COMPARISON OF SWAT AND WEPP FOR MODELING ANNUAL RUNOFF AND SEDIMENT YIELD AND QUANTIFCATION OF NUTRENT LOSS IN AGEWU-MARIYAM WATERSHED, NORTHERN ETHIOPIA

MSc THESIS

YALELET ABIE WORKU

HAWASSA UNIVERSITY, INSTITUTE OF TECHNOLOGY

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YALELET ABIE WORKU

ADVISOR: AWDENEGEST MOGES (PhD)

CO - ADVISOR: HAILU KINDIE (PhD)

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This is to certify that the thesis entitled **''Comparison of SWAT and WEPP for Modeling Annual Runoff and Sediment Yield And Quantification of Nutrient loss in Agew-Mariyam Watershed, Northern Ethiopia' '**submitted in partial fulfillment of the requirement for the degree of Master's with specialization in the Graduate Program of the Department of **Soil And Water Conservation Engineering** and has been carried out by **Yalelet Abie Worku, (ID.Nº SWCE/0012/12)** under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the research to the department.

Awudenegest Moges	______________________	__________________
Name of Major Adviser	Signature	Date
Hailu Kendie Addis	__________________	08/03/2022
Name of CO-Adviser	Signature	Date

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As member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense Examination, we have read and evaluated this thesis prepared by Mr. **Yalelet Abie Worku** Entitled **“Comparison of SWAT and WEPP for Modeling Annual Runoff and Sediment Yield and Quantification of nutrient loss in Agew-Mariyam Watershed, Northern Ethiopia**” We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in **Soil and Water Conservation Engineering.**

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DEDICATION

This study manuscript is dedicated to my family who paved the way towards my education and all my friends for their continuous support for my success throughout my life.

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STATEMENT OF THE AUTHOR

First, I declared that this thesis is my original work and all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for an M.Sc. degree in Soil and Water Conservation Engineering at Hawassa University and is deposited at the University Library to be made available to borrowers under the rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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Name: Yalelet Abie Worku Signature………………………

Place: Hawassa University

Date of submission……………………

E-mail address: yaleletabie@gmail.com

ACRONYM AND ABBREVIATION

ANSWERS Areal Nonpoint Source Watershed Environment Response Simulation

C Cover Management Factor

CN Curve Number

CSA Critical source area

DEM Digital Elevation Model

DSMW Digital soil map of world

EPIC Erosion Productivity Impact Calculator

F_{crg} Coarse Fragment Factor

GCPs Ground control points

GeoWEPP Geographic Water Erosion Prediction project

GPS Geographic Position System

HRU Hydrological Response Unit

HSG Hydrological Soil Group

K Soil Erodibility Factor

LS Slope Length/ Steepness Factor

LULC land use land cover

MSCL Minimum source channel length

MUSLE Modified Universal Soil loss Equation

NSE Nash–Sutcliffe efficiency

P Support Practice Factor

RMSE Root means squared error

SRTM Shuttle Radar Topography Mission

SWAT Soil and Water Assessment Tools

TM Thematic Mapping

TOPAZ Topographic Parameterization

USDA United State Department of Agriculture

USDA-ARS United States Department of Agriculture-Agricultural Research Service

USDA-SCS United States Department of Agriculture Soil Conservation Service method

USLE Universal Soil loss Equation

WEPP Water Erosion Prediction Project

TABLE OF CONTENTS

Contents **Page.no**

LIST OF TABLE

LIST OF FIGURE

APPENDIX TABLE

APPENDIX FIGURE

ABSTRACT

Unevenly heavy rainstorms during the rainy season create runoff and soil erosion which affects soil fertility and production, especially in northern Ethiopia. In this study soil and water assessment tool (SWAT) and geographic water erosion prediction project (GeoWEPP) were applied to compare estimation of annual runoff and sediment yield and quantification of nutrient loss in Agewu-Maryam watersheds eastern Amhara, region, Ethiopia. To run both models, need spatial and temporal data distribution is required as an input. The soil textures and other selected soil properties were determined in the field and the laboratory and a soil map were derived from the digital soil map of the world. A land-use map was prepared based on manually digitizing from Google earth image. A Digital Elevation Model of the watershed was used for delineating the watershed and preparing a slope map. ArcGIS 10.4 was used for both models for basic interface for further analysis. During each runoff event, runoff samples were collected and the sediment concentrations were analyzed in the laboratory. The simulation result of long-term (24-year) average means annual runoff and sediment yield from WEPP and SWAT models were estimated. The results were performed well as indicated by R^2 *0.86 and 0.91 and with NSE 0.54 and 0.71 for monthly runoff were satisfactory for SWAT and WEPP models compared with observed value respectively The estimated average mean annual runoff and sediment yield at the outlet of the watershed was 65.54mm and 146.14mm and 43t/ha/yr and 41.7t/ha/yr respectively for WEPP and SWAT models. The t-statics result shows that there is no statistically significant difference with p-value (0.97 for runoff and 0.98 for sediment) between the two models' simulation results. Some of the Sub-watershed were identified and prioritized as more susceptible to soil erosion and give more attention first to this area for reducing runoff and soil erosion. The total nutrients loss within the suspended sediment were 33.74kg/ha/yr N,6.79kg/ha/yr P, 642.5 OM kg/ha/yr, and 1.52 K for the watershed. Hence SWAT and WEPP models were well suited for the estimation of annual runoff and sediment yield. The sediment yield simulated from both models was high which was alarming and far beyond the soil loss tolerable rate. Therefore, the result of the model could be used as a decision-making tool.*

Keywords*: SWAT, WEPP, Runoff, Sediment yield, Nutrient loss, and Agewu-Watershed*

1. INTRODUCTION

1.1. Background

Soil erosion is continuous to be a global constraint to economic development, especially in developing countries, where soil erosion is becoming a limiting factor to increasing or even sustaining agricultural production (Arekhi, 2008). The worldwide annual rate of soil erosion from agricultural land ranges from 22 to 100 ton ha^{-1} and declines in productivity as much as 15-30% annually (Morgan, 2005). Sedimentation and soil erosion are massive problems that have threatened many reservoirs in the Northern Ethiopian highlands (Kidane et al., 2016). The range of the tolerable soil loss Level for various agro-ecological zones of Ethiopia was found from 2 to18 t/ha/yr (Hurni, 1985). Accordingly, the simulated soil loss rate of some of the sub-watersheds in the Tekeze dam watershed exceeds the maximum tolerable soil loss rate of 18t/ha/yr. This fact showed how far soil erosion is a serious threat in northern Ethiopia (Kidane et al., 2016). Soil erosion is a principal degradation process, resulting in a negative impact on different soil functions and which is the ultimate cause of an irreversible effect on the poorly renewable soil resource (Addis et al., 2015).

In river basin management, watershed hydrological models have a vital role in simulating possible feature changes and their impact. This helps to determine improved measures of river basin management (Valentina et al., 2014). The main point of watershed development is conserving land and water. However, other economic and social development of the watershed follows consequently. Any natural resource (land and water) development program must be started at the micro watershed level the primary starting point of all processes of hydrology (Dhruvanarayana, 1993). However, watershed management actions cannot be carried out at the same time over the entire area of a large watershed. Expansion of agriculture, urbanization, deforestation, and the day-to-day activities of mankind resulted in temporal and spatial changes in land use land cover that have affected water flow pathways and water balance (Rawat and Manish, 2015). In developing countries like Ethiopia, where their agriculture serves as the backbone of the economy and ensures the wellbeing of the people; the adverse effects of land use land cover change are diverse. Besides this various water resource development sectors (hydropower, irrigation, urban and rural water supply, etc.) have been persistently affected by both temporal and spatial changes of LULC (Nigussie and Yared, 2010).

Soil erosion is one of the major global environmental threats causing both on-site and off-site effects. The economic consequence of soil erosion is more serious in developing countries like Ethiopia, because of a lack of capacity to cope with it and also to replace lost nutrients. The countries have also high population growth which leads to intensified use of already stressed resources and expansion of production to marginal and fragile lands. Such processes intensify the erosion and productivity declines. The Northern Ethiopian Highlands have characteristics dominated by steep slopes; intense rainfall and sparse vegetation cover. The high poverty, lack of technology, and high population and livestock densities encourage intense soil erosion and degradation problems in these Highlands. This not only reduces crop yields but also has various negative off-site consequences (Tamene et al., 2008).

On-site monitoring of sediment loss is difficult, expensive, and time-consuming. Also, soil erosion events occur intermittently and long-term records are needed to well-characterized erosion and sediment loss from any particular site. Thus, soil erosion models are in most cases the primary tools for making assessments (Wischmeier and Smith, 1978).

Computer simulation models are increasingly popular for predicting soil loss to quantify the processes of detachment, transport, and deposition of eroded soil. It is necessary to validate soil erosion models for this area, evaluate the effects of different management practices on soil erosion, and select the best management practices. Soil erosion models can be divided into empirical and physically-based models.

Empirical models usually establish relationships between runoff, sediment yield, and precipitation, plants, soil types, land use types, tillage styles, water conservation measures, and so on. They are still used because of their simple structure and ease of application. Since they are based on coefficients computed or calibrated from measurements and/or observations, they cannot describe or simulate the erosion process as a set of physical phenomena.

Physically-based models can describe with detail the physical mechanism of sediment yield and can simulate the individual components of the entire erosion process by solving the corresponding equations, and so it is argued that they have a wider range of applicability. Such models are also generally better in assessing both spatial and temporal variability of the natural erosion processes. Now a day difference erosion modeling is applied for assessing spatial and temporal variability of soil erosion process between them WEPP and SWAT models are physical-based models used for estimating annual runoff and sediment deposition. These models are selected based on their wide usability, reputation, and use of the most up-to-date technology (Renschler and Lee, 2003, 2005). The linkages between the WEPP model or GeoWEPP and SWAT have also been studied (Renschler and Lee, 2003, 2005).

The WEPP watershed model is a continuous simulation computer program that predicts sediment yield and deposition from the overland flow on hill slopes, sediment yield and deposition from concentrated flow in small channels, and sediment deposition in impoundments. It computes spatial and temporal distributions of sediment yield and deposition and provides explicit estimates of when and wherein a watershed or on a hill slope that erosion occurs so that conservation measure has been selected as the most effective soil erosion control measures (Flanagan and Nearing, 1995). The WEPP model has compared with USLE, the Erosion Productivity Impact Calculator (EPIC), the Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS), and other models for runoff and soil erosion (Bhuyan et al., 2002; Croke and Nethery, 2006; Romero et al., 2007). Since the WEPP is a process-based continuous simulation model and SWAT is based on the empirical Modified Universal Soil Loss Equation (MUSLE).

The Soil and Water Assessment Tool (SWAT) is a semi-distributed eco-hydrological model. SWAT is one of the most widely used watershed models, which is developed by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) (Gassman P W et al., 2007). It is developed to predict the impact of land management practices on water, sediment agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods (Neitsch et al., 2005). It has become an effective means for evaluating non-point source water resource issues for a large variety of national and international water quality applications.

Prediction of hydrology and erosion at the hill slope and watershed scale is needed for the placement of conservation practices as well as for understanding the implications of land-use change. The WEPP and SWAT models are both capable of simulating stream flow and sediment transport from agriculturally based watersheds, there are many fundamental differences in the way the models have been developed and applied. The strength of the SWAT model, as characterized in many papers is the ability to match observations at the outlet of large watersheds through iterative calibration. SWAT breaks down a watershed into Hydrologic Response Units (HRUs), which are based on soil and land use characteristics. These HRUs, however, operate independently of landscape position, and flow between HRUs on the same hill slope is not accounted for in the model. This limits the ability of SWAT to predict the cumulative effects of management practices on a single hill slope. In contrast, WEPP has been primarily developed as a physically-based hill slope model that can simulate flow through diverse hill slopes however it is not well suited for extensive calibration. SWAT includes stream channel algorithms for sediment and nutrients for large streams whereas the stream channels algorithms in WEPP are primarily suited for small headwater channels.

1.2. Statement of the Problem

Now a day runoff and soil erosion in catchment areas and its subsequent deposition in rivers, lakes, and reservoirs are great worries of humanity. In Waghimra dry- land, woreda drought, famine, and serious land degradation are common problems face in northern Ethiopia to alleviate such problems Government, a non-government organization is designing plans and implementing different soil and water conservation structures (SWCS) and watershed-based water harvesting reservoirs (BOA, 2018). However, the reservoir design lifetime is under question mark within a short period because most of them are filled with sedimentation, poor design, and high evaporation problems. The study watershed is affected by ongoing land degradation due to soil erosion as a result of human interventions, such as deforestation for agricultural food production, the cultivation of marginal lands, overgrazing, and the exploitation of soil fertility accelerates soil erosion and subsequent soil depletion is accompanied with reduced crop productivity (Gebrehana *et al*., 2021).

The life expectations of many small dam structures in the Waghimra areas built for irrigation or water supply in the summer season are threatened by massive sedimentation (BOA, 2018). The mean annual soil loss of the Agewu Mariam catchment was estimated to be $25tha^{-1}yr^{-1}$(Gebrehana *et al*., 2021). The study watersheds have characteristics dominated by steep slopes; ragged topography, irregular rainfall, slope cultivation , sparse vegetation cover, the high poverty, lack of technology, and high population and livestock densities encourage intense soil erosion and degradation problems especially in the study area. Good watershed management is; therefore, need to reduce the runoff and sedimentation problem. To cite and prioritize the problem we can estimate the sediment delivery and runoff before implementing SWCS and water harvesting reservoir within the catchment using different erosion processing models. Therefore; the study was proposed to compare the modified version of the GeoWEPP and SWAT model for modeling annual runoff and sediment yield in the Agewu-Maryam watershed.

1.3. Objective

1.3.1. General Objective

The General objectives of this study was a comparison of SWAT and WEPP for modeling annual runoff and sediment yield and quantification of nutrient loss in Agewu-Maryam watershed

1.3.2. Specific Objective

- To estimate and characterize annual surface runoff and sediment yield from Agewu-Maryam watershed in terms of hydrologic response unit for sub-basin and hillside
- To compare SWAT and WEPP model for their differences in the estimation of surface runoff and sediment yield
- Identifying priority sub-watersheds for management planning and intervention
- To quantify the nutrient (NPK) and organic matter loss from suspended sediment in the entire watershed

1.4. Hypothesis

1.4.1. Null Hypothesis

Watershed management is mandatory because land degradation is increasing in the Agewu-Maryam watershed. Free grazing, improper land use, slope cultivation, etc. may increase soil erosion. Implementation of structural and biological soil and water conservation measures may be lower and not well aware to implement the SWC structure. This may increase runoff and sediment loss in the entire watershed. On-site monitoring of sediment loss is difficult, expensive, and time-consuming. Also, soil erosion events occur intermittently and long-term records are needed to well-characterized erosion and sediment loss from any particular site. therefore modeling runoff and sediment loss using the hydrological model at the watershed level is critically important and priority research need to support development organizations, policymakers decision-makers for their immediate action and long-term decision to minimize soil loss and sediment deposition as well as to sustainable agricultural production land. The null hypothesis for this study was, there is no significant difference between modeling surface runoff and sediment deposition in the SWAT and WEPP models.

1.5. Research Question

1. How to estimate surface runoff, sediment yield and identify hot spot area using the SWAT and WEPP model?

2. Which erosion process model is the good simulation annual runoff and sediment yield?

3. How much nutrient (NPK) and organic matter is lost in the watershed?

2. LITERATURE REVIEW

2.1. Soil Erosion in Ethiopia

Soil erosion is recognized as one of the most serious causes of soil degradation in Ethiopia (Awdenegest and Holden, 2007; Kassie et al., 2011) and hence in highland areas of the country the crop yield and soil fertility levels are extremely low (Zenebe et al., 2013). Continued soil erosion seriously threatens people's livelihoods, especially in highland parts of the country, where arable land is a very scarce resource (Zerihun et al., 2016). Annually about 2 billion cubic meters of topsoil loss is reported for the country (Hurni et al., 2015).

Ethiopia losses over 1.5 billion tons of topsoil annually only from the highlands due to soil erosion (Teferi et al., 216). The average annual soil loss rates from cropland were estimated as 42 tones/ha and ranged up to 300 tones/ha in extreme cases (Hurni, 1993). Especially the productive highland parts of the country, which are characterized by rugged topography, densely populated, intensive cultivation, and that host a large proportion of people and livestock, harmed highly with the problem of land degradation (Semu, 2018; Mushir and Kedru, 2012; Tegegne and Biniam, 2017). About 43% of the total highland areas of Ethiopia are highly affected by soil erosion with an estimated average annual loss of 20 tons per hectare and measured annual amounts of more than 300 tons per hectare on specific plots (Hurni , 1990), Paulos, 2001). Only the Blue Nile basin of the country loses fertile soils with a rate of 131 million tons per year (Bewke and Sterk, 2002). Not only the highlands but also the dry lowland areas of the country have also been identified as vulnerable to the problem of land degradation (UNEP, 2013).

In Ethiopia, the annual costs of land degradation related to soil erosion and nutrient loss from agricultural and grazing lands are estimated at $106 million (about 3% of agricultural GDP) from a combination of soil and nutrient loss (Bojo and Cassells, 1995; Yesuf et al., 2008). The report on the damage of soil erosion in economic terms indicated as Ethiopia losses USD 1 billion annually (Sonneveld and Keyser, 2003). The average national nutrient balances loss rate of the country reported out of their independent research works as 47 kg N ha^{-1}, 15 kg P2O5 ha^{-1}, and 38 kg K2O ha^{-1} (Stoorvogel and Smaling, 1990) and later Haileslassie et al., 2005) reported estimated national nutrient depletion rates as 122 kg N ha^{-1} y^{-1}, 13 kg P ha^{-1} y^{-1} and 82 kg K ha^{-1} y^{-1}. If no proper measures are taken to protect the soil, intensive agriculture to meet the increasing demand for food will accelerate soil erosion in the country (Gelaw et al., 2013, cited in Adugna et al., 2015).

