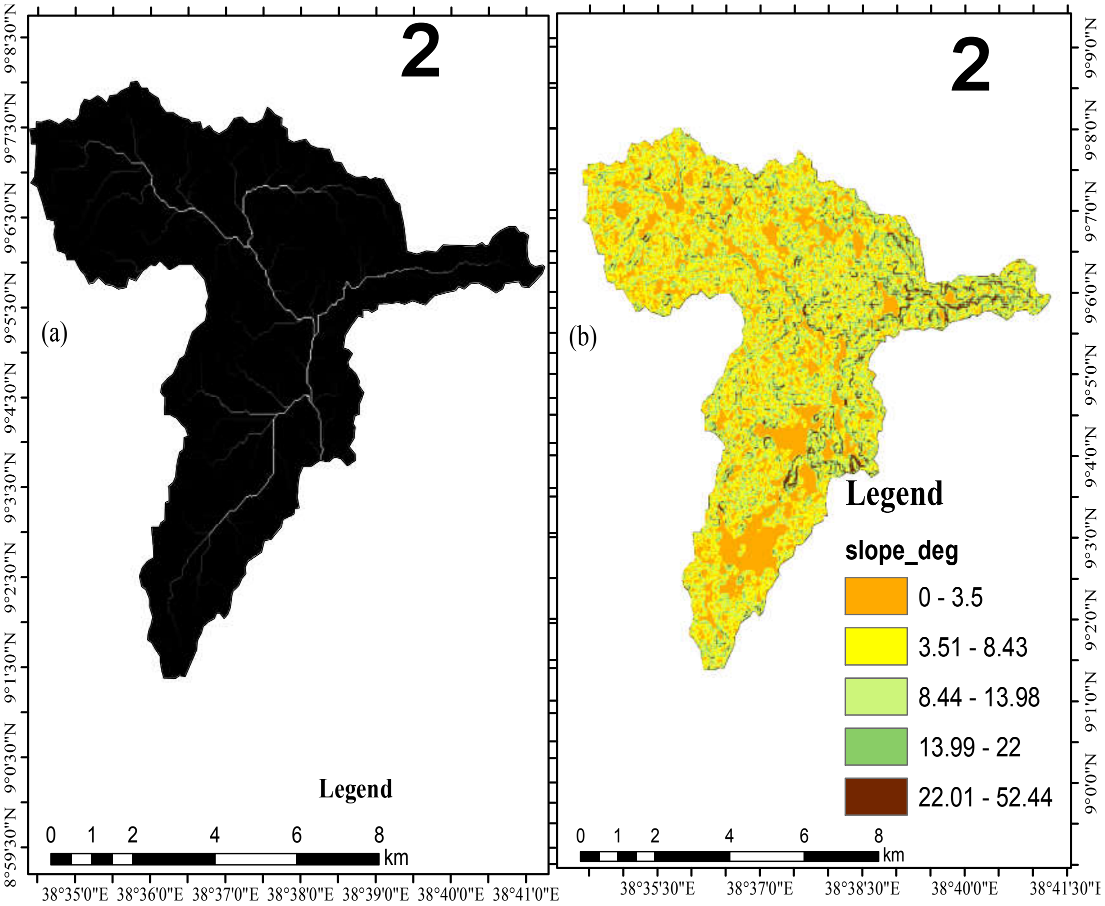

Figure 9. (a) Flow accumulation and (b) slope (in degree) map

3.8.1.4 Support practice (P) factor

The conservation practices factor (P-values) reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. It depends on the type of conservation measures implemented and requires mapping of conserved areas for it to be quantified. The P-value ranges from 0 to 1 depending on the soil management activities. The Values for P factor was assigned based on values of Hurni, 1985 and different kinds of literature. In this study, the P-factor values were assigned according to the suggestion of different academics and considering the indigenous managing performance (Table 7). Based on the land use land cover thematic map of the study area the p-values suggested by different scholars were assigned (Figure 14b).

Table 7. P-factor with corresponding Land use types (Renardetal.,1997, Wischmeier& Smith, 1978)

No	Land cover types	Area (ha)	Area (%)	P-factor
1	Forest land	1406	25.328	0.001
2	Cropland	2120.8	38.204	0.8
3	Bare Soil	2.2	0.040	1
4	Grassland	1537	27.688	0.01
5	Shrub land	155.2	2.796	0.9
6	Settlement	181	3.261	0.003
7	Water Body	135	2.432	0
8	Wetland	14	0.252	0.99

(P = Dimensionless)

3.8.1.5 Cover and management (C) factor

The cover management factor represents the effects of vegetation, management, and erosion control practices on soil loss (Renard, 1997). The C value is a ratio comparing the existing surface conditions at a site to the standard conditions of the unit plot. Each cover value of the study area was synchronized with the adopted C value in Ethiopian condition. The major land use land cover types in the watershed were analysed from satellite images and assigning the corresponding C-factor value obtained from different revisions C is the crop/vegetation and management factor. It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C-factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land (Chadli, K., 2016). (Figure. 13b and Table 8).

Table 8. Land cover classes and relevant C-factor value (Renardetal.,1997Wischmeier& Smith, 1978)

No	Land cover types	Area (ha)	Area (%)	C-factor
1	Forest land	1406	25.328	0.02
2	Cropland	2120.8	38.204	0.15
3	Bare Soil	2.2	0.040	1
4	Grassland	1537	27.688	0.01
5	Shrub land	155.2	2.796	0.014
6	Settlement	181	3.261	0.09
7	Water Body	135	2.432	0
8	Wetland	14	0.252	0.045

(C = Dimensionless)

3.9 RESERVOIR TRAP EFFICIENCY

Reservoir sedimentation has become one of the major problems facing water resources development projects in many countries around the world. However, only a limited number of studies have been reported in this field, particularly addressing the trap efficiency of reservoirs. Besides, even the available studies in this area have considered only a few parameters governing reservoir sedimentation. As a result, the available knowledge on trap efficiency is not very well-definedTrap efficiency (TE) is the proportion of the incoming sediment that isdeposited, or trapped, in the reservoir (Verstraeten and Poesen, 2000). To determine the average sediment yield from the contributing watersheds, the weight of deposited sediment needs to be adjusted for reservoir sediment TE. This helps to adjust the sediment that may leave the reservoir and avoids possible underestimation of sediment deposition. There are different approaches to estimating the TE of reservoirs (Verstraeten and Poesen, 2000). One of the most commonlyused empirical-based models for small reservoirs are that proposed by Brown, (1943), as illustrated byVerstraeten and Poesen, (2000).So Brown's curve, (1943) method was used in this study to estimate trap efficiency as (equation 1) below which is already explained in the literature part of this document.

$$TE = 100\left(1 - \frac{1}{1 + 0.0021D * \frac{C}{A}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where TE (%) is trap efficiency, C is reservoir storage capacity (m^3) and A is the catchment area (km^2). D has constant values ranging from 0.046 to 1. A value of D = 0.1 is recommended for average conditions, and values of D = 1.0 for coarse sediment; D=0.1 for medium sediment; and D=0.046 for fine sediment is recommended (Gill, 1979). From the design report, the largest portion of the Gefersawatershed is coarse sediment. So, considering the textural class of the watershed D value of 1.0 was used in this study.