Most of the factors contributing to soil erosion in the country are human-induced (Haregeweyn et al., 2017). Most cultivated lands in the hills and mountains of the country have suffered from loss of topsoil, leaving bare stones. Gullies are observed everywhere in the deep soils (Zenebe et al., 2013). It caused strong environmental impacts and major economic losses from decreased agricultural production and off-site effects on infrastructure and water quality by sedimentation processes (Amsalu and de Graaff, 2007). It has put a substantial threat to the agriculture of the country. Out of a total surface area of 112 million hectares, the estimates made in the mid-1980s showed that about 27 million hectares are significantly eroded, 14 million hectares are seriously eroded and 2 million hectares have reached the point of no return (Woldeamlak and Sterk , 2002; Bobe, 2004).

2.2. Factors of Soil Erosion

Soil Erosion is caused by natural factors and human activities mainly by the mismanagement of the soil by human beings such as the cultivation of steep slope areas, deforestation, and improper agricultural practice (Gustafson, 2005). Human activities contribute to about 60% to 80% of all soil erosion and soil degradation (McNeill, 2000). Generally, there are five primary types of factors that affected soil erosion. These are climatic factors, soil factors, topography, land use/cover, and agricultural support practice.

2.2.1. Climate factor

When raindrops strike the soil surface soil erosion will occur due to the detaching power of raindrops and through the contribution of rain to runoff. Rainfall erosivity is a property of rainfall that can quantify the potential capacity of rain to cause erosion in given circumstances, and it measures the combined effect of rainfall and its associated runoff (Saavedra, 2005).

2.2.2. Soil factor

The rate of soil erosion depends upon soil properties, such as texture, structure, moisture, roughness, color, organic matter content, and chemical and biological characteristics (Vrieling, 2007). Soils having faster infiltration rates, higher levels of organic matter, and improved soil structure have a greater resistance to erosion (Saavedra, 2005). Soil with small particle size, such as silt and fine sandy soils (particle size of less than 0.6 mm) are less resistant to erosion (Pilesjo, 1992) whereas soils with particle size greater than 0.6 mm are more resistant to transportation and the erodibility is low due to cohesiveness properties (Saavedra, 2005). Red soil is easily erodible than brown and black soil due to less resistance to detachment and transportation, fewer cohesiveness properties of its particles (Hellden, 1987).

2.2.3. Topography factor

Topographic factors refers to the slope length and slope steepness factors which express the ratio of soil loss from field slope length and the field slope gradient (Robert and Hilborn, 2000). The local slope gradient (S) influences flow velocity and thus the rate of soil erosion while slope length (L) describes the distance between the origin and termination of inter-rill processes that deposition starts (Renard *et al.,* 1997). Increasing slope steepness and slope length will accelerate erosion rate as a result of respective increases in velocity and volume of surface runoff (Doere, 2005).

2.2.4. Land use land cover factor

Land cover is the attributes of the earth‘s land surface, such as the vegetation, water, bare land, and also man-made structures such as mine exposures (Chrysoulakis *et al*., 2004). On the other hand, land use is the economic use placed on the land cover by human activities such as industrial zones, residential zones, agricultural fields, grazing, logging, and mining among many others (Chrysoulakis *et al.*, 2004; Zubair, 2006). According to (Estifanos, 2004), land cover is the observed biophysical cover on the earth’s surface whereas land use refers to the arrangements, activities, and inputs that people undertake on a certain land cover type (Estifanos, 2004). It represents the land cover types such as fieldwork, vegetation, grassland, and how different land cover classes affect soil erosion (Wischmeier and Smith, 1978).

The land cover influences soil erosion at different rates because their potential of protecting the soil against the action of falling raindrops affecting the degree of infiltration of water into the soil is quite different (Alejandro and Omasa, 2007). For example, soil loss rates decrease exponentially as vegetation cover increases (Gyssels *et al.*, 2005) as it increases the infiltration rate and reduces the speed of the surface runoff.

2.2.5. Management practice factor

The management factor describes how human interventions, such as mulching, terracing, strip cropping, contour plowing, stone/soil bund, etc. affect flow paths and flow hydraulics (McCool *et al*., 1995) and how it reduces soil erosion (Panagos *et al*., 2015). It includes the control factors that reduce the erosion of potential runoff (Ganasri and Ramesh, 2015). Soil covered by plants, crops, mulches, or residues can be protected from erosion (Renard and Foster, 1994).

In cultivated lands, conservation practices such as contouring, strip cropping, or terracing, reduce soil losses. For instance, in areas where there is terracing, runoff speed could be reduced with increased infiltration, ultimately resulting in lower soil loss and sediment delivery (Renard and Foster, 1983). The effectiveness of such practices is often analyzed with a support practice factor which is defined as the ratio of soil loss with the practice applied and up and downslope cultivation (Wischmeier and Smith, 1978; Renard *et al.,* 1997)

2.3. Soil Erosion Modeling

Erosion prediction models can be used as predictive tools for soil loss assessment and inventories, conservation and project planning, decision making, and policy development. Moreover, the models can be used as tools for understanding erosion processes and their impact (Habtamu *et al*., 2013). According to Renard et al., (1997), soil loss equations were developed to enable conservation planners, environmental scientists, and others concerned with soil erosion to extrapolate limited erosion data to the many localities and conditions that have not been directly in the research. Erosion prediction models are categorized into three types namely, empirical, conceptual, and physical-based (Rabin and Dushmanta, 2005; Habtamu *et al*., 2013; Umesh *et al*., 2002; Morgan, 2005).

Empirically based models tend to require fewer data and are easier to apply, particularly over large areas. However, the models suffer from a lack of specificity and do not incorporate mechanisms. Despite this, the results of empirical models can be reasonably accurate and reflect the underlying processes generating the erosion and sediment yield without modeling for the actual processes.

Physically-based models attempt to capture the physics of the system and if specified properly can be used to provide significant insight into the behavior of the system of interest. However, these models may be so complex that it is difficult to determine how to translate management practices into specific changes in the model parameter values or physical processes simulated by the mathematics in the model. Based on the temporal and spatial scales of application, erosion models can be classified as Black-box, Grey-box, and White-box. Black-box models are primarily based on observation and are usually statistical. Whereas, the Grey box models are used, when some details of how the system works are known, and the white-box models are intended to represent the essential mechanisms and processes controlling erosion.

Estimation of soil erosion or its consequences, such as sediment yield can be realized by applying appropriate models. Empirical models have been and are still used in hydrology and environmental engineering for computing the amount of potential soil erosion and sediment yield (Ashish *et al.,* 2009). The most widely used empirical soil erosion models include Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Loss Equation (MUSLE), and Soil Loss Estimation Model for Southern Africa (SLEMSA).

Due to uncertainty in delivery ratio and the inability of USLE and RUSLE models to give direct sediment yield estimates, a modified universal soil loss equation was proposed by (Williams and Berndt, 1977) which has been generally used to predict sediment yields on a single storm base. An improved erosivity factor was therefore introduced by (Williams, 1975 ; Foster *et al.,* 1977), into account the runoff shear stress effect in terms of the product of runoff volume and peak discharge on soil detachment for single storms (Mizuyama *et al*., 2010; Sadeghi *et al*., 2013). The approach (William and Berndt, 1977) in developing the modified version of USLE was to drive a sediment yield estimation model based on runoff characteristics as the best single indicator for storm event sediment yield prediction at the watershed outlet and some factors affecting soil erosion. MUSLE increases sediment yield prediction accuracy and eliminates the need for sediment delivery ratio (Arekhi *et al*., 2010)

2.4. Description of SWAT and WEPP Model

2.4.1. Description of the SWAT Model

Soil and Water Assessment Tool (SWAT) is a continuous simulation model developed by the USDA Agricultural Research Service. It is a physically-based model to estimate runoff, nutrient losses, chemical, and sediment transport within the Watershed scale for daily time steps (Arnold et al., 1998). The surface runoff estimation in the model can be done by two methods; the Soil Conservation Service method (USDA-SCS) sometimes called the Curve

Number (CN) method (USDA-SCS, 1972), and the Green and Ampt method (Green & Ampt, 1991 as quoted by (Neitsch et al., 2009). The daily precipitation data has been required to estimate the surface runoff by the SCS curve number method, the curve number estimation depends on certain soil types (permeability), land use, and antecedent soil moisture conditions. The Green and Ampt infiltration method estimates the infiltration rate based on hydraulic conductivity and matric potential of the wetting front, so it requires sub-daily precipitation data. The SCS curve number method is an empirical method to estimate the surface runoff based on studies of different rainfall-runoff relationships for small rural watersheds, then developed for different types of soils and land use (Neitsch et al., 2009). The equation of estimating the runoff depth in the SCS curve number method is:

$$Q_{surf} = \frac{(R\ day - Ia)2}{(R\ day - Ia + S)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where: - Q_{surf} = accumulated runoff (mm)

R day = daily rainfall depth

I_a = initial abstraction and

S = retention parameter

The retention parameter varies depending on soil type, slope, land cover and management, and antecedent moisture condition it is equal to:

$$S = 25.4(\frac{1000}{CN} - 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where: - CN= curve number for normal hydrological condition. The initial abstraction (Ia) is considered equal to 0.2s, so the equation (1) becomes in the following form.

$$Q_{surf} = \frac{(R\ day - 0.2S)2}{(R\ day + 0.8S)} \quad \text{for R day > 0.2s .... (3)}$$

The curve number for normal moisture condition (field capacity) is identified based on soil type and land use then it is modified based on antecedent moisture condition. The sediment load or yield estimation in the SWAT model is executed for each hydrological response unit. (HRU) divided into two phases, the overland phase, and channel flow.

The peak runoff rate in the SWAT model has been estimated by using the modified rational formula. Flow is a route through the channel using a variable storage coefficient method developed by (Williams, 1969) or the Muskingum routing method. The watershed concentration-time will estimate using Manning's formula, considering both overland and channel flow.

The rational formula is

$$\mathbf{q_p} = \frac{c * i * Area}{3.6} \qquad (4)$$

Where, qp - peak runoff rate (m^3s^{-1}), C - runoff coefficient, I - rainfall intensity (mm/h), Area - sub-basin area (km^2), and 3.6 is a unit conversion factor (Neitsch et al., 2005), I is calculated from the maximum half-hour rainfall for a month, which is provided to the model in the weather database.

2.4.2. Description of WEPP Model

The water erosion prediction project (WEPP) model is a continuous simulation computer program that predicts sediment yield and deposition from the overland flow on hill slopes, sediment yield and deposition from concentrated flow in small channels, and sediment deposition in impoundments. It computes spatial and temporal distributions of sediment yield and deposition and provides explicit estimates of when and wherein a watershed or on a hill slope that erosion occurs so that conservation measures will be selected for the most effective controls of soil erosion (Flanagan and Nearing, 1995). It is used for hill slopes and watersheds based on fundamental principles of overland flow dynamics, infiltration, evaporation, evapotranspiration, erosion mechanics, percolation, drainage, surface ponding, interception of rainfall and runoff by plant, residue decomposition, soil consolidation, and tillage and soil management. It uses climate data from a robust file to account for mean daily precipitation, maximum and minimum temperature means daily solar radiation, mean direction and speed of the wind and other climate factors. WEPP can predict soil erosion on a storm event and continuous basis for diverse tillage and cropping systems (e.g., crop rotations, terracing, contouring, strip cropping).

In the WEPP watershed model, a watershed has been divided into one or more overland flow elements (OFEs), which are areas of uniform soil properties, slope, and management. The watershed consists of hill slopes, channels, and impoundments; the smallest possible watershed being one hill slope and one channel. Each hill slope has been represented as a rectangle. Runoff, detachment, and deposition are first calculated on each hill slope, with the hill slope component of WEPP for the entire simulation period. Then the model combines simulation results from each hill slope and performs runoff and sediment routing through the channels and impoundments. It simulates soil erosion at different temporal (daily, monthly, annual basis) and spatial (hill slope, small, medium, and large watersheds) scales. It simulates rill and inter rill erosion over hill slopes and sediment transport and deposition in channels and impoundments interaction with surface cover conditions, soil properties, surface roughness, and soil management. The main components of the model are (Flanagan and Nearing, 1995): Weather conditions, plant growth, winter processes, Plant residue decomposition, Irrigation practices, Soil parameter, Infiltration dynamics, Hill slope erosion and deposition, Overland flow hydraulics, Watershed channel hydrology, Water balance , and Watershed impoundment component.

The peak intensity of a storm is computed as follows (Nicks et al., 1995)

$$r_P = -2p \ln (1-rl) \quad \text{.................................} \quad (5)$$

Where rp is the peak intensity of the precipitation (mm h^{-1}), P is the precipitation amount (mm), and rl is the gamma distribution of the monthly mean half-hour precipitation amounts.

The primary purpose of the WEPP surface hydrology component is to provide the erosion component with the duration of rainfall excess, the rainfall intensity during the period of rainfall excess, the runoff volume, and the peak discharge rate.

2.5. Soil fertility depletion

Soil nutrient diminution is a continuous process and occurred due to: soil erosion, poor land use policy, poor routine crop residue left on fields, low addition of organic and inorganic inputs are the main constraint of agricultural production and productivity in sub-Saharan Africa. Continuous depletion of soil N, P, and K in most African countries and other least developed countries, coupled with low crop production levels, poses a real threat to agricultural sustainability and food security (Smaling et al., 2007).

Ethiopia is affected by soil nutrient depletion (Eyasu *et al*., 1998; Amare et *al*., 2005). Soil erosion by water lowered soil quality by transporting surface soil nutrients and SOM selectively from the top to lower slope positions. Grain yields and aboveground biomass have been discovered to amplify from the higher to lower slope positions. In steep-slope areas, soil erosion was a predominant reason for soil degradation and grain yield discount (Zheng-An *et al.,* 2010). In the central highlands of Ethiopia, soil erosion is essential agricultural trouble that resulted from inappropriate land management practices (Gebremedhin et *al*., 2014).

Soil nutrient management practices for different land-use types by smallholder farmers could not support improving macronutrient stocks in the Jimma zone, of western Ethiopia due to the added nutrients were not sufficient to compensate for the loss (Abebayehu and Eyasu, 2011). However, in the highlands of Ethiopia, the depletion of soil nutrients increased over time with a mild decrease in crop production (van Beek *et al*., 2016). Most Ethiopian soils have low nutrient contents particularly nitrogen and phosphorus (Assefa *et al.,* 2015).

2.5.1. Cause of nutrient loss

Essential plant nutrients are lost in different ways (Storvoogel and Smaling, 1993; Bindraban et al., 2000). The outflows occur in the form of harvested crop product, removal of straw yield, leaching, gaseous loss, and soil erosion (Stoorvogel and Smaling, 1993). The amount varies depending on crop type, soil type, agronomic practices, and plant nutrient uptake (Brady and Weil, 2002). Nitrogen outflows through five paths such as grain and straw yield, volatilization, de-nitrification, leaching, and soil erosion. While phosphorous is lost by grain yield, straw removal, and soil erosion. Potassium is also exported from the soil via crop yield, straw removal, leaching, and soil erosion (Storvoogel and Smaling, 1993).

2.5.2. Effect of soil erosion on nutrient loss

Soil erosion is the removal of soil with mineral nutrients by wind, water, gravity, and ice. It is the upper layer's gradual slow process movement and transport of the soil. Soil erosion is a complex process that depends on soil properties, ground slope, vegetation cover, rainfall amounts, and intensity (Wuepper *et al.*, 2020). Also, it is at an alarming rate causing a serious loss of topsoil. The loss of soil from farmland may be reflected in reduced crop production potential, lower surface water quality, and damaged drainage networks (Apollo *et al.*, 2018). Soil loss causes food insecurity and livelihood income as well as, retarded in Ethiopia (Bekele, 2019).

Rapid population growth, cultivation on steep slopes, clearing of vegetation, and overgrazing are the main factors that accelerate soil erosion in Ethiopia. Soil erosion and nutrient depletion in Ethiopia became a serious threat to agricultural productivity (Fassil and Charles, 2009). Smallholder farmers can’t afford mineral fertilizers to replace the lost nutrient from their farmlands (Eyasu, 2002). Management options should be taken to ensure the long-term sustainability of agricultural systems and to avoid irreversible losses (Fassil and Charles, 2009). Soil erosion is one of the major causes of soil degradation along with soil compaction, low organic matter, destruct soil structure, poor internal drainage, salinization, and soil acidity problems (Awdenegest and Holden, 2007).

2.5.3. Soil fertility maintenance

Soil fertility management has multiple approaches and supplying essential plant nutrients adequately, conserving soil from erosion, leaving crop residue in the farm, and adding organic fertilizers are some of the alternatives. A decline in soil fertility of Africa is a threat and that needs great attention (Smaling *et al*., 1997). Improving soil nutrient availability is a necessity for increasing crop productivity in SSA (Wortmann and Sones, 2017).

Soil fertility can be restored through maintaining and protecting from erosion as well as using organic and inorganic fertilizers (Fanuel and Kibebew, 2020). The use of the early maturing soybean variety as a precursor with FYM and phosphorous fertilizer in the short rainy season boasted the yield of the subsequent finger millet (Abebe and Deressa, 2017). ISFM through grain legumes and synthetic fertilizers enhance soil fertility, and increase crop yield by maximizing nutrient use efficiency, in southern Ethiopia.

3. MATERIAL AND METHODOLOGY

3.1. Description of Study Area

The study was conducted at Agewu-Maryam model watershed in Sekota woreda Waghimra zone, Amhara region northern Ethiopia. The study area covers 155.685 ha, which is located at 38^{o} 55‘10‘‘to 38^{o} 56’10” E longitudes to 12^{o} 31’ 40” to 12^{o} 32’30” N latitudes. The elevation of the watershed ranges from 2108 to 2395 m above sea level (figure1). Based on an ArcGIS watershed delineation using a 30 m$_*$ 30m grid Digital Elevation Model (DEM) produced by SRTM (Shuttle Radar Topography Mission)

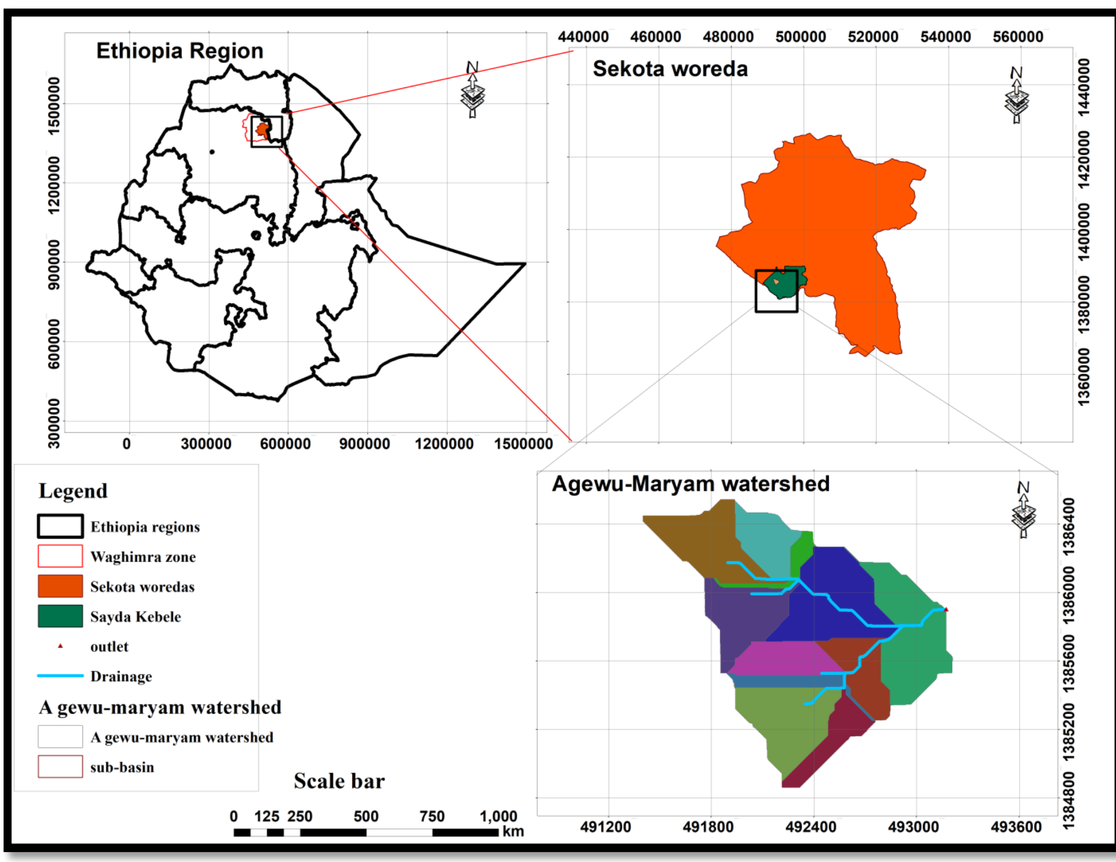


Figure 1: Location map of Agewu-Maryam watershed

The watershed is characterized by highly rugged topography with steep slopes ranging from over 50 % (very steep slope) to less than 5% (gentle slope). According to (FAO, 1998) the soil type of the Agewu Maryam watershed was mainly of two types namely Eutric Regosol covering (38.73%) and Eutric Cambsol covering (61.268%). The soil textural class in the Agewu-Maryam watershed is mostly dominated by sandy loam covering 65.9% of the watershed, and the rest is sand clay loam 2.7%, loam 8.6%, and loamy sand 20.4% sand 2.4 % illustrated in (Table 3 and Figure 9).

The land-use type coverage 63.168% of the total catchment area is covered with cultivated, 23.831% is bush land 8 % is area closure and forest, 1.986% is bare land, and 3.014% is settlements illustrated in (Table 2 and Figure 8). The people of the Agewu-Maryam watershed exercise rain-fed, subsistence-oriented mixed crop-livestock farming. The major crops grown in the area are sorghum, teff, wheat, barley, and pulses (Yonas et al., 2018)

There are many households settled in the watershed and surrounding. The landholding size of the watershed is characterized as small and fragmented. The livelihoods of the households in the watershed are depending on livestock and crop production. The area has a high potential for livestock production including cattle, apiculture, poultry, goat, sheep, and donkey. The number of household heads was 259 and the total population was 1113 in the study area. From the total household heads 215 are males and 44 females and from a total population 547 are male and 566 are females according to (Yonas et al., 2018) reported.

The mean annual rainfall of area 582mm and the mean minimum and maximum annual temperatures are 12.8^{o}C and 28^{o}C, (Figure2). According to Dejene, (2003), the climatic zone classifications of Ethiopia based on altitude, rainfall, average annual temperature, and length of the growing season, the study area belongs to dry semi-arid lowlands.

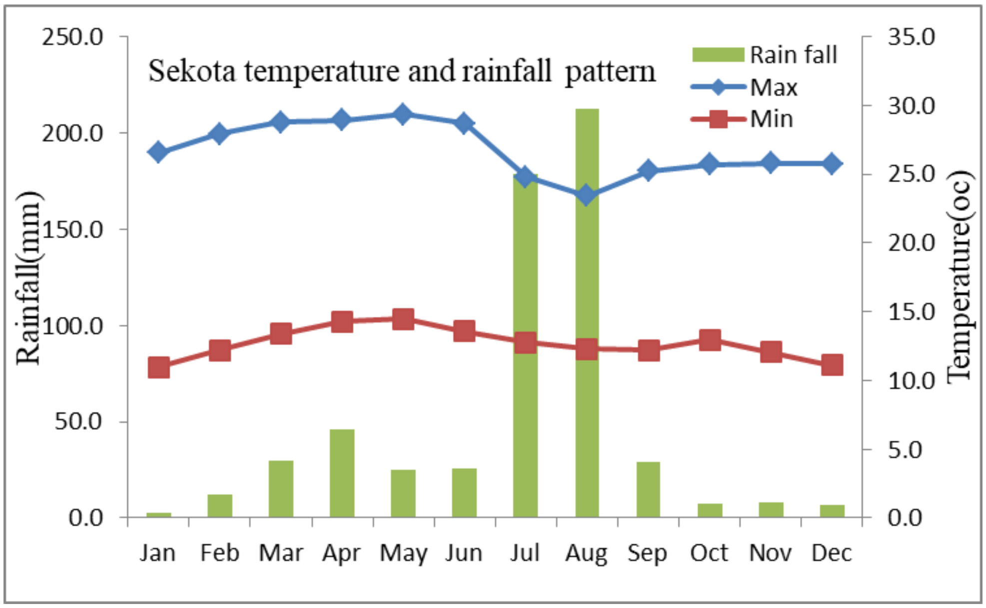


Figure 2: Mean annual rainfall and maximum and minimum temperature

(Source: Combolcha metrology station data (1990- 2020))

3.2. Material and model used for the study

For conducting any research, data is basic and taken as an input for analyzing the research. The following are materials that were used for collecting the different data and used for analyzing the research data.

Auger: - During the primary data collection, the auger was used to collect the soil sample. It is a material that was used to drill the soil and collect the soil sample for further analysis in the laboratory to study the soil properties. The analyzed data were used as input for GIS software to map the soil texture of the Agewu Maryam watershed.

Current meter: - current meter or flow meter was used to measure the flow velocity of runoff water at the outlet of the watershed. The velocity of runoff was recorded using a current meter was used for calculating discharge and sediment yield deliberated to the outlet.

Global position system (GPS):- GPS was used to collect the coordinates of the geographic location of the required point in the study area and to record the outlet coordinate of the geographic location point of the watershed. The coordinates were recorded using GPS were also used to delineate the watershed from the DEM. This has served as input data for further use in both the SWAT and WEPP models.

Geographical information system software (GIS):- ArcGIS version 10.4.1 was used for locating the study area, delineating the watershed, mask DEM, and preparing raster and vector slope, the land use, soil type, and soil textural map of Agewu-Maryam watershed were also prepared. These were used as the basic interface in the SWAT and GeoWEPP models.

SWAT and WEPP model: - In this study basically, two hydrological models have been used namely the SWAT, and GeoWEPP model. Additionally, WEPP, MWSWAT, and SWAT-CUP software were used for the analysis of runoff and sediment yield, preparing climatic data for GeoWEPP, soil database with interface map window, and calibration and validation of the SWAT model respectively. SWAT and WEPP models were also used to model the annual runoff and sediment yield of the watershed. The following are materials that were used to prepare input data and source use for running SWAT and WEPP model (Table1).

3.3. Input Data collection and sources of data

Primary and secondary data were used in conducting the study. Soil Samples, four years, rainfall, and discharge data were primary data. The secondary data were DEM, land use/land cover map, soil map, population data, livestock data, and meteorological data. These data were obtained from different sources (table1).

Table 1: Data used to do the research and their sources

Data type	Source of data	description /period	Purpose
DEM	USGS produced by SRTM (Shuttle Radar Topography Mission)	SRTM 30m pixel resolution	Used to delineate watershed and analysis slope map
Land-use land cover map	Google earth pro/Google earth image	These are the ground cover types obtained in 1m pixel resolution, acquired in December 2020.	As input in the models through manual Digitizing land use type from Google earth pro image
Metrological data	Combolcha metrological Agency and Arc SWAT global weather data	This includes the daily, monthly climatic data for 24 years(1996-2020)	Used as input data in the models and preparing user weather generator (user WGN)
Soil type map	Digital soil map of the world (DSMW)	(FAO,1998)	Input data for models
Stream flow	From hydrological gauge	Time series	To determine observed

data	weir manual stage reading	recording of stage head discharge (2017-2020)	discharge and compare with the model outputs
Demography data	Sekota dry-land agricultural research (SDARC) documented file	Yonas et al., 2018 biophysical and socio-economic characterization of Agewu-Maryam watershed	Population size, livestock N^{o}, and crop type cultivated in the watershed
Soil data	Primary soil data were collected from the Agewu-Maryam watershed	Using 100*100m grid-based soil samples were collected a 159 points using the auger at (0-20cm)	Selected Soil physic-chemical property determination further use for SWAT user soil template
Sediment loss	Manually collect runoff samples using a plastic bottle	Runoff sediment concentration	Measuring sediment loss quantify nutrient and organic matter loss

3.4. Hydrological data collection

The model requires climate data that includes daily values for precipitation, runoff, and sediment data were collected at the watershed Experimental Station. The watershed has two rain-gauge installed for recording 24-hours rainfall amount and event-based rainfall amount. The other required daily climate data (solar radiation, maximum and minimum temperature, relative humidity, wind speed, sun-shine hour) were obtained from Combolcha metrological Station, SWAT weather generator, and using climate explorer models. The SWAT weather generator was used for simulating missing daily weather data (Schuol and Abbaspour, 2007). Management input files are built for the watershed from management records (height, depth, and velocity) of runoff in the hydrological wire investigation. The Agewu-Maryam Soil and Water Conservation Experiment Station researcher and personnel have been monitoring the watershed hydrological data continuously.

The sediment and runoff samples collected using a sampling bottle for each rainfall-runoff event at the outlet of the watershed for a period of 3 years (2018- 2020) were used for calculating observed data. A rectangular weir (constructed in 2017) was used for continuous collection of hydrological data served for runoff sample collection. At each rainfall-runoff event, 8 runoff samples distributed over the whole runoff event were collected. Manually subsequently sediment concentration of each sample was determined in the laboratory. The sediment load was filtered by flask bottle with filter paper. The sample dried in the laboratory at room temperature and the dried sediment was weighed to determine the sediment load of each runoff sample (Appendix Figure 4). Sediment yield is then calculated by multiplying discharge by the mean sediment concentration. The data have been used to compare and verify the performance of both SWAT and GeoWEPP models simulation results.

3.5. Soil data collection and analysis

The field Soil sampling was carried out for determining soil properties in a 100m*100m grid over the watershed. 159 soil samples were taken at each location from the topsoil layer (0-20cm); using a polythene plastic bag for soil physical and chemical property analysis. The soil sample collected from the field is grinding and sieved to pass through a2mm and 0.5mm sieve size for further analysis of soil physical and chemical analysis following standard laboratory procedure. Available phosphorus and total nitrogen were tested following Olsen's method and the Kjeldahl procedure, respectively (Jackson, 1967; Olsen et al., 1954). The particle size distribution (texture) of the soils was analyzed according to the procedures outlined by FAO (1986) with help of the hydrometer method. The measurement of soil pH is conducted using the pH meter method in the supernatant suspension of 1:2.5 soil to water ratio (Jackson, 1973). Organic carbon of the soils is determined following the wet digestion method as described by (Walkley and Black, 1947). The OC was calculated from titrating volume. The percentage of organic matter of the soils was calculated by multiplying the percentage of organic carbon value by 1.724 conversion factors (Sahlemedhin and Taye, 2000).

3.6. Runoff and Sediment data analysis

Rainfall and runoff data were collected using manually for the last 3 years from 2018 to 2020 at the monitoring stations of the Agewu-Maryam watershed. To determine the runoff in the study area the runoff volume and peak discharge was recorded manually through stage reading within 10-15 minutes interval time on a rectangular hydrological weir on a watershed outlet. Total runoff volume (Q) and Peak discharge (qp) were determined using the stage-discharge relationship rating curve from collected data at the gauging station.

The rating curve for the Agewu-Maryam watershed was developed from frequent measurements of flow velocity and channel profile to calculate peak flow and runoff volume based on equation 1, is recommended to rectangular crested weir section (R Herschy, 1993; Klik et al., 2016). (Figure 3 and Equation 1 and 2), the flow capacity through a rectangular weir is given by the following formula, which applies to multiple-step sharp rectangular weirs: A graph of stage versus discharge developed represents the stage-discharge relationship in regression line of power equation known as the rating curve with R^2 (0.97). The developed rating curve equation would take the form as shown below (Figure 4). It is used to calculate flow rate and volume for the gauging stations at the Agewu Maryam watershed.

$$Q = A*V \quad \text{(1)}$$

$$Q = C\left(L_1 h_1^{3/2} + (L_2 - L_1)h_2^{3/2} + \ldots + (L_n - L_{n-1})h_n^{3/2}\right) \quad \text{(2)}$$

Where Q =discharge over the weir (m^3/s), A = cross-sectional area of weir (m), V = Velocity of runoff water, C = flow coefficient (3.36), L= length of weir (m) and h = head over the crust of weir (m)

The sediment yield was obtained from sediment concentration in conjunction with total event runoff volume. Whereas, sediment concentration was determined from a manual runoff sample that was taken by using plastic bottles. Hence, a total of 8 bottles per event were collected and submitted to Sekota dry-land agricultural research soil laboratory for sediment concentration analysis. The samples were filtered using filtration paper. Finally, the filtered sediment was dried at 105 ^{0}C for about 24 hours and weighed independently in the standard laboratory procedures to determine the sediment concentration. Sediment yield is then calculated by multiplying discharge by the mean sediment concentration.