3.10 SEDIMENT DELIVERY RATIO (SDR)

S_{DR} is a measure of sediment transport efficiency, which accounts for the amount of sediment that is transported from the eroding sources to a catchment outlet compared to the total amount of soil that is detached over the same area above the outlet. Significant research has been performed to estimate the sediment delivery ratio related to watershed size. For this study, sediment delivery ratio and the total amount of sediment that transported from the eroding sources, reach the reservoir was estimated using the following relationship developed by USDA (1972).

$$S_{DR} = 0.5656 * A_W^{-0.11} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

$$S_Y = S_{DR} * A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where: S_{DR} = Sediment Delivery Ratio

A_w = Area of the watershed, (km^2)

S_Y = Sediment yield (t/ha/yr)

A = soil loss (t/ha/yr) obtained by RUSLE model

There is no precise procedure to estimate S_{DR}, although the USDA has published a handbook in which the $S_{DR}$is related to drainage areas (USDA SCS, 1972). S_{DR}can be affected by many factors including sediment source, texture, nearness to the mainstream, channel density, basin area, slope, length,land use/land cover, and rainfall-runoff factors. The relationship established for sediment delivery ratio and drainage area is known as the S_{DR}curve. For example, a watershed with a higher channel density has a higher sediment delivery ratio compared to the same watershed with a low channel density. A watershed with steep slopes has a higher sediment delivery ratio than a watershed with flat and wide valleys. To estimate sediment delivery ratios, the size of the area of interest should also be defined.

3.11 ESTIMATING SPECIFIC SEDIMENT YIELD (SSY)

Sediment yield refers to the total sediment discharge from the watershed into the reservoir measured over a specific period. The specific sediment yield is calculated by dividing Sediment yield by the catchment area (Verstraeten and Poesen, 2001) as (equation 7) below:

$$SSY = \frac{S_Y}{A_W} \qquad 7$$

In this study, estimation of sediment yield and specific sediment yield of the watershed was done based on the above formula. Where S_Y is sediment yield, SSY is specific sediment yield.

4. RESULT AND DISCUSSION

4.1 RESULT

4.1.1 Rainfall erosivity factor (R)

In the current investigation, the average annual rainfall was used for the calculation of the R factor as indicated in (Eq. 2). Fig. 10b, shows the erosivity map of the study area based on the rainfall data of the study area. The value of R ranges from 303.12 to 446.34 MJ/mm/ha/h/year. The spatial average rainfall distribution in the study area for rainfall data from 1987 to 2017 years using the four rainfall stations in and around the study area is also shown. Fig. 11a.

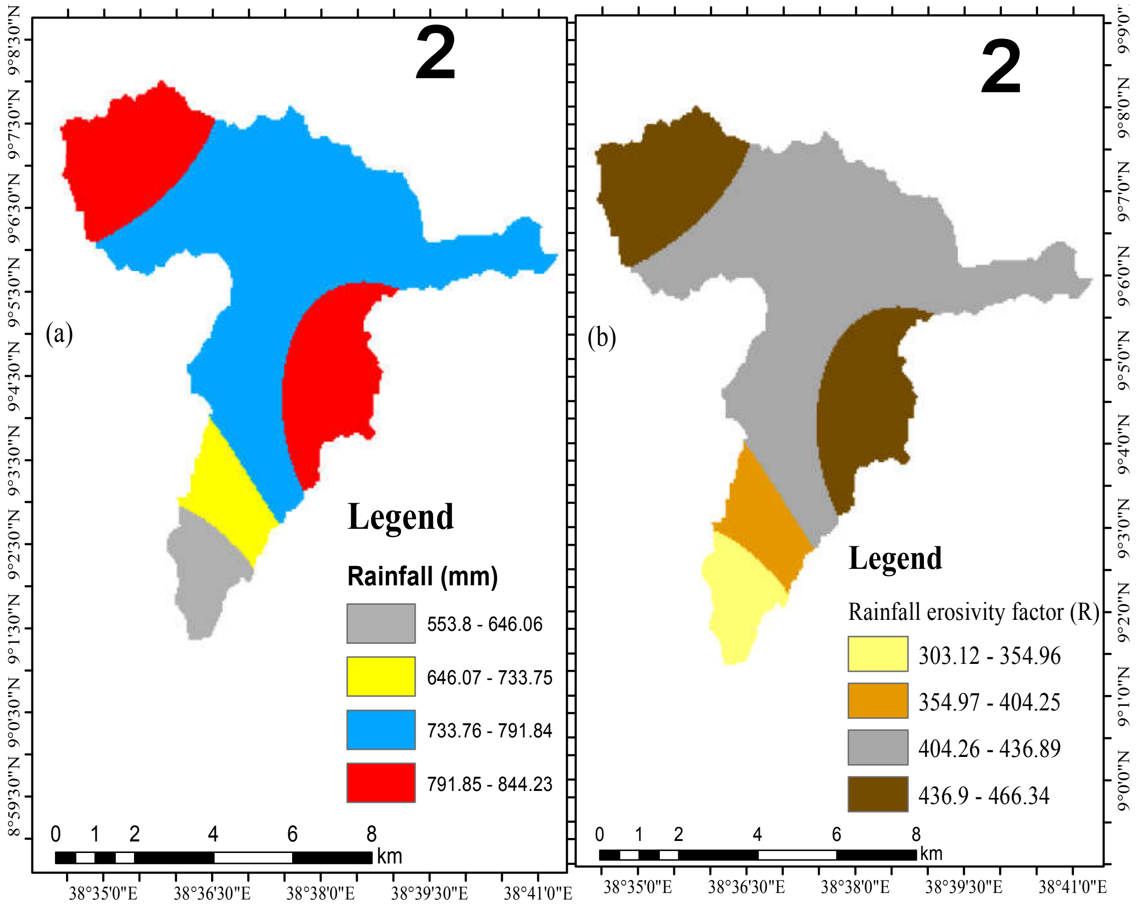

Figure 10. Rainfall and rainfall erosivity map (R)

4.1.2 Soil erodibility factor (K)

The values of the K-factor generated from the respective soil types to obtain a map of the soil erodibility at the Gefersa catchmentare shown in Fig.11b. The catchment soil map has been reclassified with the given value of K (Fig. 11b). The value of K ranges from 0 to 0.3, values close to 0 being less prone to soil erosion.