Sediment concentration = ∑ (Total duration of runoff(s)*discharge (l/s)*average concentration of sediment (gr/l))………………………………………………………….. (3)

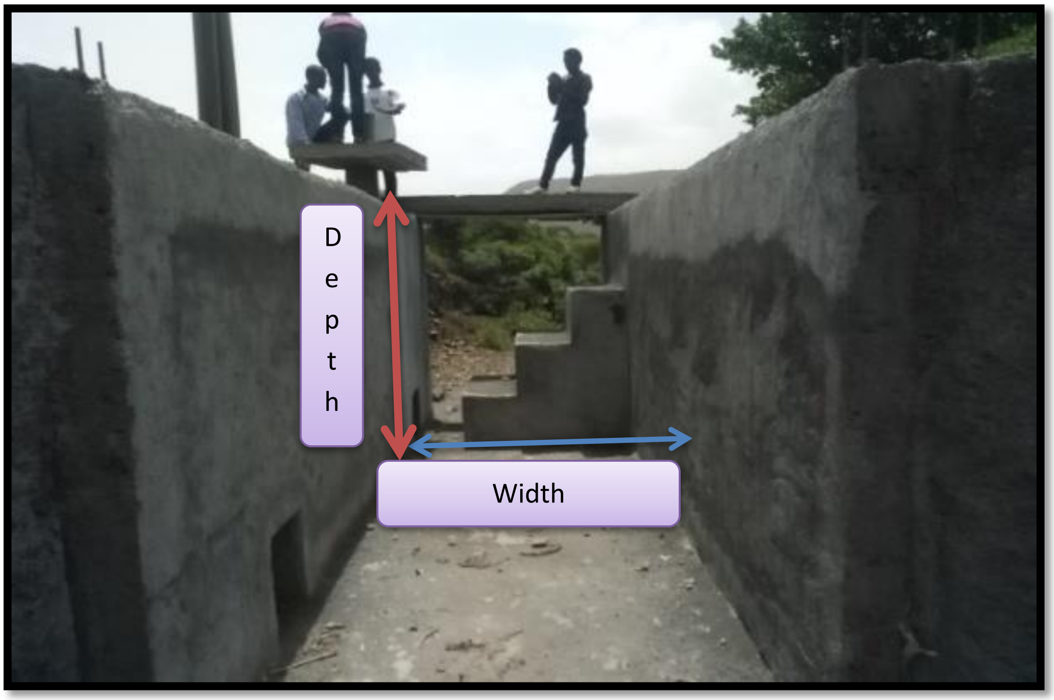


Figure 3: Hydrological weir used for flow and sediment measurement

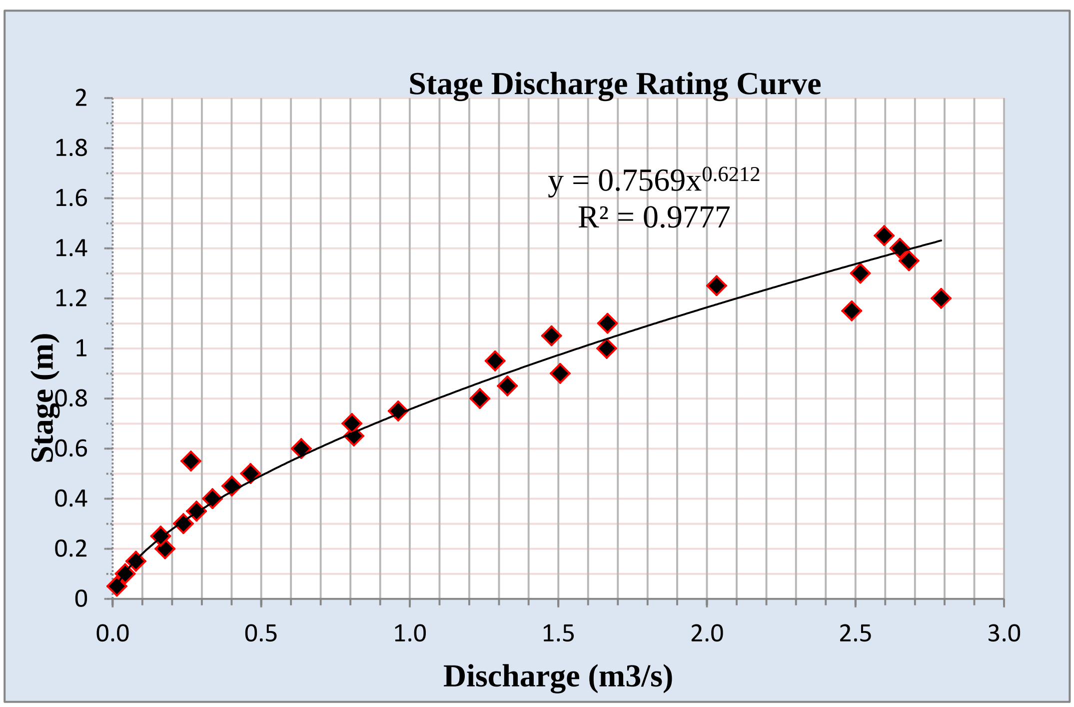


Figure 4: Rating curve develop for Agew-Mariyam watershed

On the other hand, the runoff and sediment loss from the watershed outlets has been analyzed using a modified version of the GeoWEPP and SWAT model.

3.7. SWAT model setup

Runoff and sediment yield data collected from the watersheds during 2017 and 2020 were used for model comparison with observed data Mean daily runoff and sediment data from watersheds are used for comparing the SWAT and WEPP model. Some of the appropriate parameters were adjusted until the predicted daily runoff and sediment yield nearly the measured data at the outlets of the watershed. Based on the given threshold areas and manual input data automatic sub-basin delineation was done for the watershed. The SWAT model divided the sub-basin into detailed HRUs. The model delineates each HRUs with a user-defined threshold based on the percentage of the slope classes, soil type, and land use (Arnold et al., 2011). In the SWAT model, erosion and sediment yield are estimates for each HRU with MUSLE (Williams, 1975). In Ethiopia Modified Universal Soil Loss Equation (MUSLE) was applied with integration of Soil and Water Assessment Tool (SWAT) and GIS and Remote Sensing to predict event-based sediment yield (Abdi *et al*., 2012; Habtamu *et al*., 2013; Addis *et al*., 2016; Hassen *et al*., 2015; Zelalem and Devendra, 2016). The Modified Universal Soil Loss Equation is considering estimating the erosion and sediment load from rainfall and overland flow.

$$Sed = 11.8\ (Q_{surf}\, q_{peak}\, A_{hru})^{0.56}\, K_{usle}\, C_{usle}\, P_{usle}\, L_{usle}\, F_{c\ frg} \qquad (4)$$

Where: -Sed is the sediment yield (t) on a given day Q surf is the surface runoff volume (mm ha-1) Q peak is the peak runoff rate (m^3s^{-1}), A hru is the area of the HRUS (ha), K usle is the

USLE soil erodibility factor, C usle is the USLE cover and management factor, P usle is USLE support practice factor, L usle is the USLE topographic factor and F_{cfrg} is the coarse fragment factor.

The runoff curve number was developed from an empirical analysis of runoff from small catchments and hill slope plots monitored by the USDA. It is widely used and efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area (Wikipedia). The basic assumption of the SCS curve number method is that, for a single storm, the ratio of actual soil retention after runoff begins to potential maximum retention is equal to the ratio of direct runoff to available rainfall (USDA-SCS, 1985), where curve number (CN) represents a convenient representation of the potential maximum soil retention (S) (Ponce and Hawkins, 1996)

The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition. The runoff curve numbers for characteristic land cover descriptions and a hydrologic soil group specified by (Renolde et al., 1997), (Appendix Table 5)

The equation of estimating the runoff depth in the SCS curve number method is:

$$Q_{surf} = \frac{(R\ day - Ia)2}{(R\ day - Ia + S)} \quad \text{……………………………………………………… (5)}$$

Where: - Q surf = accumulated runoff (mm)

R day = daily rainfall depth

Ia = initial abstraction and

S = retention parameter

The retention parameter varies depending on soil type, slope, land cover and management, and antecedent moisture condition it is equal to:

$$S = 25.4(\frac{1000}{CN} - 10) \quad \text{.. (6)}$$

Where: - CN= curve number for normal hydrological condition. The initial abstraction (Ia) is considered equal to 0.2s, so the equation (1) becomes in the following form.

$$Q_{surf} = \frac{(R\ day - 0.2S)2}{(R\ day + 0.8S)} \quad \text{for R day > 0.2s} \quad \text{.................................... (7)}$$

The peak runoff rate in the SWAT model has been estimated by using the modified rational formula. Flow is a route through the channel using a variable storage coefficient method developed by (Williams, 1969) or the Muskingum routing method. The watershed concentration-time will estimate using Manning's formula, considering both overland and channel flow.

The rational formula is

$$\mathbf{q_p} = \frac{c*i*Area}{3.6} \qquad (8)$$

Where, qp - peak runoff rate (m^3/s^{-1}), C - runoff coefficient, I - rainfall intensity (mm/h), Area - sub-basin area (km^2), and 3.6 is a unit conversion factor (Neitsch et al., 2005). i is calculated from the maximum half-hour rainfall for a month, which is provided to the model in the weather database.

Area of hydrological response unit (A hru) is calculated using SWAT model after the reclassification of the land use, soil, and slope grids, overlay operation was performed. When the overlay was finished, the catchment was divided into HRUs based on soil type, land use, and slope classes. Finally the aerial distribution table of each HRU definition was reported by SWAT model.

3.7.1. Soil erodibility factor (K)

The soil data of the study area were collected during the baseline survey of the watershed by a grid of 100X100m and each data was collected from the center of the grid. More than 159 soil samples were collected from the watershed to determine the physical and chemical properties of the watershed (155.68ha) (Appendix table 1).

Soil erodibility factor (K) was determined based on the observed physical and chemical properties of the soil, such as organic matter content, texture, structural and permeability class code. Analysis of physical and chemical properties of the soil samples was performed based on the standard laboratory procedures.

Particle size distribution was analyzed using the hydrometer method. The hydrometer method of silt and clay measurement relies on the effects of particle size on the deferential settling velocities within the water. Whereas organic carbon and organic matter contents were determined by the wet combustion method of Walkley and Black as outlined by (Van Ranst *et al*., 1999).

Soil structure was identified under field condition with the help of soil structure assessment kit to determine soil structural class code. Soil structural class code was determined based on the observed shape and size of soil structure. In this case, the structural code (s) was adopted from the USLE nomograph (Wischmeier *et al*., 1978) and assigned as (1, 2, 3 and 4) for very fine granular, fine granular, moderate or coarse granular and blocky or platy structural classes respectively. Whereas, the permeability class code was obtained from soil textural classes which is encoded from textural triangle based on the observed soil texture (Appendix table 2). K factor was calculated from observed soil properties, such as texture, organic matter, and structural and permeability class with the following equation (Foster *et al*., 1991, Pongsai *et al*., 2010). In this study K factor was calculated equation (9) and map as has been applied by other studies such as (Abate, 2011; Hailu and Klik, 2015; Kebede *et al*., 2015).

$$K\ (factor) = 2.77*10^{-7}\ (12-OM)\ M^{1.14} + 4.28*10^{-3}\ (s-2) + 3.29*10^{-3}(p-3) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (9)$$

$$\text{Where } M = [(100-C)\ (L+ Armf)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (10)$$

C is % of clay (<0.002 mm), L is % of silt (0.002-0.05 mm) and Armf is % of very fine sand (0.05-0.1 mm), OM is the organic matter content (%), p is a code indicating the class of permeability (Appendix table 2) and s is a code for structure size. Permeability and Structure will be analyzed on-field assessment. A point soil erodibility factor was calculated based on the soil parameters. Soil sample points of erodibility factors were converted to surface data interpolation techniques using ordinary kriging in the ArcGIS environment and the Gaussian model was suggested by (Hailu and Klik, 2015).

The structural code (s) was derived from the USLE nomograph (Wischmeier and Smith, 1978), based on the structural shape and size of each soil sample and assigned as (1, 2, 3 and

4) for very fine granular, fine granular, moderate or coarse granular and blocky or platy structural classes respectively. Whereas, the permeability class code was obtained from soil textural classes which is encoded from textural triangle (Appendix Figure1) based on the observed soil texture and also hydrological soil group determine based on permeability and saturated hydraulic conductivity specified by (Renard *et al.*, 1997), (Appendix table5)

3.7.2. Slope length and gradient factor (LS)

Slope length and gradient factor were estimated by ArcGIS 10.4 spatial analysis of hydrology and terrain processing tools. First, the watershed was digitally delineated from 30 m spatial resolution SRTM digital elevation model (DEM) to determine watershed parameters such as slope length and gradient factor, drainage pattern and its characteristics and total watershed area. The slope gradient was obtained from a digital elevation model (DEM) and the combined LS factor was determined by multiplying L and S factors from the created map. According to (McCool *et al.*, 1987), that the slope length and steepness (LS) factors of classic USLE can be calculated using the following equation

$$LS = (l/22.13)^{m} * (0.43 + 0.30s + 0.043s^{2})/6.574 \qquad (11)$$

Where S is field slope in percent, l is the slope length in meters and m is the dimensionless exponential varies from 0.2 for slopes <1% to 0.6 for slopes >10% (Somnuck *et al.*, 2010). However, (McCool *et al.*, 1987) improved the LS factor from classic USLE for use in terrain with steeper slopes and can be calculated by the following equation.

$$LS = (l/22.13)^{m} (16.8\sin\Theta - 0.5) \qquad (12)$$

Where l is slope length in meter and m is the dimensionless exponential calculated from the equation below,

$$m = \sin\Theta / \sin\Theta + 0.269 (\sin\Theta) 0.8 + 0.5 \quad \ldots\ldots \quad (13)$$

Where Θ is field slope in degrees = $\tan^{-1}$ (s/100) and s is filed slope in length.

The study was used the topographic factor (LS factor) grid can be estimated with the following equation (14) proposed by (Wischmeier and Smith, 1978; Moore and Burch, 1986); which was also used in other similar studies different parts of the country (Abate, 2011; Gerawork and Awdenegest, 2014 and Temesgen *et al*., 2017).

$$LS = (X/22.1)\ m\ (0.065 + 0.045\ S + 0.0065\ S^2) \text{ ------ } (14)$$

$X = (\text{Flow acc} * \text{Cell value})^{0.5} * (0.065+0.045S + 0.0065S^2) \backslash LS= \text{flow acc*cell value})$

Where LS is slope length- steepness factor, X=slope length (m), m=a variable slope-length exponent, and S=slope gradient (%).

3.7.3. Crop management factor (C)

The cover management factor represents the ratio of soil loss from a land with specific cropping and management to that from tilled and fallow conditions generally varies from 1 for bare soil, 0.01 for grassland and 0.001 for forest land (Arekhi, 2008). The factor indicates the level of protection of a soil under a certain land cover.

Land cover is one of the most crucial factors in reducing soil erosion by: protecting the soil against the action of falling raindrops, increasing the degree of infiltration of water into the soil, reducing the speed of the surface runoff, binding the soil mechanically, maintaining the roughness of the soil surface, and improving the physical; chemical and biological properties of the soil (Asis and Omasa, 2007). Once, the vegetation cover converted to agricultural land erosion rates could be increased because of the removal of the protection cover.

In order to identify the cover factor for soil erosion assessment, ArcGIS and Google earth image pro application play a great role to facilitate the data entry, analysis and presentation of the results. Application of Google earth is used to preprocess digitizing images manually for each land use type polygon and line feature. Google earth Image for the watershed classified in to numerous polygons and line feature order to make effectively displayed or recorded the data for subsequent visual interpretation. Then the Google earth KML/KMZ file convert to shape file using GIS environment process image into meaningful categories.

The study watershed was classified into 5 major land uses, that area cultivated land, forest land, bush land, bare land and settlement and C- Factor values published by (Wischmeier and Smith, 1978; Hurni, 1985) were used to assign C values to respective cover management type there cover management factor. Finally, the classified land use land cover map was converted to cover factor raster layer using ArcGIS conversion tools and the cover factor values were assigned and reclassified corresponding to each land uses classes.

3.7.4. Support practice factor (P)

Support practice factor or also known as erosion control practice factor is the ratio of soil loss with a specific conservation practice like contouring, strip-cropping, or terracing measures to the corresponding loss with up and downslope cultivation (Wischmeier and Smith 1978). Thus, the P-factor for USLE can be mapped by collecting data from field observations

(Bewket and Teferi, 2009; Tadesse and Abebe, 2014; Temesgen *et al*., 2017). However, in the study area, there were no conservation measures, as data were lacking on permanent management factors and there were no management practices. In this condition, the P-value factors suggested by (Wischmeier and Smith, 1978). This method has also been confirmed in similar studies conducted highland area of Ethiopia (Abate, 2011; Gerawork and Awdenegest, 2014; Gizachew and Mersha, 2015; Tegegne and Binam, 2017 and Legass and Assen, 2019). This method categories land covers into agricultural land, shrub-land and forest land. P-value was assigned 0.8 and 1 regardless of their slope for shrub and forest. However, P-value for agricultural land was given concerning its slope. Therefore, the agricultural land is also sub-divided into six classes based on the slope percentage, to assign different P-value for Each slope class (0–5, 5-10, 10-20, 20-30, and > 50 %) as shown in (Table 5 and Figure 10). High P- values are determined from agricultural land practiced on slope classes greater than 30% after forest land and Shrub land.

3.7.5. Coarse fragment factor (F_{crg})

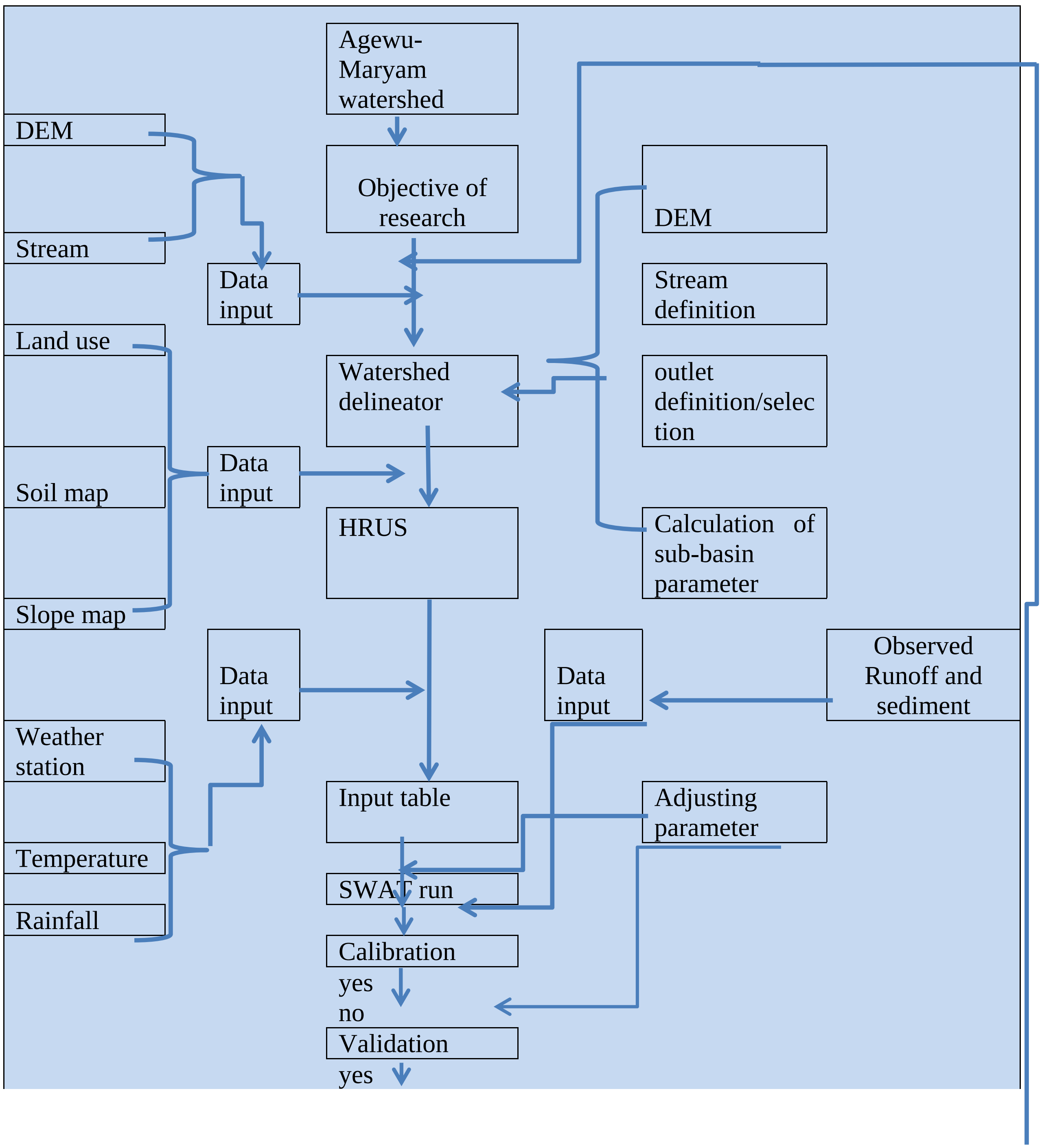
The soil surface data of the study area were collected during the baseline survey of the watershed by a grid of 100X100m and each data was collected from the center of the grid. More than 150 soil samples were collected from the watershed to determine the physical and chemical properties. The rock present and stoniness in the upper most layer was collected through field observation at each grid point during base line survey in the study watershed (155.68ha) (Appendix table 1). Based on the base line survey soil surface information the spatial prediction map of surface fragment factor illustrated in (Figure 12a) was created by Thiessen polygon method.

CFRG is coarse fragment factor, which is estimated as:

$$CFRG = \exp(-0.053 \times Rock) \quad \ldots\ldots (15)$$

Where, rock is % rock in the uppermost soil layer.

Conceptual framework SWAT model



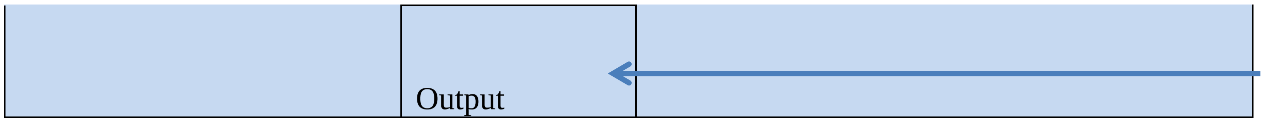


Figure 5: Flow chart of SWAT model simulation of runoff and sediment

After running SWAT model all USLE factors and CN values are used for manually edited SWAT input parameters one by one in the databases, Sub basin data, and watershed data parameters. Finally rerun the model after finessing editing SWAT input parameter tables.

3.8. WEPP model setup

For watershed delineation, WEPP uses the Topographic Parameterization (TOPAZ) method (Renschler and Lee, 2005; Renschler, 2003; Flanagan et al., 2013), described by (Garbrecht and Martz, 1999). The TOPAZ method of delineation was based on Digital Elevation Models (DEMs). The drainage network was determined by assessing each raster cell. TOPAZ employs the critical source area (CSA) concept that asserts the cells comprising the drainage network are those cells that have a drainage area of the CSA. 5ha CSA and 100m Minimum Source Channel Length (MSCL) was used as an input for TOPAZ delineation, and this value determines the smallest size channel that has been represented. CSA and MSCL are the two most consequential parameters in the TOPAZ model, as the input of these two controls the number, density, and size of the drainage channels (Garbrecht and Martz, 1999).

In the WEPP model, the sequence of calculations relevant to surface hydrology is infiltration, rainfall excess, depression storage, and peak discharge. The runoff has been computed using kinematic wave equations and an approximation to the kinematic wave solutions. The surface runoff is estimated using the kinematic wave model (Stone, 1992), which is based on the continuity equation:

$$\frac{\mathbf{dh}}{\mathbf{dt}} + \frac{\mathbf{dq}}{\mathbf{dx}} = \boldsymbol{v} \quad (16)$$

And the depth of peak discharge is:

$$\mathbf{q = \alpha h^{m}} \quad (16.1)$$

Where h, is runoff flow depth (m), q is runoff discharge per unit width ($m^3\ m^{-1}\ s^{-1}$), α is the coefficient of the depth of runoff discharge, m is depth-discharge exponent, and x is distance downslope (m). Infiltration also computes using an implementation of the Green– Ampt Mein Larson (GAML) model for unsteady intermittent rainfall:

$$\mathbf{F_{inf,t} = k_e \left(1 + \frac{\Psi wf\ \ \Delta\theta v}{f\ inf,t)}\right)} \quad (17)$$

Where $f_{inf,t}$ is the infiltration rate at time t (mm h^{-1}), K_e is the effective hydraulic conductivity (mm h^{-1}), Ψ_{wf} is the wetting front matric potential (mm), Δθv is the change in volumetric moisture content across the wetting front and $F_{inf,t}$ is the cumulative infiltration at time t (mm).

In the WEPP model, watershed sediment yield has been calculated from both hill slope and channel areas, because of detachment, transport, and deposition of sediment. The movement of suspended sediment on rill, inter-rill, and channel flow areas is based on a steady-state erosion model that solves a sediment continuity equation at a peak runoff rate. The steady-state sediment continuity equation is described as:

$$\frac{dG}{dx} = Df + Di \qquad (18)$$

Where G is sediment load (kg s^{-1}), x represents distance downslope (m), DF is rill erosion rate (kg s^{-1} m^{-2}) and Di is inter-rill sediment delivery to the rill (kg s^{-1} m^{-2}). Di is considered as independent of x, and always >zero. Df is > 0(positive) for detachment and <0(negative) for deposition. For model calculation both Df and Di were computed on a per rill area basis, thus G is solved on a per unit rill width basis after computations, sediment yield was expressed as sediment yield per unit land area. The rill detachment is computed as per Equation (18.1).

$$\mathbf{Df = Dc\ (1- \frac{\mathit{G}}{\mathit{Tc}})} \qquad 18.1$$

Where Dc is detachment capacity by rill runoff (kg s−1 m−2), and Tc is sediment transport capacity (kg s−1 m−1). If the hydraulic shear stress of the rill is higher than the critical shear stress of the soil, Dc is described as per Equation. (18.2)

$$\mathbf{Dc = K_r\ (\tau\ f - \tau_c)} \qquad 18.2$$

Where Kr (s m−1) is a rill erodibility parameter, is τ f hydraulic flow shear stress, and τc is the rill detachment threshold parameter. The sediment transport capacity (Tc) is estimated as Equation (18.3)

$$Tc = k_t \tau_f^{\ 3/2} \qquad 18.3$$

Where kt is a transport capacity coefficient ($m^{0.5}$ s^2 $kg^{-0.5}$)

Conceptual framework of GeoWEPP Model

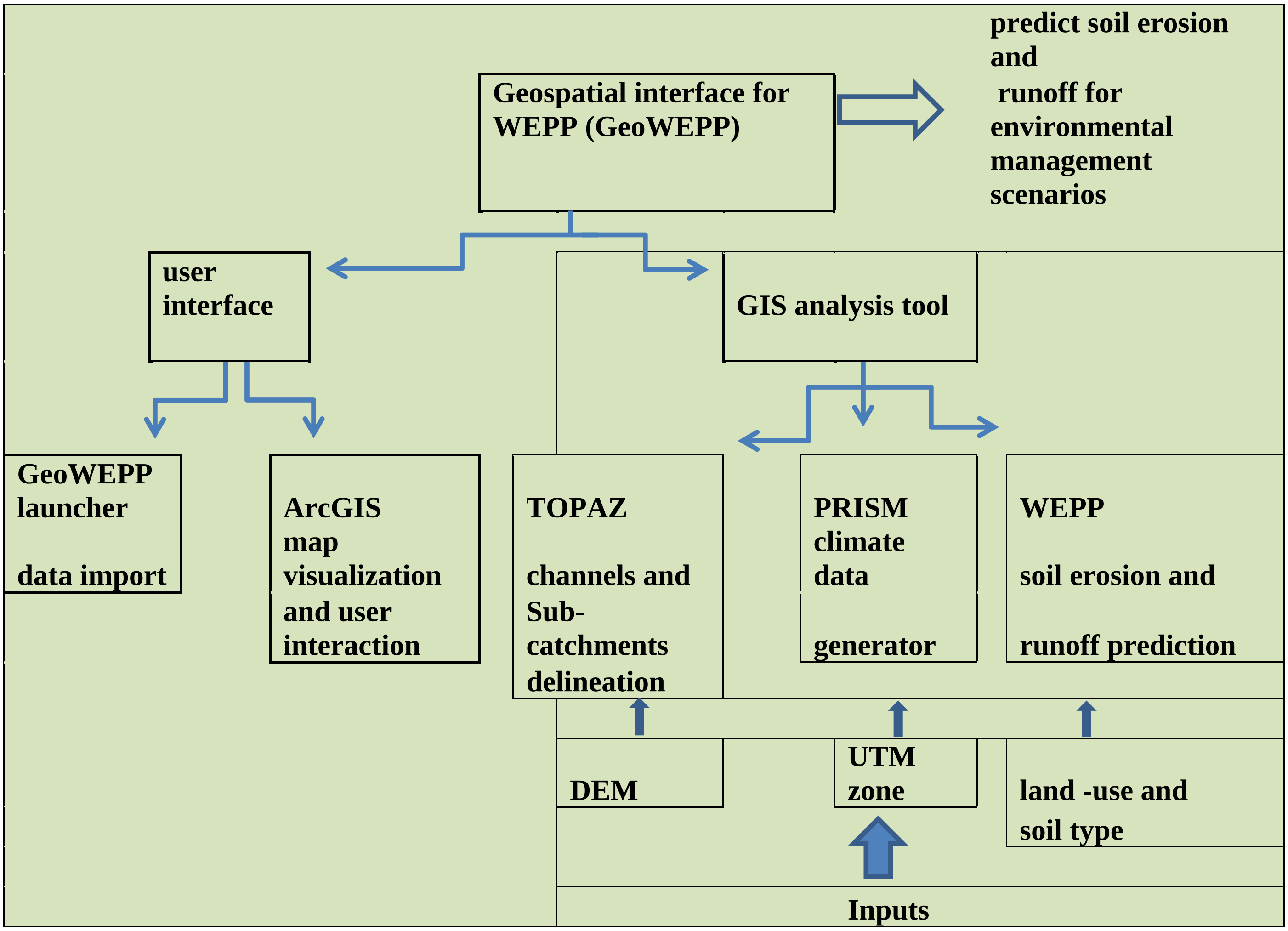


Figure 6: flow chart of Geo WEPP model prediction of runoff and sedimentation

3.9. Estimation of nitrogen; phosphorus and organic matter loss

The sediment in runoff sampled water collected for each event was allowed to settle down at filter paper on the top was decanted in laboratory beakers. The turbid water remained at the bottom and the sediment at the top and air-dried. Nutrient loss from each runoff event was estimated by measuring the sediment yield, and the collected samples were dried at room temperature. Then the collected sample was analyzed for N, P, K and OM contents based on their appropriate standard laboratory procedures. The amount of NPK and OM delivered to the outlet of the watershed with suspended sediment was calculated using equations 19 and 20.

$$Nsi = Ncsi * SSL \text{ and } TNs = \sum_{i=1}^{n} Nsi \quad \ldots\ldots\ldots\ldots\ldots\ldots 19$$

$$TNL = \sum_{i=1}^{n} Nsi / A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 20$$

where Nsi = amount of nutrient with in suspended sediment, Ncsi = nutrient concentration on each sediment sample (gr/Kg) , SSL = suspended sediment load(Kg) TNL = total nutrient loss ,and A = area of catchment/watershed/.

3.10. SWAT and WEPP Model input parameter

For both SWAT and WEPP model ArcGIS10.4 was used for the discretization of the catchment into small grid cells and to integrate layers of spatial information for a quantitative assessment of runoff and sediment yield. The derived spatial model input parameters were compiled into one coherent raster database for modeling annual runoff and sediment yield prediction.

3.10.1. Digital elevation model (DEM)

DEM was used to automatically delineate the watershed into several hydrological connected sub-watersheds. The first step in the watershed delineation was loading the properly projected DEM. The DEM of the Agewu-Maryam watershed was extracted (clipped) from the DEM of the Tekeze basin by using ArcGIS and loaded to Arc SWAT for further processes. After the

DEM grid was loaded, the grid DEM map was processed to remove the non-draining zones. Stream network and sub-basin outlets were defined based on the drainage area threshold approach. The threshold area defines the minimum drainage area required to form the origin of a stream. The interface lists a minimum, maximum, and suggested threshold area. In this study, a 7 ha threshold area was used based on the minimum and maximum area suggested. To delineate the watershed from the DEM of the Tekeze river basin the outlet was selected at the outlet of the gauge location of the Agewu-Maryam watershed. The total area of the delineated watershed was 155.68ha (Figure 7)

3.10.2. Land use land cover map

The land cover map of the Agewu Maryam watershed was identified by drawing manually digitized polygon and line features from 1m pixel size Google earth pro for each land-use type. Open Arc GIS and open conversion tools from Arc toolbox then covert the KML file to layer after conversion project and export map into a shape file. Finally, dissolve the land cover map data in a projected shape file format and then load it to the Arc SWAT interface to determine the area and the hydrologic parameters of each land-soil category simulated within each catchment. The land cover classes were defined using the look-up table. A look-up table that identifies the 4-letter SWAT land cover/land use was prepared to relate the grid values to SWAT land cover/land use classes. Then, the land cover loaded was reclassified. After the land cover, the SWAT code was assigned to all map categories, calculation of the area covered by each land use, and reclassification was done. The land use land cover of the study watershed includes agricultural land, bare land, bush land, forest land, and settlement illustrated (Figure 8).

3.10.3. Soil map

The obtained soil map shape file was co-referenced with the FAO, (1998) soil database to obtain the physical description and characteristics of the map. However, the SWAT database has no FAO soil but American soils. To add FAO soil to the SWAT database, MWSWAT was downloaded from (http://www.waterbase.org/) and installed. Then, FAO soil was copied from the MWSWAT database and added to the Arc SWAT database for further process. As the land cover, the soil layer in the map was linked to the user soil database information by loading the soil look-up table and reclassification was done. In the watershed, the soil distribution was mainly of two types namely Eutric regosol and Eutric Cambsol (Figure 9). A point soil sample was used to determine selected soil physicochemical property and used for mapping soil textural using Arc GIS through the Thiessen polygon method (Figure 9).

3.10.4. Slope map

Topographic characteristics have a significant impact on the spatial distribution of erosion and deposition (Moore and Burch, 1986b). Slope length and gradient factors have been derived from the SRTM 30-meter spatial resolution DEM of the study area obtained in the USGS earth explorer. The elevation of the study area ranges from 2204 to 2378 meters above sea level. The highest and lowest aspect of elevations is found in the Middle Western and eastern parts of the study area respectively. A steeper slope causes higher runoff velocities, more splashes downhill, and faster flow, and therefore contributes to greater soil erosion (Remortel *et al*., 2001). The average slope of the study watersheds was 8.447, 17.095, 33.49, 28.95, and 12.00 for the Agewu Maryam watershed, which is illustrated in (Figure 10).

The land slope classes were also integrated with defining the hydrologic response units. The DEM data used during the watershed delineation was also used for slope classification. The multiple slope discretization operation was preferred over the single slope discretization as the watershed has a wide range of slopes between them. Multiple slope class in Arc SWAT was used to classify the slope into five slope classes. Based on the suggested minimum, maximum, mean, and median slope statistics of the watershed, five (5) slope classes (0-8, 8-15, 15-30, 30-50, and >50%) were applied and the slope grid was re-classified (Table 5).

3.10.5. Weather data

The weather variables required by the model for driving the hydrological balance include daily rainfall, minimum and maximum air temperature, solar radiation, wind speed, and relative humidity. These data were obtained from 1990 to 2020 from Ethiopian National Meteorological Agency, the Combolcha branch used for station data (Sekota) located near the catchment. Missed data for daily rainfall, temperature, solar radiation, wind speed, and relative humidity were estimated using the weather generator in the SWAT model and using the mean average method. The wgen_user.csv file was prepared by following steps WGN parameter estimator tool and after preparing wgen_user.csv open SWAT database 2012 paste on WGN user as a new station.

3.11. SWAT Hydraulic response unit (HRU) analysis

After the reclassification of the land use, soil, and slope grids, overlay operation was performed. When the overlay was finished, the catchment was divided into HRUs based on soil type, land use, and slope classes. HRUs analyses are lumped land areas within the sub-basin that are comprised of unique land cover, soil, and management combination. Land cover, soil, and slope map were required to create HRUs, and the procedure followed to create the HRUs is as follows. In multiple HRU definitions, a threshold level was used to eliminate minor land uses, soils, or slope classes in each sub-basin. Land uses, soil, and slope classes that cover less than the threshold levels are eliminated. After the elimination of the process, the area of the remaining land use, soil, and slope class was repartition so that 100% of the land area in the watershed was modeled. The threshold level set is a function of the project goal and the amount of detail required.

3.12. Geo WEPP Channel and Hill slope analysis

The inputs used for the Geo-WEPP model were 30*30m DEM with no missing data value for each cell, soil type, and land use land cover data file type with ASCII format were required to run the model. The critical source area (CSA) and minimum source channel length (MSCL) were used at 5ha and 100m respectively. The next task for Geo-WEPP is to specify a watershed outlet to delineate the watershed by selecting one stream network cell to ask automatically specify your UTM zone in my case UTM zone 37N. After delineating the watershed, 23 numbers hill slope and 9 channels created was by the Geo-WEPP interface window illustrated (Figure12).