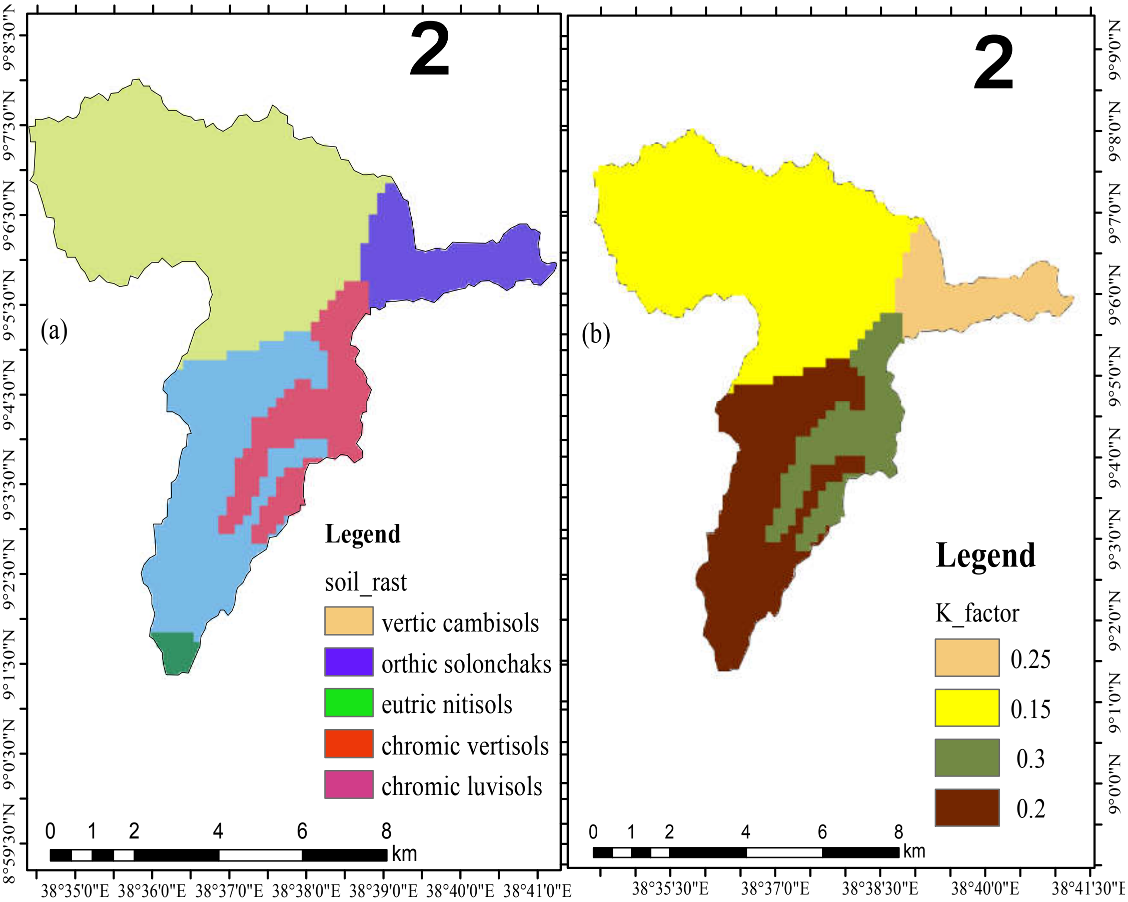

Figure 11. Soil and soil erodibility map (K)

4.1.3 Slope length and steepness factor

To run the Length-Steepness (LS) equation (Eq.4), the slope in degree was processed and the LS was then calculated using the raster calculator tool by using the formula on Equation 4. The resulting combined LS-factor map varied between 0 and 144.11 (Fig. 12)

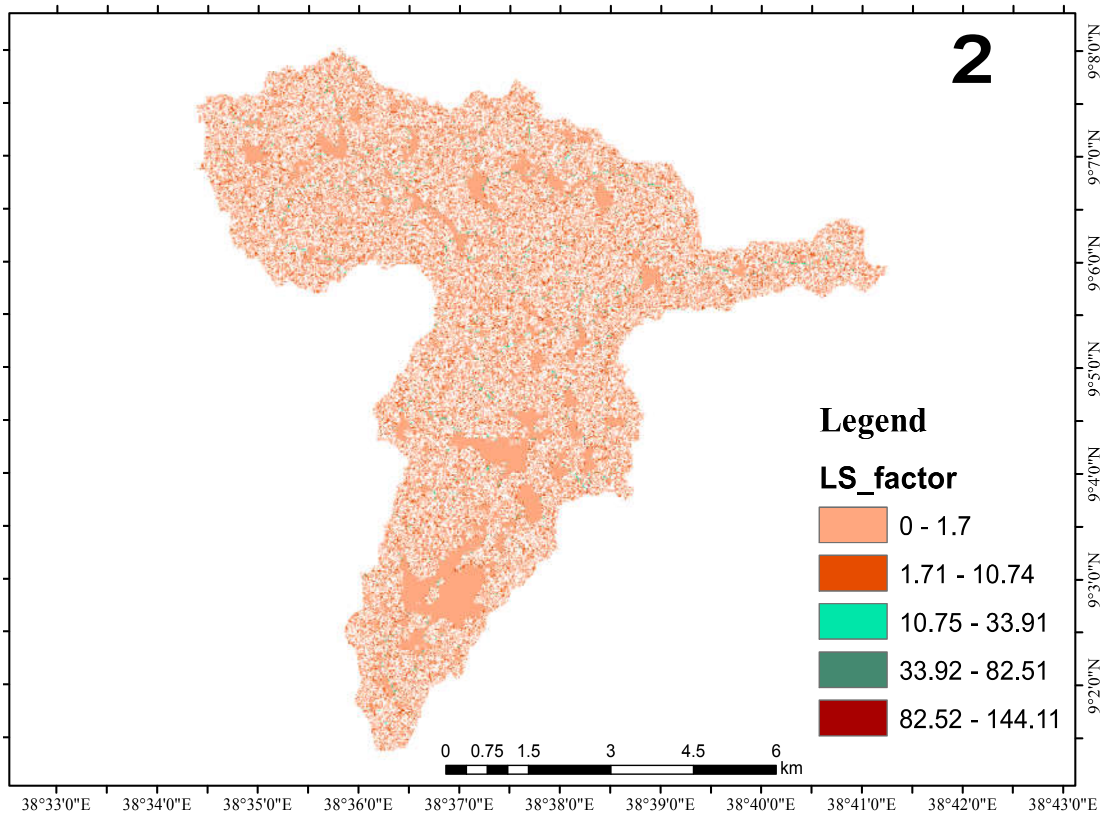

Figure 12. Slope length steepness factor of the study are

4.1.4 Crop management factor (C)

Information on land use permits a better understanding of the land utilization aspects of cropping patterns, fallow land, forest, wasteland, and surface water bodies, which are vital for developmental planning or erosion studies. Remote sensing and GIS technique has the potential to generate a thematic layer of land use-land cover of a study area for 2019 yearLand sat Oli8 satellite images. The overall accuracy of image classification is 87.7% and The Kappa coefficient is calculated to be 82.9%. This kappa value shows strong agreement. According to the formula given by (Congalton& Green, 2008). The study area has been classified into eight land use classes. Crop management factor was assigned to different land-use patterns using the values given in Table 8. Using land use-land cover map and C-factor value, the C-factor map was prepared. Available land-use data provide a good understanding of the land-use characteristics of surface water, wastelands, cropping patterns, forests, and fallow land. The values of C are given in Table 8. The value of the C factor determined by using the land use map is shown in fig. 13b.