3.13. Performance Evaluation of Model efficiency

The two model efficiency was compared by using t-test statics. *It* is statistics calculated from data to measure the strength of evidence against the null hypothesis. The *t*-test provides information about the results of the comparisons between the two means. Perhaps the most important element of reporting the *t*-test is its significance level (α= 0.05). Larger *p*-values (small Z or t) indicate little or no evidence against the null hypothesis and the null hypothesis is rejected when the *p*-value is small. T-test two-sample equal mean was used to compare two population means where you have two samples in which observations in one sample can be paired with estimations in the other sample. To test the null hypothesis the true mean difference is zero, the procedure is as follows.

Calculate the difference ($d_i = y_i - x_i$) between the two observations on each pair, making sure you distinguish between positive and negative differences where yi = measured/observed value and xi= model output then Calculate the mean difference, ($\bar{d}$).

$$\bar{d} = \sum_{i=0}^{i=n} di/\text{n} \qquad (21)$$

Calculate the standard deviation of the differences, *sd*, and use this to calculate the standard error of the mean difference,

$$SE(\bar{d}) = \frac{s_d}{\sqrt{n}}$$

To calculate the t-statistic, this is given by,

$$T = \frac{\bar{d}}{SE(\bar{d})}.$$

Under the null hypothesis, this statistic follows a t-distribution with n - 1degrees of freedom. Use tables of the t-distribution to compare your value for T to the t_{n-1} distribution. This will give the p-value for the t-test.

The performance of the model was evaluated to assess how the model simulated values fitted with the observed values. Several statistical measures are available for evaluating the performance of a hydrologic model. The goodness of the model fit related to annual runoff and sediment yield was assessed based on Nash–Sutcliffe efficiency (NSE) and coefficient of determination (R^2).

The Nash-Sutcliffe efficiency is calculated as:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(E_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad (22)$$

The range of E lies between −∞ and 1.0 with E=1 describing a perfect fit. Values between 0-1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicate that the mean observed value is a better predictor than the model (Krause et al., 2005).

The coefficient of determination R^2 is defined as the squared value of the coefficient of correlation (Stigler, 1989). It is calculated as follows:

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \bar{O})(E_i - \bar{E})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(O_i - \bar{E})^2}} \right]^2 \qquad (23)$$

Where n is the number of observations or samples; Oi are observed values; Ei are estimated values; Ō is the mean of observed values; Ē is the mean of estimated values; i is the counter for individual observed and predicted values. The range of R^2 lies between 0 and 1 and describes how much of the observed value is explained by the predicted value (Krause et al., 2005). A value of 1 means the predicted value is equal to the observed value, whereas a value of zero means there is no correlation between the predicted and observed values.

4. RESULTS AND DISCUSSION

4.1. SWAT and WEPP Model Input Parameter Estimation

Digital elevation model (DEM):-The primary input parameter for both models to delineate the watershed was DEM. The DEM of the watershed were downloaded in USGS produced by SRTM 30m pixel. The total area of the delineated Agewu Maryam watershed was 155.68ha (figure7). It is surrounded at the North by Likan at the South by gasman, at the West by Mizrbchilkiwu, and in the East by Agewu-Maryam church. It includes Walka, Keymeret , Gishman, and Likan goties.

Land use land cover map: - The land cover map of the Agewu Maryam watershed was identified by drawing manually digitized polygon and line features from 1m pixel size Google earth pro for each land-use type. The larger area of the Agewu Maryam watershed is covered with cultivation land (Gebrehana et al., 2021). The land use land cover map and SWAT code of the study watershed include agricultural land covered 63.168%, bare land covered (1.986%) bush land covered (23.831%), forest land (8%), and settlement (3.014%) illustrated (Figure 8 and Table 2). The dominant land use in the watershed is Agricultural land and bush land which covered 87% of the total watershed.

Table 2: Areal distributions of land cover on Agewu-Maryam watershed

No	Land-use type	SWAT CODE	Area coverage(ha)	Area coverage (%)
1	Agricultural land	AGRL	98.343	63.168
2	Bare land	BARR	3.092	1.986
3	Bushland	RNGB	37.101	23.831

4	Forest land	FRSD	12.456	8.000
5	Settlement	PEAS	4.692	3.014
6	Total		155.684	100

Soil map: - In the watershed, the soil distribution was mainly of two types namely Eutric Regosol and Eutric Cambsol (Figure 9). A large portion of the watershed is Eutric Cambsol covered (61.268%) and the remaining 38.731 portions of the watershed are covered with Eutric Regosol. A point soil sample was used to determine selected soil physicochemical property and used for mapping soil textural using Arc GIS through the Thiessen polygon method (figure9). The soil textural class of the watershed is five (sandy loam, sand clay loam, loamy sand, sand, and loam). The dominantly textural class is a sandy loam that covered (66.71%), loamy sand-covered (19.79%), sandy clay loam covered (8.97%) sand-covered (3.69%), and the small portion covered with loam (0.8%) illustrated (Figure 9; left).

Table 3: Areal distribution of soil type on the watershed

No	Soil type	SWAT CODE	Area coverage (ha)	Area coverage (%)
1	Eutric Regosols	Re29	60.299	38.731
2	Eutric Cambisols	Be 5	95.385	61.268
	Total		155.684	100

Table 4: Areal distribution of soil texture in the study watershed

No	Soil texture	Area coverage(ha)	Area coverage (%)	HSG

1	sandy loam	103.86	66.71	B/D
2	loamy sand	30.82	19.79	B/D
3	sandy clay loam	13.97	8.97	C
4	Sand	5.75	3.69	A/D
5	Loam	1.25	0.8	C

Slop map: - Topographic characteristics have a significant impact on the spatial distribution of erosion and deposition (Moore and Burch, 1986b). Slope length and gradient factors have been derived from the SRTM 30-meter spatial resolution DEM of the study area obtained in the USGS earth explorer. The elevation of the study area ranges from 2109 to 2389 meters above sea level. The highest and lowest aspect of elevations is found in the Middle Western and eastern parts of the study area respectively (Figure10). A steeper slope causes higher runoff velocities, more splashes downhill, and faster flow, and therefore contributes to greater soil erosion (Remortel *et al*., 2001). The average slope area coverage of the study watersheds was 8.447% flat slope, 17.095% gentle slope, 33.49% moderate slope, 28.95% steep slope, and 12.00% very steep slope for the Agewu-Maryam watershed, which is illustrated in (Figure 10). The multiple slope discretization operation was preferred over the single slope discretization as the watershed has a wide range of slopes between them. Multiple slope class in Arc SWAT was used to classify the slope into five slope classes. Based on the suggested minimum, maximum, mean, and median slope statistics of the watershed, five (5) slope classes (0-8, 8-15, 15-30, 30-50, and >50%) were applied and the slope grid was re-classified to use further SWAT model analysis (Table 5).

Table 5: Slope range and area coverage of Agewu-Maryam watershed

No	Slope range (%)	Area covered (ha)	Area coverage (%)
1	0-8	13.152	8.447
2	8-15	26.614	17.095
3	15-30	52.151	33.498
4	30-50	45.072	28.951
5	>50	18.695	12.008
6	Total	155.684	100

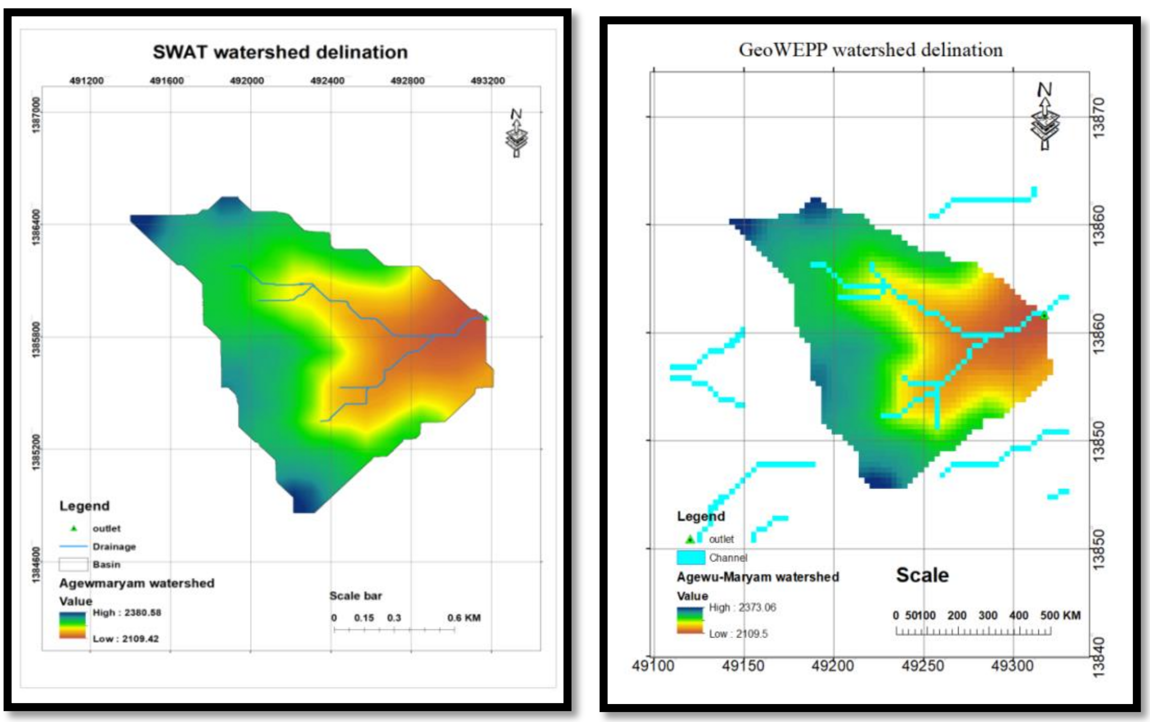


Figure 7: SWAT (left) and WEPP (right) delineation of Agewu-Maryam watershed

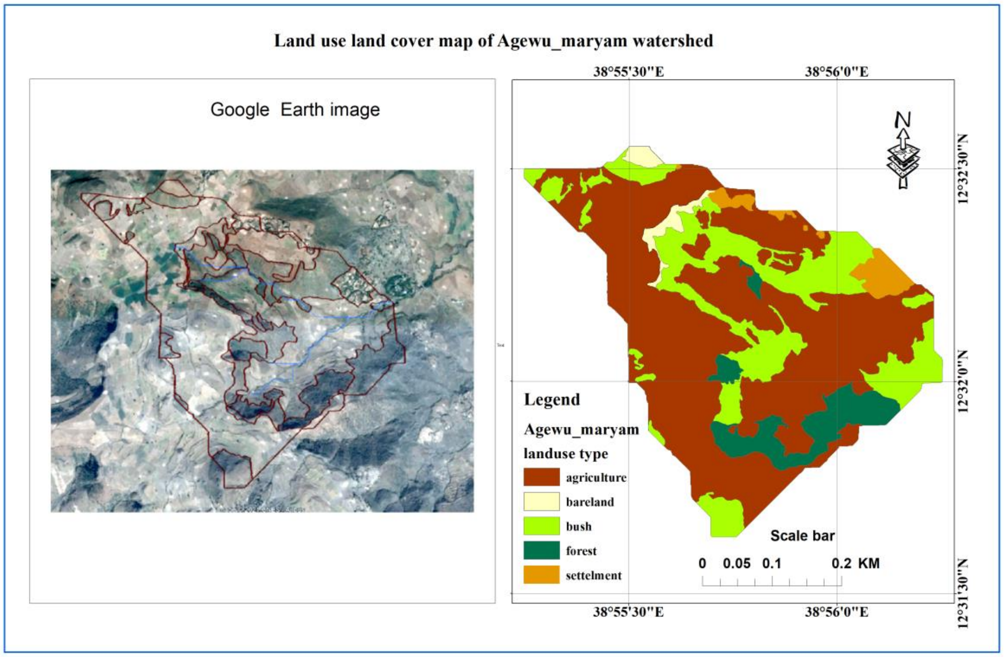


Figure 8: Google Earth Image and land use land cover map of Agewu-Maryam watershed

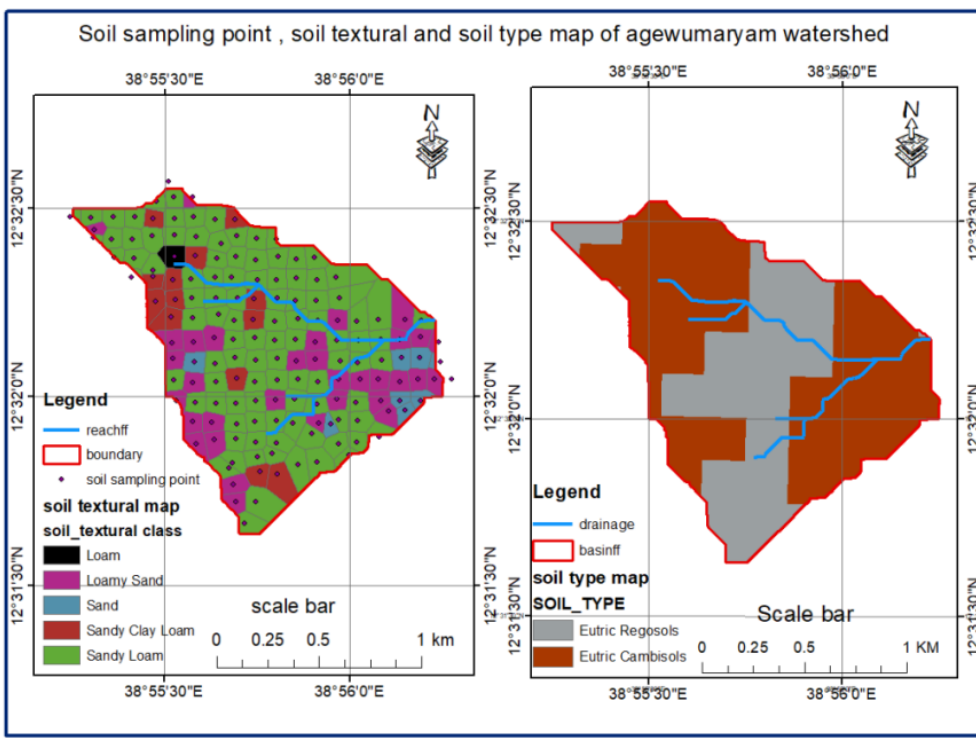


Figure 9: soil textural map (Left) and soil type map (right) of Agewu-Maryam watershed

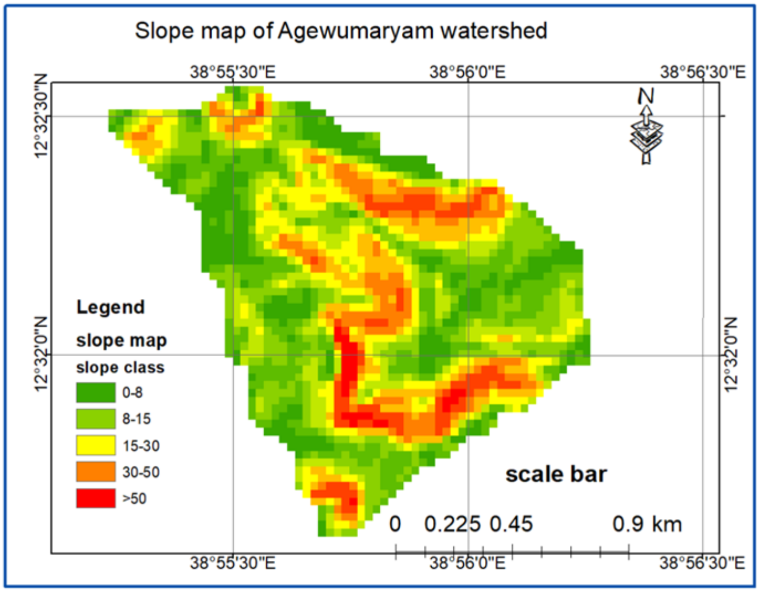


Figure 10: Slope map of Agewu-Maryam watershed

After the reclassification of the land use, soil type, and slope grids, an overlay operation was performed for the SWAT model. When the overlay was finished, the catchment was divided into HRUs based on similar soil type, land use, and slope classes.

4.1.1. SWAT HRU analysis map

The HRU definition in this study was determined by assigning multiple HRU to each slope, land use/land cover, and soil. In the SWAT user manual it was suggested to use a larger number of HRUs a maximum of 10 HRU in a sub-basin is recommended. In this case, 5%, 10%, and 5% threshold levels for the land use, soil, and slope classes were applied, respectively to encompass the spatial details. After analyzing the soil, land use/land cover, and slope of the watershed, the number of HRU and sub-basin were 134 and 11 respectively.

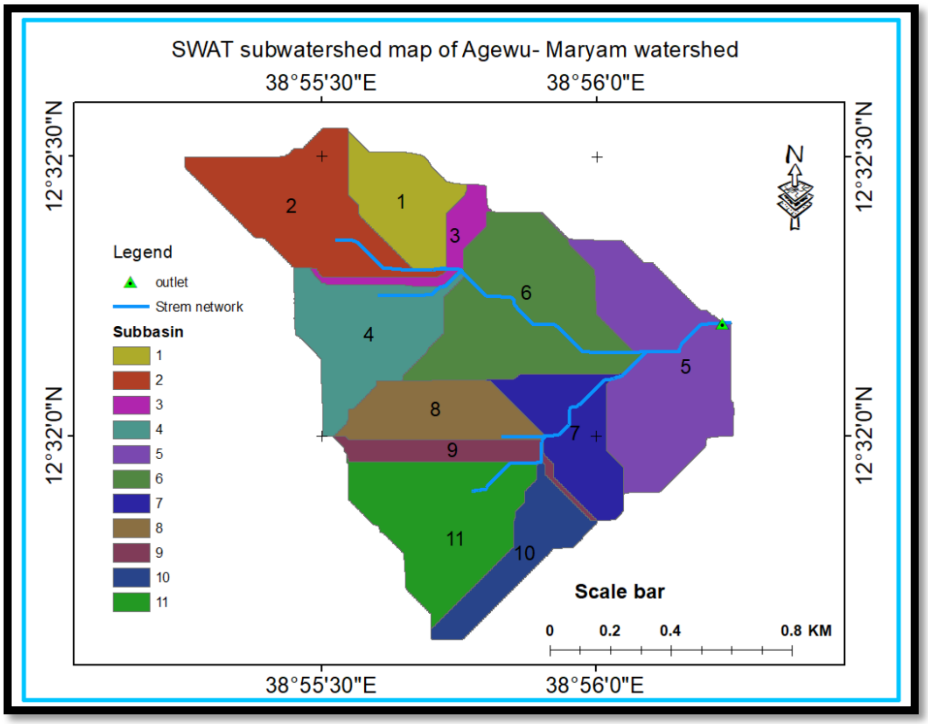


Figure 11: SWAT HRUs sub-watershed map of Agewu-Maryam watershed

Table 6: Distribution of sub basins shape length (m), shape area (m) and area coverage (m^2)

Sub-basin number	Mean Elevation (m)	Minimum Elevation(m)	Maximum Elevation(m)	Std. Elevation (m)	shape length(m)	Area (m^2)
1	2270	2204	2346	24.6	1700	10.3044
2	2296	2204	2346	30.2	2716	18.7760
3	2248	2199	2281	24.9	1944	3.7568
4	2275	2200	2328	25.5	2348	15.9616
5	2156	2109	2280	34.4	3388	25.0336
6	2206	2123	2300	43.2	2952	26.0160
7	2182	2123	2272	35.7	2292	11.3132
8	2262	2159	2326	42.3	1788	10.6200
9	2245	2159	2326	54.6	2332	5.2356
10	2272	2163	2378	47.4	2268	8.5356
11	2277	2163	2376	40.2	2436	20.1328

4.1.2. Geo-WEPP watershed and channel delineation Map

The GeoWEPP model was run after adding the metrological data namely rainfall, temperature maximum and minimum, relative humidity, solar radiation, and wind speed organized daily as per the requirement of the WEPP model and after adding new station observed climate data on the WEPP interface launch GeoWEPP with input parameters (ASCII DEM, land use and soil type). The hill slope and channel are important to calculate the amount of sediment yield delivered and runoff generated at the watershed for the GeoWEPP model. Next, associate my ASCII land use and soil data to WEPP management and GIS land use and soil data then run WEPP by selecting a watershed method of simulation from the watershed, all flow paths, and watershed and flow paths options. Finally Geo-WEPP model gives the analysis result of an offsite event and offsite summary of 23 hill slopes and 9 channels runoff and sediment yield result of the Agewu-Maryam watershed.

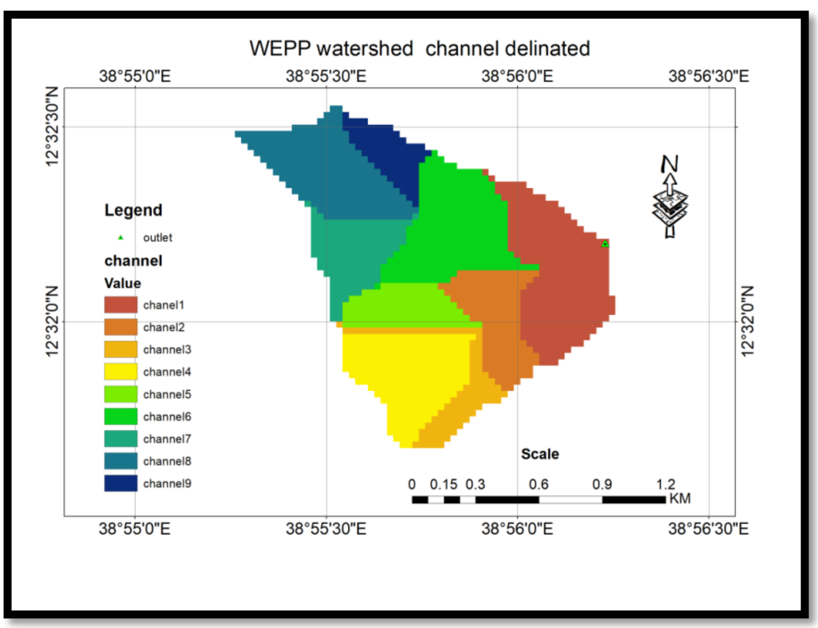


Figure 12: GeoWEPP watershed and channel map of Agewu-Maryam watershed

4.2. Modified universal soil loss parameter estimation

4.2.1. Soil erodibility (K)

Soil erodibility was determined based on the physical and chemical properties of the soil such as soil texture, structure, permeability and organic matter content (Gebreyesus and Kirubel**,** 2009; Prasannakumar et al., 2012). Soil erodibility factor was calculated based on the soil parameters. Whereas, the permeability class code was obtained from soil textural classes which is encoded from textural triangle (Appendix Table1) based on the observed soil texture and also hydrological soil group determine based on permeability and saturated hydraulic conductivity specified by (Renard et al., 1997), (Appendix Table 5)

Table7. Statistical summary of selected soil parameters in the study watershed

No	Soil parameter	maximum	minimum	mean	Standard deviation	CV
1	Sand	92%	49%	70.98%	9.8%	1.54
2	Silt	30%	3%	17.77%	5.72%	0.89
3	Clay	31.25%	4%	11.23%	5.59%	0.87
4	%OM	5.479%	0.0336%	1.55%	1.19%	0.18
5	pH	7.9	5.6	6.55	0.43	0.068
6	%TN	0.506	0	0.085	0.125	0.019
7	Avi. P (ppm)	15.87	1.61	5.87	2.91	0.45

Table 8: Permeability classes corresponding to the hydraulic conductivity and hydrological soil group in study watershed

No	Soil texture	Permeability Class Code	Permeability Class of 1951	Saturated hydraulic conductivity (in/hr.)	HSG
1	sandy loam	2	Moderate to rapid	0.8-2.4	B/D
2	loamy sand	2	Moderate to rapid	0.8-2.4	B/D
3	sandy clay loam	4	Slow to moderate	0.08-0.2	C
4	sand	1	Rapid	>2.4	A/D
5	loam	3	Moderate	0.2-0.8	C

The minimum, mean and maximum percentage of sand soil shown in table 2 was 49, 71 and 92 percent, for silt + very fine sand was 3, 18 and 30 percent; clay was 4, 12 and 31percent.The organic matter was 0.03, 1.3 and 5.5 percent respectively. Based on the above soil information the spatial prediction map of soil erodibility factor illustrated in (Figure 13I b) was created by ordinary kriging interpolation procedure using semi vario gram coefficient of the Gaussian model.

Generally, the soil erodibility was smaller in middle parts of the watershed ranges from (0.059 - 0.068) Mg h MJ^{-1} mm^{-1}. On the other hand, the soil erodibility tends to increase in central and southwest and eastern parts of the watershed that ranges (0.089 - 0.1) Mg h MJ^{-1} mm^{-1} which is illustrated in (Figure 13I b). This result is in line with the study conducted by (Gebrehana et al., 2021) in the study watershed.

4.2.2. Topographic factor (LS)

Topographic characteristics have a significant impact on the spatial distribution of erosion and deposition (Moore and Burch, 1986b). Slope length and gradient factors have been derived from the SRTM 30meter spatial resolution DEM of the study area obtained in USGS earth explorer.

The elevation of the study area ranges from 2109 to 2389 meters above sea level. The highest and lowest aspect of elevations is found on the northern and southern parts of the study area respectively. Steeper slope causes higher runoff velocities, more splashes downhill and faster flow and therefore contributes greater soil erosion (Remortel *et al*., 2001). The average slope of the study watersheds were 27.54% for Agewu-Maryam watershed which is illustrated in (Figure 13III b). Therefore, the average slope gradient in the study areas is more than 5% and thereby, the slope exponent was 0.5 for all study catchments.

In the GIS-based application of Universal soil loss equation and Modified version of it, the slope length and steepness factors are quantified together as a product of LS factor value. To create a combined raster layer for slope steepness and length (LS) factors equation (14) was used which is proposed by (Moore and Burch, 1986a and 1986b).

The minimum, maximum and mean value of topographic factor Agewu- Maryam watershed was (0, 132.4 and 20.8) respectively with the standard deviation of 18.06. The result showed that the topographic factors (LS) range from 0 in plain areas to 132.4 from hillsides and along a stream bank (Figure 13III b). This is clearly showed that soil erosion increases potentially when the slope length and steepness of the land increases.

4.2.3. Management factor (C)

The cover and management factor is the ratio of soil loss from the land with specific vegetation to the corresponding soil loss from fallow with the same rainfall (Wishmeier and Smith, 1978). In order to identify the cover factor for soil erosion assessment, ArcGIS and Google earth image pro application play a great role to facilitate the data entry, analysis and presentation of the results. Application of Google earth is used to preprocess digitizing images manually for each land use type polygon and line feature. Google earth Image for the watershed classified in to numerous polygons and line feature order to make effectively displayed or recorded the data for subsequent visual interpretation. Then Google earth KML/KMZ file convert to shape file using GIS environment process image into meaningful categories. The study watershed was classified into 5 major land uses, that area cultivated land, forest land, bush land, bare land and settlement.

C- Factor values published by (Wischmeier and Smith, 1978) were used to assign C values to respective cover management type and assigned as, 0.17, 0.02, 0.014, 0.06, and 0.14 respectively. Finally, the classified land use land cover map was converted to cover factor raster layer using ArcGIS conversion show in (Figure 13II b).

The result shows that area coverage for land uses was defined (Figure7 and Table 2) show that cultivated land was the largest proportion of the study area, followed by shrub land and forestland. The average value of cover and management factor in the Agewu-Mariyam watershed was 0.080. The maximum cover factor was 0.17 assigned for cultivated land adopted from (Wischmeier and Smith, 1978) for cereal-based agriculture. The cultivated land had a maximum cover factor which indicated that higher erosion. It covers the largest of the land use of the study area.

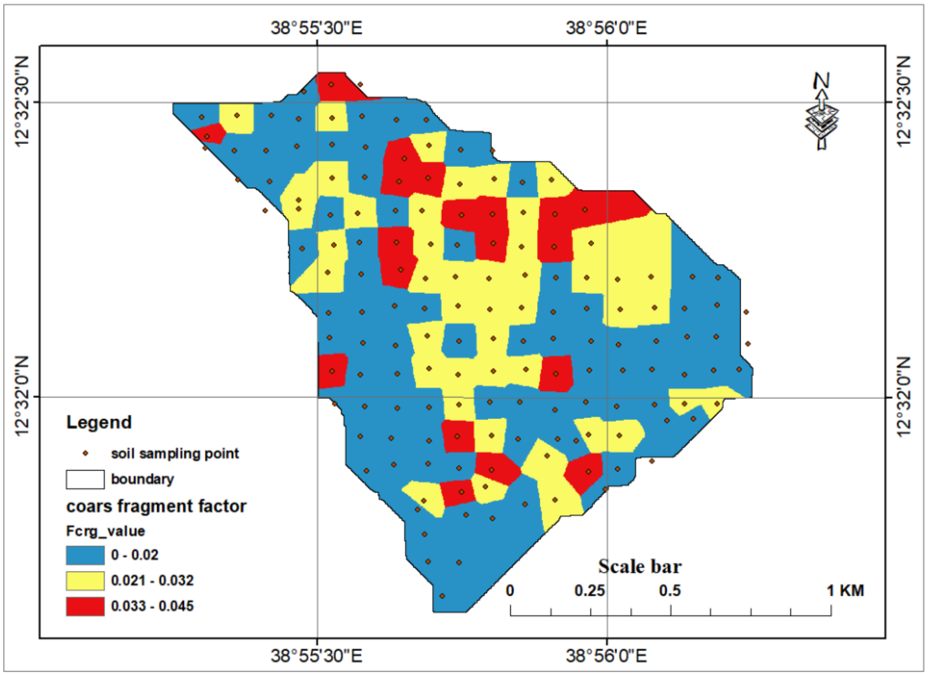
4.2.4. Support practice (p)

The conservation practice (P) factor or also known as erosion control practice factor is the ratio of soil loss with a specific conservation practice like contouring, strip-cropping, or terracing measures to the corresponding loss with up and downslope cultivation (Wischmeier and Smith 1978). Thus, the P-factor for USLE can be mapped by collecting data from field observations (Bewket and Teferi, 2009; Tadesse and Abebe, 2014; Temesgen *et al*., 2017). However, in the study area, there were no conservation measures, as data were lacking on permanent management factors and there were no management practices. In this condition, use the P-value factors suggested by (Wischmeier and Smith, 1978). This method has also been confirmed in similar studies conducted highland area of Ethiopia (Abate, 2011; Gerawork and Awdenegest, 2014; Legass and Assen, 2019 and Gebrehana et al., 2021).

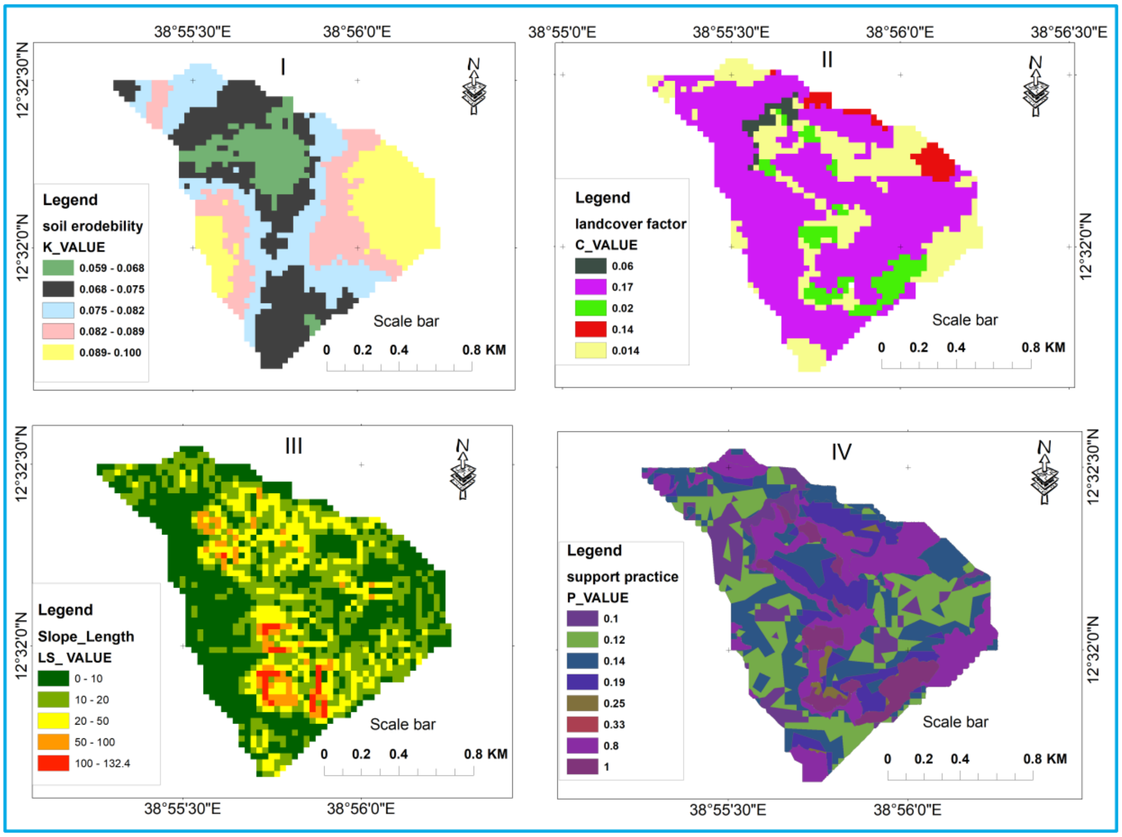
P-value was assigned 0.8 and 1 regardless of their slope for shrub and forest. However, P-value for agricultural land was given concerning its slope. Therefore, the agricultural land is also sub-divided into six classes based on the slope percentage, to assign different P-value for each slope class (0–5, 5-10, 10-20, 20-30, and > 50 %) as shown in (Table 5 and Figure 10 above). High P values are determined from agricultural land practiced on slope classes greater than 30 % after forest land and Shrub land show in (13IV b).

4.2.5. Coarse fragment factor (Fcrg)

The soil surface data of the study area were collected during the baseline survey of the watershed by a grid of 100X100m and each data was collected from the center of the grid. More than 150 soil samples were collected from the watershed to determine the physical and chemical properties. The rock present and stoniness in the upper most layers was collected through field observation during base line survey in the study watershed (155.68ha) (Appendix table 1). Based on the base line survey soil surface information the spatial prediction map of surface fragment factor illustrated in (Figure 13a) was created by Thiessen polygon method. The result show that the coarse fragment factor value ranges (0- 0.45) occurred in south east and northwest part of the watershed.



(a)



(b)

Figure 13: MUSLE model parameter value map

4.2. Observed runoff and Sediment Concentration from hydrological weir

Daily rainfall and runoff data were collected using manually for the last 4 years from 2017 to 2020 at the monitoring stations in the Agewu-Maryam watershed. The rainfall information was recorded using a rain gauge for 24-hour intervals whereas; the runoff data was determined through manually recorded stage reading. In this study, three year rainfall, runoff and sediment data were used for observed data analysis. 30 storm events occurring from June2018 to September in 2020 were selected that have a daily rainfall depth of more than 12.7mm, which is a threshold value of daily rainfall developed by Wischmeier and Smith

(1978). The amount of runoff volume and peak discharge was derived from time serious data using the respective weir equations for the Agewu Maryam watershed. The mean depth of observed runoff volume for selected events was 93.47mm and the daily average peak discharge was1.39 m^3/s for the Agewu Maryam watershed.