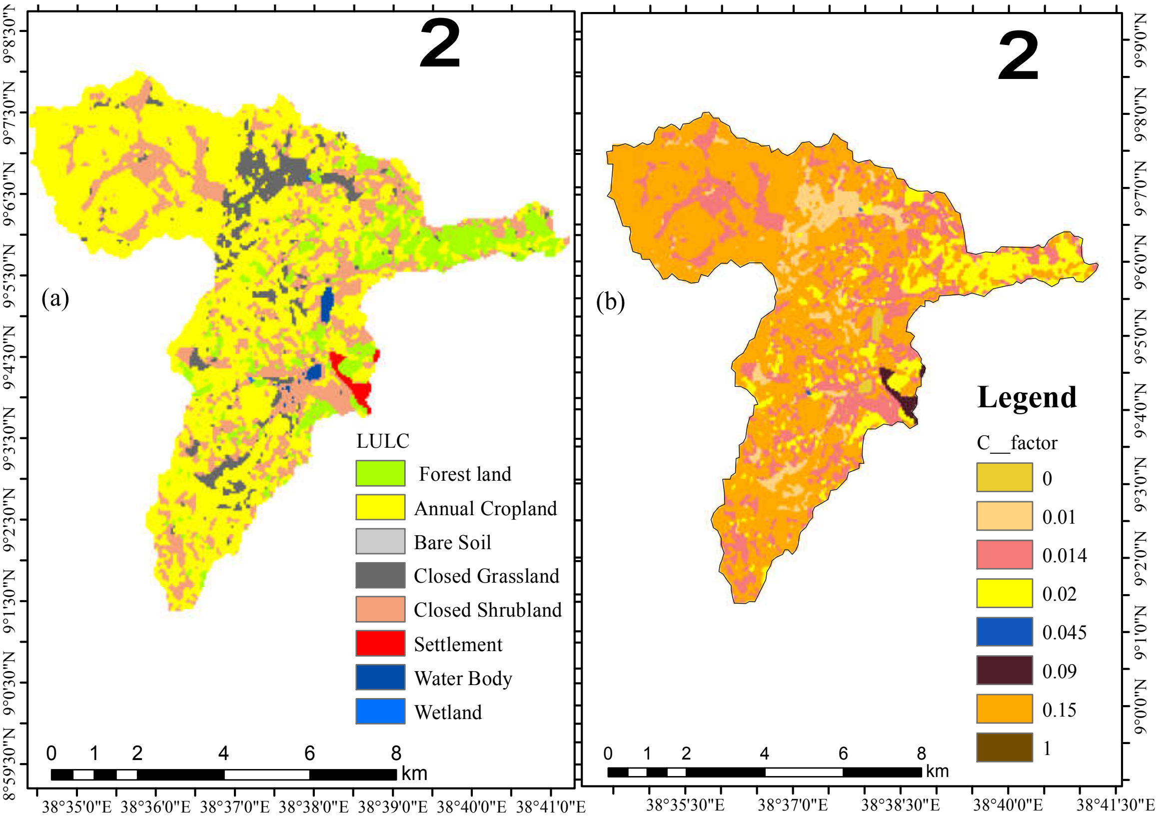

Figure 13. Crop management factor (C) with LULC

4.1.5 Conservation support practice factor (P)

The results of the P-factor are shown in Fig. 14b. The P-factor explains the mechanism that reduces the erosion possible of runoff by influencing runoff concentration, hydraulic forces, and runoff velocity, drainage patterns, applied by surface runoff. The value of the P factor varies from 0.003 to 1, the value which closes to 0.003 shows good protection practices and on the other hand, the value close to 1 shows bad protection practices (fig. 14b).

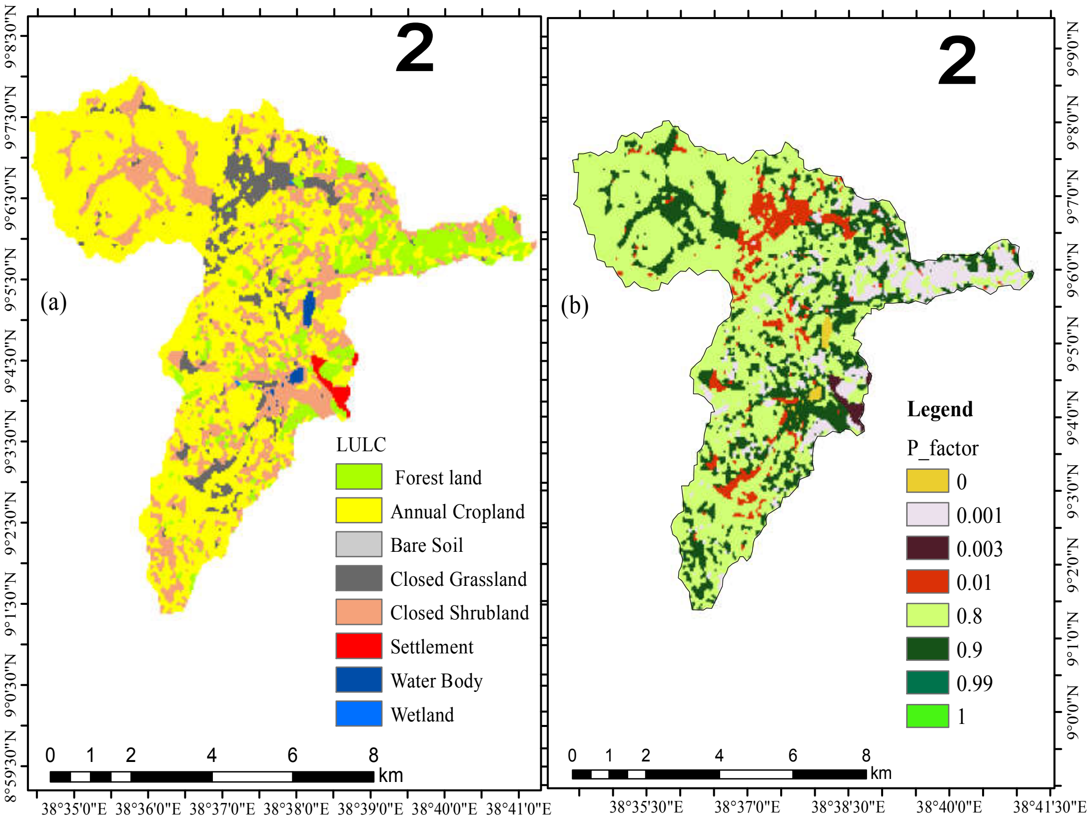

Fig. 14. Land use land cover and P-factor

4.1.6 Soil erosion (Loss) probability zones

The soil erosion map resulting from the spatial overlay of the factor layers with the RUSLE model for the Gefersa watershed is presented in figure (15). From this analysis, the annual soil rate and average annual soil loss rate (yearly soil erosion rate)are estimated to be 596 ton/ha/yr and 20 tones/ha/year respectively. This result falls within the ranges of the findings of FAO and others. According to FAO, (1984), the annual soil loss of the highlands of Ethiopia ranges from 16 to 300 t/ha/yr. In many developing countries sustainable land management and water resource development are threatened by soil erosion and sediment related problems. In Ethiopia, accelerated sedimentation of reservoirs that are intended to provide irrigation water has resulted in the loss of both the intended services from the dams and considerable investments made for their construction. The frequent power cuts and rationing based electric power distribution experienced in the country are also attributed to the loss of storage capacity of hydro-electric power lakes due to erosion. Besides, the on-site effect of erosion, which results in the loss of nutrient-rich topsoil and hence reduced crop yields, is chronic in the country. As estimated by Hurni

(1993), soil loss from cultivated fields due to water erosion in Ethiopia amounts to 42 ton/ha/y. An estimate by FAO (1986) also shows that some 50% of the highlands were already significantly eroded, and erosion was causing declines in land productivity at the rate of 2·2% per year. The rate of soil erosion is more severe in the more barren and mountainous Tigray region, some studies estimating erosion rates of more than 80 t/ha/yr (Tekeste and Paul, 1989). On the other hand, the sediment yield estimates based on suspended sediment sampling at gauging stations may not be reliable, since measurements are not systematic and continuous (NEDECO, 1997). The spatial scales of measurements in the latter case are also generally coarse, with limited potential to be adapted for small catchment scale studies. There is therefore a need to determine the rate of soil loss and sediment yield at scales that can help narrow the missing link between plot and large basin-based studies (Verstraeten and Poesen, 2001a). The soil loss rate map in figure (16) shows that the spatial distribution of soil loss severity classes of the study watershedand the study area requires the implementation of different types of soil and water conservation measures to assist the silt trap provided for the dam to prevent the dam from sediment problem. By delineation of watersheds as erosion-prone areas according to the severity level of soil loss, priority is given for targeted and cost-effective conservation planning (Kaltenrieder, 2007). This result indicates that the upper catchment was conserved well to prevent the reservoir from the sediment problems but based on the soil loss rate limit, the obtained result shows that the catchment must further conserved to extend the service life of the reservoir for the future.

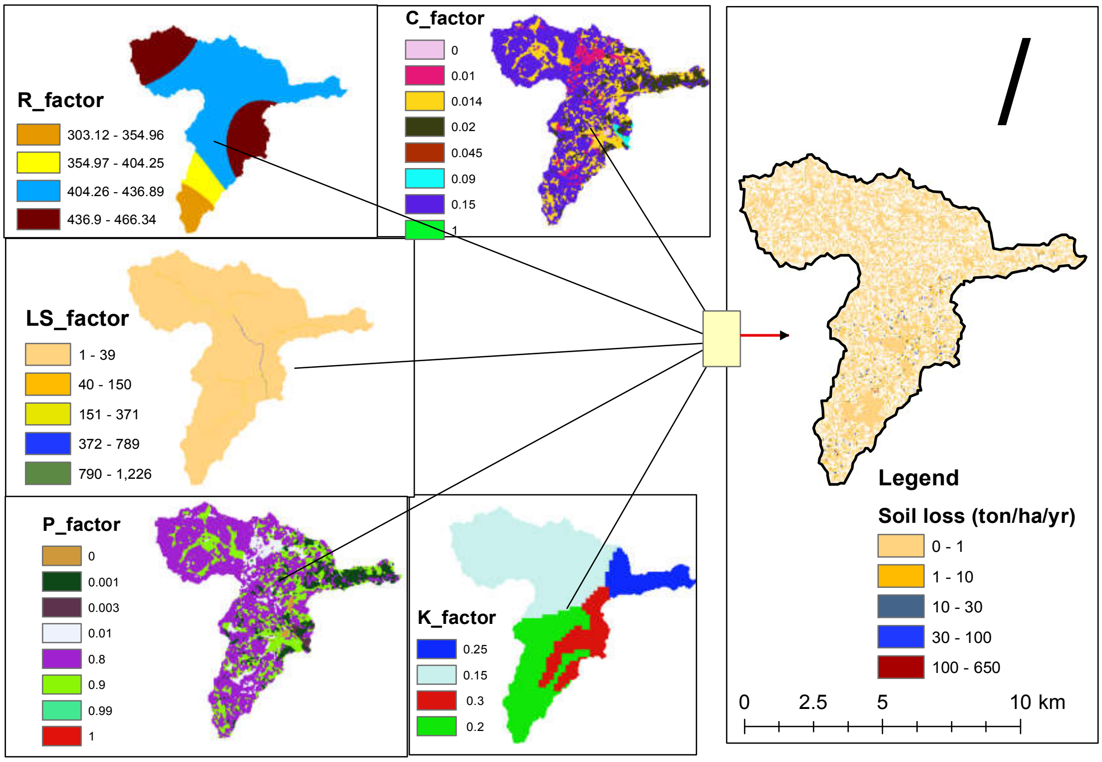

Figure: 15. Annual soil loss rate map of Gefersa watershed

Soil erosion severity classification based on FAO, (1984) evaluation in terms of the risk areas was shown in figure (16) and table (9) respectively. Analysis of these results indicated that 14.14% of the study area was found in between high to extremely high erosion rates and 71.52% of the land area was found with a low erosion rate. Figure 15 Annual average soil loss rate map of Gefersa watershed. The basis for the classification of soil erosion risk was a different literature review and different findings' output.

Table 9. Numeric Soil loss summary of the watershed

No	Numeric range of soil loss	Soil erosion risk class	Area (ha)	Area (%)	Annual soil loss(ton/year)	Percentage of total soil loss
1	0 - 1	Low	3969.897	71.52	11.69	1.30
2	1 - 10	Medium	795.9742	14.34	42.1	4.68
3	10 - 30	High	528.0346	9.51	100.56	11.17
4	30 - 100	Very high	165.5564	2.98	245.56	27.28
5	100 - 650	Extremely	91.51538	1.65	500.1	55.57

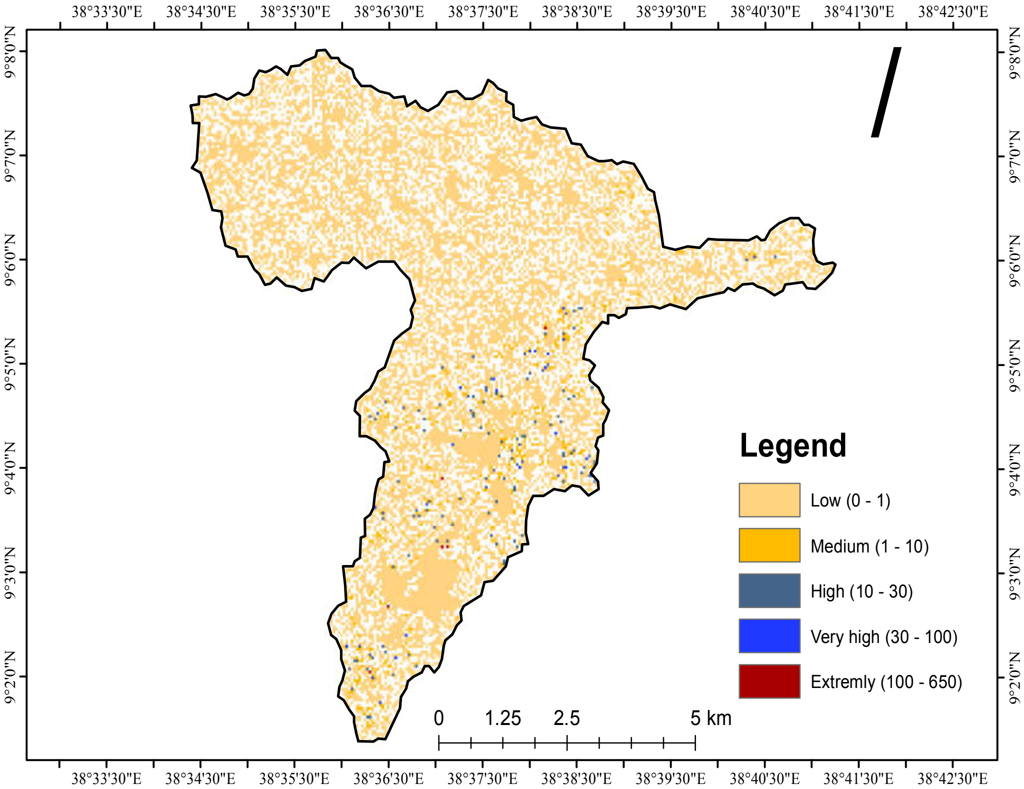

Figure 16: Spatial distribution of soil loss severity classes of the study watershed

4.1.7 Reservoir Trap efficiency

To determine the average sediment yield from the contributing watersheds, the weight of deposited sediment needs to be adjusted for reservoir sediment TE. This helps to adjust the sediment that may leave the reservoir and avoids possible underestimation of sediment deposition. The Reservoir Trap efficiency of the Gefersa reservoir is calculated by equation 2 as explained in the material and methods section. Taking 55.51km^2 watershed areas and 6,500,000 m^3 reservoir capacities the trap efficiency calculated on the equation stated in the methodology of this document was 99.59%. This value indicates that the reservoir performs well.

4.1.8 RUSLE model sediment yield output of the study area

Sediment delivery ratio is necessary for this study to quantify the amount of transported sediment reach to the reservoir outlet. Based on equation (5) the sediment delivery ratio of the Gefersa watershed was 0.36 within this sediment delivery ratio amount of transported sediment that reaches the reservoir using equation (6) was 214 t/ha/yr. This amount of transported sediment estimated by the RUSLE model was decreased by 382 t/ha/yr. The soil losses from rill and sheet erosion in the Lakes Basin area are account for 67% of gross erosion as in the study by Wade and Heady (1976). Therefore, the result is realistic as compared to Wade and Heady (1976). Based on the bathometric study the current reservoir capacity of Gefersa Dam I/II is 8.49 MCM at Full reservoir level of 2587.09 m.a.s.l. while, the current reservoir capacity of Gefersa Dam III is 1.00 MCM at Full reservoir level of 2604.25 m.a.s.l. and nearly 3.02 MCM at 2613 m.a.s.l, which is considered as the maximum level for heightening of the Gefersa Dam III work.

4.1.9 Specific Sediment Yield of Gefersa Watershed

To compute the sediment yield (S_Y) and specific sediment yield (SSY) of Gefersa Watershed the average annual soil loss was estimated. Then S_Y and SSY of the Gefersa watershed are calculated by equation 3.4 as explained in the material and methods section of this document.

The specific sediment yield outflow from the watershed to the reservoir was 3.85ton/km^2/yr. The result indicated that there is a minimum erosion in the watershed area. When comparing the result of specific sediment yield in a regional context, this study found smaller order of specific sediment yield. This result shows the catchment was conserved for keeping the Gefersa reservoir from sediment problem. According to Tamene et al., (2015) for severe soil erosion, reported that the specific sediment yield value is not within the range from 345 to 4935 ton/km^2/yr in the highlands of northern Ethiopia.

4.2 DISCUSSION

4.2.1 Rate and severity of soil erosion in Gefersa catchment

The average soil loss rate estimated for the entire watershed was 20tons/ha/year, which is comparable to the average soil loss rate reported by Hurni (1985) for the highlands which is 18ton/ha/year). The current result agrees with similar findings reported in Gashaw et al. (2018) for Geleda watershed, Upper Blue Nile basin, Northwestern highlands (23.7 ton/ha/year). This result is also in line with the findings of Amare et al. (2014) for the Wondo Genet watershed in the eastern highlands (26t/ha/yr) and Tadesse and Abebe (2014) for the JabiTehinan watershed in the north-western highlands (30.4 ton/ha/year). The relatively higher average soil erosion rate estimated in the currently studied watershed could have resulted from the topography, which is dominated by steep (38.51 - 48.71%) and moderately steep sloping (28.06 - 38.5%), which accounted for 2.23% and 9.42% respectively of the watershed (Table 1). This is in line with the studies of Gashaw et al. (2018) who reported higher erosion rates in steeper slopes. High erosion rates on steep slopes were also reported in other similar studies such as in the Medego watershed where the slope ranged between 30 and 50% (Gebreyesus and Kirubel 2009) and Abate (2011) reported an erosion rate of more than 80 ton/ha/year on steep slope areas in the Borena watershed. Tang et al. (2013) also reported that the highest soil loss rates reaching up to 200 tons/ha/year have been recorded in very steep slope areas. Very low erosion rates were recorded at slopes less than 31.08% in this study. The other contributing factor is the land use and high erosivity values in the studied watershed. Theremaximumerosivity values reaching up to 500.1ton/ha/yr (55.57%) that contribute to a high amount of soil loss in the Gefersa watershed (figure 16). The type of land use also affects the soil loss rate in the watershed. Since the majority of the land use type is cultivated land (38.204%) (Table 4), this also contributes to the high amount of soil loss. Tang et al. (2014) also confirm a very high soil erosion rate because of land cover. Ganasri and Ramesh (2016) also reported that erosion rates increased by 3.1% due to small increases in agricultural areas and a decrease in forest areas. The increase in soil loss rate may also be associated with the management practice where poorly constructed soil bunds and the absence of any conservation practice on cultivated areas may promote the increase in soil loss rate in the study area. This was mainly due to the steep slopes and cultivation of these steep slope areas. Similar studies show very low rates of soil erosion ranging from 2 to 12 ton/ha/year for the Mediterranean environments (Irvem et al. 2007; Trabucchi et al. 2012). Moreover, Ustun (2008) reported an average soil loss rate of 10 tons/ha/year in Ganos Mountain, Turkey. This was also because of the gentle slope existing in the study areas.

5. CONCLUSION AND RECOMMENDATION

This study was designed to estimate soil loss and assess the erosion-prone areas of the Gefersa watershed. The results of the study focused on the application of the RUSLE model associated with Geographic Information System (GIS) and Remote sensing data analysis to assess erosion-prone areas and estimate soil loss in the upper catchment of the Gefersa reservoir. The outcomes of the study conclude that the mean annual loss of soil estimated with the RUSLE model is nearly 20t/ha year in the area. Besides, it detected the amount of erosion varies mainly in LU/LC and topographic characteristics.

Gefersa reservoir, which is part of the Akaki river catchment, supplies an average of 30,000m^3 of treated water per day to Addis Ababa city. The high rate of siltation is a major long-term problem for the reservoir, as it severely affects the capacity of the reservoirs and results in a shortage of usable water for Addis Ababa as well as increasing the water treatment costs. A systematic approach to determine the rate of sediment yield from Gefersa catchment was doneusing the RUSLE model integrated with the GIS environment. This study presents the sediment delivery ratioand specific sediment yield of the watersheds approximately 0.36 and 214ton/ha/yr respectively. This research presents that the trap efficiency of the reservoir was 99.59%, which indicates that the reservoir performs well.

From the available reservoir sediment management approach, watershed management is the best method to reduce the yield of sediment and its entry into the reservoir. Vegetative screens at the upstream end of the reservoirs may withhold a significant part of the entering sediment. Construction of sedimentation basins at the mouths of the reservoir (like Gefersa III) would be the most feasible solution to sedimentation problems in the Gefersa reservoir. Periodic sluicing of sediments through the operation of bottom outlet gates maybe another approach to sediment management in this reservoir.Soil erosion control measures within catchments should be undertaken regularly, as erosion has been identified as the basic means of sediment detachment and transportation into the reservoir. Besides this, the change of land use from cultivation toperennial crop development and grass strip around buffer zone for sediment trap helps for reduction of sediment inflow to the reservoir from the catchment.Sediment accumulation from the upstream agricultural and urban land may shorten the lifetime of the reservoir thus reducing its long-term benefits. Based on the output of this study the researcherrecommends based on the result of sediment yield and annual soil loss rate with the design document. Therefore, to give more life to the reservoir and achieve the purpose for which it was constructed, means ofreduction of sediment inflow into the reservoir is hereby recommended.

To reduce soil erosion and sediment inflow to the reservoir,land management methods, particularly integrated watershed managementshould be implemented. Integrated watershed management encompasses the implementation of physical soil and water conservation and biological conservation measures by focusing on a prioritized watershed.

There are some gullies in the catchment especially around the reservoir area whichhighly contributesto sediment inflow. Therefore, it is very important to treat these gullies to reduce the incoming sediment by constructingsmall check dams and sediment detention basins at catchment level that are in turn very important to help the Gefersa III, which is the detention damor silt trap for the reservoir. In addition to the retention dam which already exists, there must be Sediment removal techniques that should be applied like, flushing of deposited sediment from reservoirs through bottom outlets level.The result of the study implies the need for applying context-specific soil and water conservation techniques in the areas of high and extremely affected parts of the studied watershed to prevent the dam from sediment deposition.

6. REFERENCES

ASCE- American Society of Civil Engineers, 1982 Relationships between the morphology of small streams and sediment yield. Rep. of Task Committee. J HydrolDiv 108:1328-1365

Ayalew L., 2002. Some Thing That We Need to Know About Our Rivers' Hydropower Potential. Lulseged_on_hydroelectric.htm [12 March 2003].

Aynekulu, E., 2009. "Regeneration Response of Juniperusprocera and Oleaeuropaeasubspcuspidata to Exclosure in a Dry Afromontane Forest in Northern Ethiopia." Mountain Research and Development 29(2): 143-153.

Aynekulu, E., Atakliti, S., &Ejersa., 2006. A Small-scale reservoir sedimentation rate analysis for a reliable estimation of the irrigation scheme's economic lifetime. A case study of the Adigudom area.

Bazzoffi, P., Baldassarre G., Vacca S., 1996. Validation of PISA2 model for automatic assessment of reservoir sedimentation. Proceedings of the International Conference on Reservoir Sedimentation. M.Albertson Ed. Colorado State Univ. 519-528.

Boardman, J., Ligneau, L., De Roo, A., Vandaele, K., 1994. Flooding of property by runoff from agricultural land in north-western Europe. Geomorphology, 10: 183-196.

Bowonder, B., Ramana, V.K., & Rao, H.T., 1985. India Land use policy. India: Butterworth and Company Publishers Limited. 68

Chadli, K., 2016. Estimation of soil loss using RUSLE model for Sebou watershed (Morocco). Modeling Earth Systems and Environment, 2, pp.1-10.

Chihombori, J., Nyoni, K..,&Gamira, D., 2013 Causes and Rate of Reservoir Sedimentation Due to Changes in Catchment Management. A Case of Marah Dam in Masvingo Province of Zimbabwe. Greener Journal of Geology and Earth Sciences ISSN: 2354- 2268, 1 (1):007-012,

Crosson, P., 1997. Will erosion threaten agricultural productivity? Environment, 39 (8): 4-5.

David, B. G., 2017 Dams - Impact of Dams - Water, River, Flow, and Sediment JRank Articles. Encyclopedia of science retrieved online on.

Ehigiator, M. O., Oladosu, O. S., and Ehigiator – Irughe, I. R., 2017 Determination of Volume and Direction of Flow of Kainji Reservoir Using Hydro-Geomatics Techniques. Nigerian Journal of Technology

Ellis, E., and Pontius, R., 2007. Land-use and land-cover change. *Encyclopedia of earth*, pp.1-4.

Flaxman, E.M., 1972. Predicting Sediment Yield in the western United States. Proceedings of the ASCE, Journal of the Hydraulics Division, 98: 2073-2085.

Foster, G. R., and Meyer, L. D., 1977. “Soil erosion and sedimentation by water an overview.” Procs. National Symposium on Soil Erosion and Sedimentation byWater, Am. Soc. Of Agric. Eng., St. Joseph, Michigan, 1-13.

Garde, R.J., Kathyari, U.C., 1990. Erosion prediction models for large catchments. In: Proceedings of the International Symposium on Water Erosion, Sedimentation, and Resource Conservation. Dehradun, India, pp. 89 - 102.

Garg, S. K., 2009 Hydrology and Water Resources Engineering. Second Edition Khanna Publishers, New Delhi, India. P. 1244

Haregeweyn, N., Melesse, B., Tsunekawa, A.,Tsubo, M., Meshesha, D., &Babulo, B.B., 2012. Reservoir sedimentation and its mitigating strategies: a case study of Angereb reservoir (NW Ethiopia). Journal of Soil and sediments assessment, protection and remediation, 12, (2), 291-305. 69

Howard, C. D. D., 2000, Operations, Monitoring and Decommissioning of Dams, South Africa, Cape Town.

Hurni H., 1993. Land degradation, famine, and land resource scenarios in Ethiopia. In World Soil Erosion and Conservation.

IGBP-BAHC (International Geosphere-Biosphere Programme), 1997. Modeling the transport and transformation of terrestrial materials to freshwater and coastal ecosystems, IGBP Report No. 39, IGBP, Stockholm, Sweden.

International Union of Soil Sciences (IUSS). 2015. World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome. 145 p.

JAIN, M. K. & KOTHYARI, U. C., 2000. Estimation of soil erosion and sediment yield using GIS. Hydrological Sciences Journal, 45, 771-786.

Julien, P. Y. (1998). “Erosion and sedimentation”. Cambridge University Press, Cambridge, New York.

Klik, A. and Eitzinger, J., 2010. Impact of climate change on soil erosion and the efficiency of soil conservation practices in Austria. The Journal of Agricultural Science, 148(5), pp.529-541.

Lixian, W., Lida, S., Xijing, H., Bogging, Z., Qingyu, W., Guiyun, L., 1996. Application of regression analysis to the prediction of the average annual yield of silt. In: Lixian, W. (ed.) Combating desertification in China, China Forestry Publishing House: 210-221.

Mahmood, K., 1987. Reservoir sedimentation impact, extent, and mitigation. (World Bank Tech.No. 71.) .Washington, DC.

Mavima, G. A., Soropa, G., Makurira, H.,&Dzvairo, W., 2011. Sedimentation impacts the reservoir as a result of land-use on a selected catchment in Zimbabwe. International Journal of Engineering Science and Technology, 3 (8):6599-6608.

MenaleWondie, Werner Schneider, Assefa M. Melesse, and DemelTeketay., 2011. Spatial and Temporal Land Cover Changes in the Simen Mountains National Park, a World Heritage Site in Northwestern Ethiopia.

Milward A, Mersey JE (1999) Adapting the RUSLE to model soil erosion poten-tial in a mountainous tropical watershade. Catena 38(2):109–129

Moges, M. M., 2018. "Investigating reservoir sedimentation and its implications to watershed sediment yield: The case of two small dams in data-scarce upper Blue Nile Basin, Ethiopia." Lakes & Reservoirs: Research & Management 23(3): 217-229.

Morris, G. L., and Fan, J., 1998. Reservoir Sedimentation Handbook, McGraw-Hill Book Co. New York.

Morris, G.L. and Fan, J., 1998. Reservoir sedimentation handbook: design and management of dams, reservoirs, and watersheds for sustainable use. McGraw Hill Professional.

Muller, E. N., 2007. Quantification of Transient sediment storage in the river bed for a dry land setting in N.E Spain. paper submitted to Journal of River Basin Management.

Mulugeta, D., 2013. The impact of sedimentation and climate variability on the hydrological status of Lake Hawassa. Unpublished Master thesis university of Hawassa, Ethiopia.

NEDECO. 1997. Tekeze River Basin Integrated Development Master Plan Project, Second Phase Report, Vol. 1 – Land Degradation and Soil Conservation. Netherlands Engineering Consultants Addis Ababa.

Onstad, C.A., 1984. Sediment yield modeling. In: Hadley, R.F., Walling, D.: Erosion and sediment yield: some measurements of measuring and modeling. Geobooks, Norwich, England: 71-89.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science, 267(5201): 1117-1123.

Prasannakumar, R., Shiny, N., Geetha, H., Vijith, H., 2011. Spatial prediction of soil erosion risk by remote sensing, GIS and RUSLE approach: a case study of Siruvani river watershed in Attapady valley, Kerala, India. Environ. Earth Sci. 64, 965–972.

Raghunath, H. M., 2006. Hydrology: principles, analysis, and design, New Age International.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting soil erosion by water a guide to conservation planning with the Revised Universal Soil Loss

Equation (RUSLE). United States Department of Agriculture, Agricultural Research Service (USDA-ARS) Handbook No. 703. United States Government Printing Office, Washington, DC.

Roy, P.S., and Roy, A., 2012. Land use and land cover change in India: Remote sensing & GIS perspective. *Journal of the Indian Institute of Science*, *90*(4), pp.489-502.

Shiferaw, M., 2019. Reservoir Sedimentation And Estimation Of Watershed Sediment Yield To Small Reservoir; In Abrajit Micro Earth Dam, East Gojjam, Ethiopia (Doctoral dissertation).

Shin, G.J., 1999. "The analysis of soil erosion analysis in a watershed using GIS", Ph.D. Dissertation, Department of Civil Engineering, Gang-won National University.

Sibbesen, E., 1995. Phosphorus, nitrogen, and carbon in particle-size fractions of soils and sediments. In: Correl, A. (ed.) Surface runoff, erosion and loss of phosphorus at two agricultural soils in Denmark, plot studies 1989-1992, SP-report No. 11: 135-148.

Steegen, A., Govers, G., Takken, I., Nachtergaele, J., Poesen, J., Merckx, R., 2001. Factors controlling sediment and phosphorus export from two Belgian agricultural catchments. Journal of Environmental Quality, 30(4): 1249-1258.

Sumi, T. & Hirose, T., 2009 Accumulation of sediment in reservoirs, Water storage, transport and distribution, UNESCO-IHE andEOLSS Publishers Co. Ltd., Paris, France, 224– 252.

Tamene, L., 2005. Reservoir siltation in Ethiopia: causes, sources areas, and management options. Unpublished doctoral dissertation. Bonn University

TAMENE, L., PARK, S. J., D., R., & VLEK, P. L. G., 2015. Analysis of factors determining sediment yield variability in the highlands of northern Ethiopia. Geomorphology.

Tekeste G, Paul DS. 1989. Soil and Water Conservation in Tigray, Ethiopia: Report of a Consultancy Visit to Tigray.

Turner, B.L., Clark, W.C., Kates, R.W., Richards, J.F., Matthews, J.T., Meyer, W.B., 1990. The earth as transformed by human action. Cambridge University Press.

Verstraeten G, Poesen J., 2001a. Factors controlling sediment yield from small intensity cultivated catchments in a temperate humid climate. Geomorphology 40: 123 –144.

Verstraeten, G. Poesen, J., 2001. Factors controlling sediment yield from small intensively cultivated catchments in a temperate humid climate. Geomorphology, 40: 123-144.

Verstraeten, G., Poesen, J., 1999. The nature of small-scale flooding, muddy floods, and retention pond sedimentation in central Belgium. Geomorphology, 29(3-4): 275-292.

Verstraeten, G., Poesen, J., de Vente, J., Koninckx, X., 2003. Sediment yield variability in Spain: a quantitative and semi-quantitative analysis using reservoir sedimentation rates. Geomorphology, 50: 327-348.

Voogd H., 1983. Multi-Criteria Evaluation for Urban and Regional Planning. Pion, Ltd.: London.

Walling, D. & Fang, D., 2003 recent trends in the suspended sediment loads of the world’s rivers, Global Planet. Change, 39:111–126.

Walling, D.E., 1983. The sediment delivery problem. Journal of Hydrology, 65: 209237.

Wei L, Kinouchi T, Velleux M L, Omata T, Takahashi K, Araya M., 2017. Soil erosion and transport simulation and critical erosion area identification in a headwater catchment contaminated by the Fukushima nuclear accident. J Hydro-environment Res, 17: 18–29

Wischmeier, W.H. and Smith, D.D., 1978 “Predicting rainfall erosion losses A guide to conservation planning.” U.S. Department of Agriculture handbook No. 537.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses. A Guide to conservation planning. United States Department of Agriculture, Agricultural Research Service (USDA-ARS) Handbook No. 537. United States Government Printing Office, Washington, DC.

Zeleke, G. and H. Hurni, 2001. "Implications of land use and land cover dynamics for mountain resource degradation in the Northwestern Ethiopian highlands." Mountain Research and Development 21(2): 184-192.

Zounemat-Kermani M, Kisi Ö, Adamowski J, Ramezani-Charmahineh A., 2016. Evaluation of data-driven models for river suspended sediment concentration modelling. J Hydrol (Amst), 535: 457–472

Chalachew, A.M., 2007. Analysis of reservoir sedimentation process using empirical and mathematical method: case study: Koga irrigation and watershed maangement project, Ethiopia (Doctoral dissertation, Unesco-IHE).

Admasu, A., 2005. Study of sediment yield from the Watershed of Angereb reservoir. M. Scthesis, Department of Agricultural Engineering, Alemaya University, Ethiopia.

Congalton, R. & Green, K., 2008. Assessing the accuracy of remotely sensed data: principles and practices. Available at: https://books.google.nl/books? [Accessed April 12, 2017].