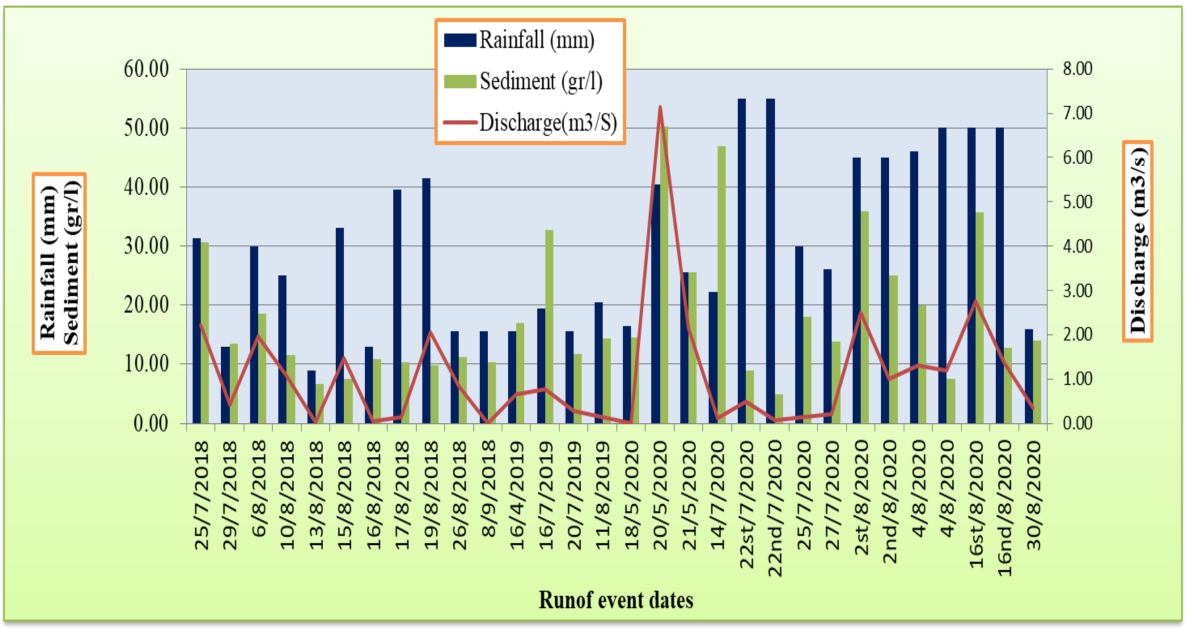


Figure 14: Observed runoff, rainfall, and sediment on Agewu-Maryam watershed

The runoff is usually being discharged with a certain amount of suspended sediment, which is determined by sediment concentration in conjunction with a total runoff volume that arrives at a defined confluence point. The sediment yield in the study area was extracted from the runoff volume based on corresponding sediment concentrations for individual events. The sediment concentration in the study watersheds was relatively high at the start and mid of the rainy season as presented in (Figure 14). It could be related to the seasonal variation of rainfall and vegetation cover that lags behind the most intensive rainfall at the start of the rainy season.

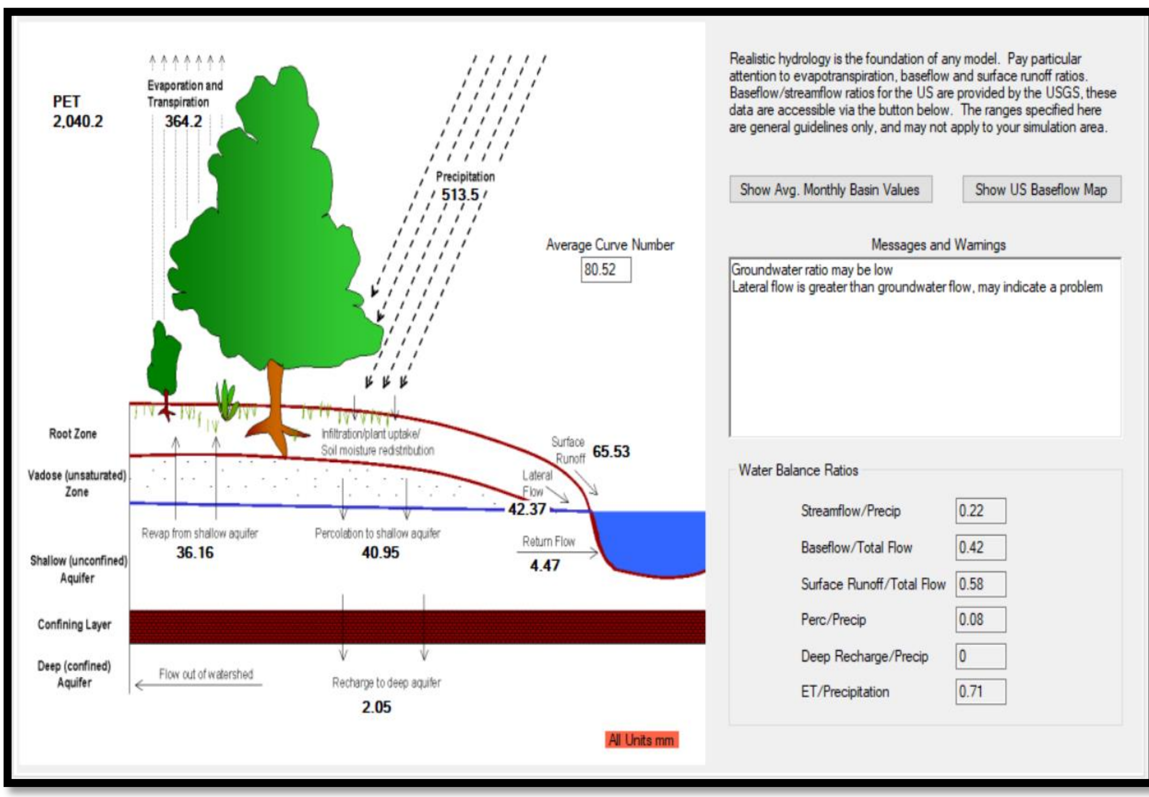
4.3. Runoff and sediment loss prediction with SWAT and WEPP model

Rainfall mainly occurred from July to mid of September in the observation period (2017-2020) creating the highest runoff and sediment yield in the watershed. The average mean monthly runoff and sediment was predicted in August and July 24.62 and 9.14 t/ha/yr because almost 69.5 % of rainfall was obtained in the two months as shown in (Table 9).

The mean annual rainfall for the period (2017-2020) was 626.5 mm. The annual runoff amount generated by the SWAT model in 2017 (148.42 mm) was much higher than in 2018 (33.32 mm) and 2019 (39.44mm) but the similar value in 2020 (126.82 mm) rainy seasons. Similarly, the results of the analysis showed the same trend of soil erosion in the watershed. The sediment yield recorded in 2017, 2018, 2019, and 2020 were 92.3 t/ha, 34.66 t/ha 27t/ha, and 90.1 t/ha, respectively. The annual sediment yield simulated result was highly variable over the four years (2017-2020) this may be due to the annual variability of rainfall slope cultivation and low vegetation cover.

The long-term average means annual rainfall, runoff, and sediment yield generated for the watershed with the SWAT model were 513.5mm, 65.54mm, and 41.7t/ha/yr respectively shown in (Table 9 and Figure 15). The long-term average mean sediment yield is high it may be due to the unevenly distributed rainfall and there is 41% of the area in the watershed is above 30% of slope and cultivation land use type. These results indicate that soil erosion is bound up with slope gradient, and the main erosion degree increases with the slope gradient increasing under all land-use types. The result agrees with the finding of (Zhanyu et al., 2015) reported that erosion degree increase with the slope gradient increasing. The acceptable soil loss that can maintain the economy and a high level of production (Husen and Abate, 2020; Gebreyesus and Kirubel, 2009) ranges from 5 to 11 t/ha/yr (Foster et al., 2002). However, the soil loss from the watersheds is above this range and the area is more susceptible to soil loss.

The sediment yield estimated by the SWAT model for the Agewu-Maryam watershed (41.7) t/ha/yr was in agreement with other studies (Kidane, 2016) report a sediment yield of 32.57t/ha/yr exported from the Tekeze dam sub-watershed while (Niguse et al., 2017) reported that the SWAT model prediction from treated and untreated watershed (33.5 and 44.8 t/ha/yr) was a satisfactory result. In another study with USLE (Gebrehana et al., 2021) 25t/ha/yr underestimate the soil loss rate is still above the soil loss tolerable limit (18t/ha/yr) reported by (Hurni, 1985).



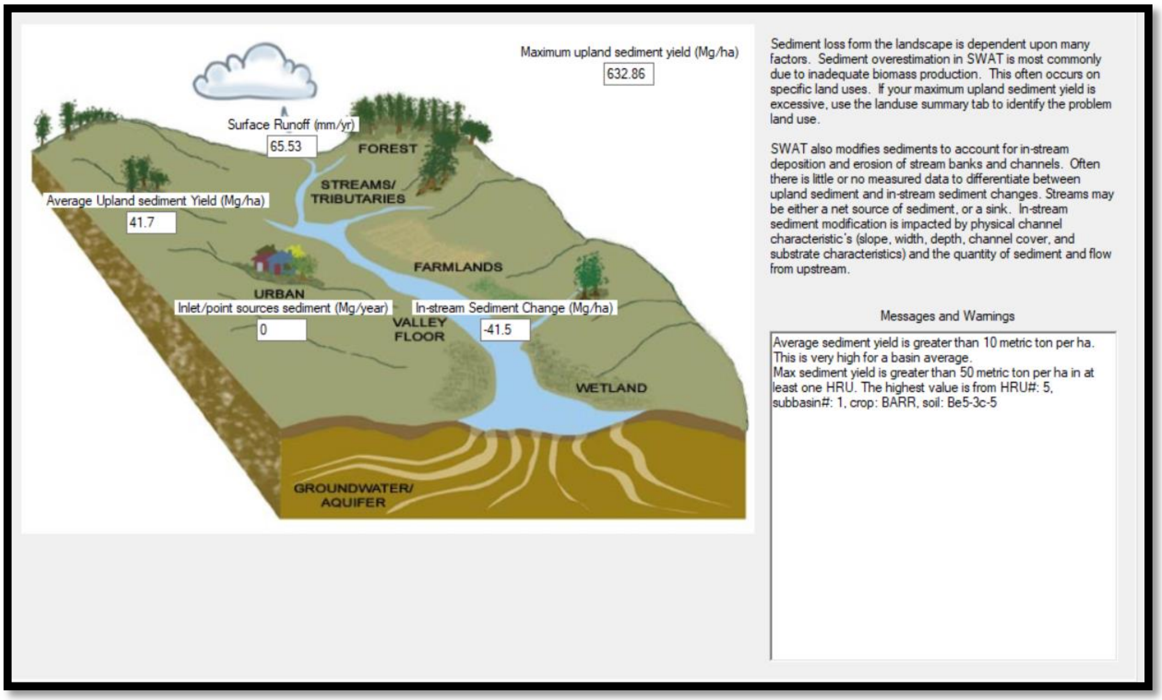


Figure 15: Average mean annual Runoff (top) and Sediment (bottom) SWAT output for Agewu-Maryam watershed

Table 9: SWAT predicted average mean monthly runoff and sediment yield

Months	Rain (mm)	Surface Q(mm)	Lateral Q(mm)	Water yield (mm)	ET (mm)	Sediment yield(t/ha/yr)
Jan	1.97	0.01	0.12	0.31	6.06	0.01
Feb	11.02	1.58	0.58	2.28	8.22	1.93
Mar	16.78	0.88	0.88	1.86	32.63	0.55
Apr	20.68	1.33	1.37	2.77	42.08	0.87
May	30.57	1.41	2.06	3.53	26.78	1.2
Jun	19.31	0.13	1.11	1.28	18.81	0.25
Jul	158.16	13.85	11.4	25.27	61.5	9.14

Aug	198.79	41.4	19.22	60.78	76.78	24.62
Sep	43.77	4.34	4.83	10.66	48.21	2.95
Oct	6.49	0.45	0.47	3.19	24.58	0.15
Nov	3.09	0.01	0.16	1.63	11.17	0.01
Dec	3.05	0.15	0.16	0.81	7.52	0.06
Total	513.68	65.54	42.36	114.37	364.34	41.74

The annual runoff amount generated by the WEPP model in 2017 (293.6 mm) was much higher than in 2018 (217.61mm) and 2019 (273.16 mm) but the similar value in 2020 (283.45 mm) rainy seasons. Similarly, the results of the analysis showed the same trend of soil erosion in the watershed. The sediment yield recorded in 2017, 2018, 2019, and 2020 were 48.9 t/ha, 26.9t/ha 32.3 t/ha, and 48.6 t/ha, respectively.

The long-term average means monthly rainfall, runoff, and sediment yield generated for the watershed with the WEPP model were 522mm, 54.38mm, and 43.1t/ha/yr respectively shown in (Table 10 and Figure 16). The long-term average mean sediment yield is high it may be due to the unevenly distributed rainfall and there is 41% of the area in the watershed is above 30% of slope and cultivation land use type. These results indicate that soil erosion is bound up with slope gradient, and the main erosion degree increases with the slope gradient increasing under all land-use types.

The WEPP model prediction clearly shows that large proportions of watersheds have a sediment loss of greater than 4t/ha/yr. 67.4% of watersheds contributed a sediment loss of above 4 t /ha/yr (Figure 16). On the other hand, 32.6% of watershed contributes less than 4 t/ ha/yr of offsite sediment loss. Generally WEPP long–term average mean annual runoff and sediment yield generated in the watershed is 146.14 mm and 43t/ha/yr respectively. The result high due to the unevenly distributed rainfall and there is 41% of the area in the watershed is above 30% of slope gradient and 63.16% of the watershed is cultivation land use type.

Table 10: Geo WEPP predicted average mean monthly runoff and sediment yield

Month	Precipitation mm	Average runoff(mm)	Average peak flow(m^3/s)	sediment t/ha/yr
January	0.32	0.04	0.004	0
February	0.00	0.35	0.0001	0
March	8.00	0.34	0.026	0
April	34.18	2.54	0.150	0.035
may	52.07	1.78	0.110	0.006
June	1.32	0.78	0.051	0.000
July	78.02	2.76	0.156	0.575
August	261.12	37.29	1.607	39.507
September	66.35	6.59	0.357	3.047
October	8.48	1.55	0.099	0.001
November	4.58	0.47	0.033	0.000
December	7.52	0.22	0.016	0.000
Total	522	54.38	2.609	43.1

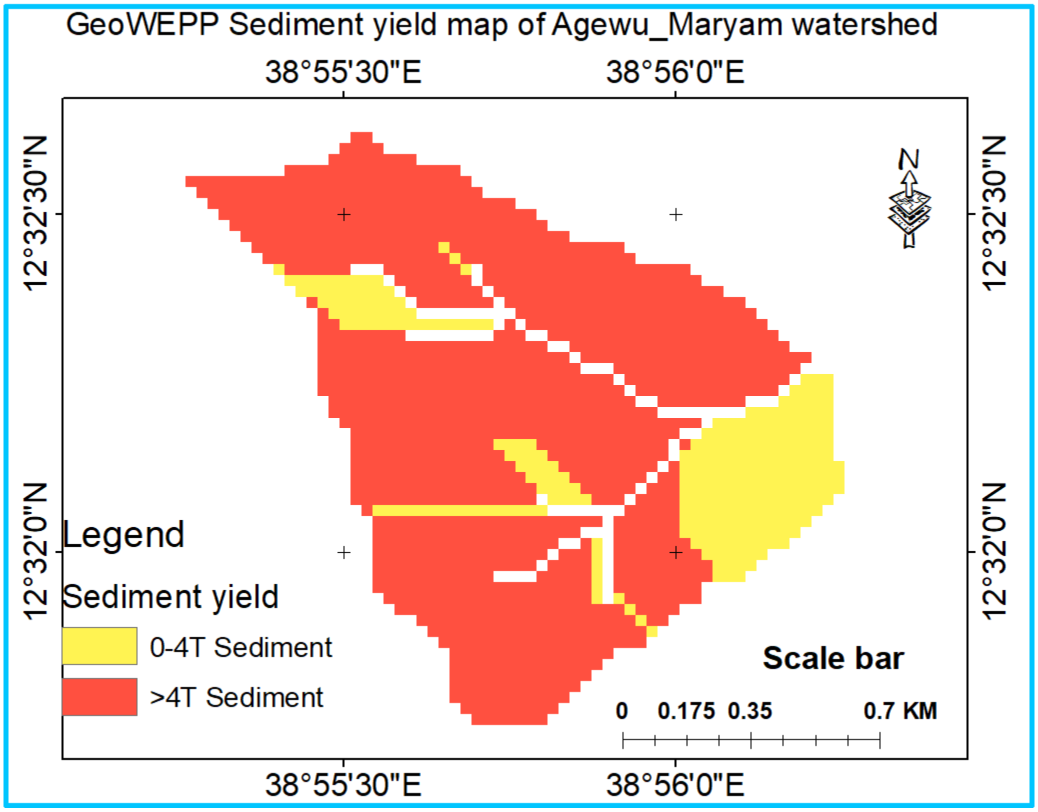


Figure 16: WEPP sediment yield map of Agewu-Maryam watershed

The watershed is characterized by high steep slope coverage sparse vegetation cover (Figure2 and Figure10). The WEPP model simulation result agrees with (Niguse et al., 2017) reported that the WEPP model predicts from the untreated watershed 64.1 t/ha/yr was a satisfactory result in the northern highland of Ethiopia. The above result disagrees with the result of (Akbari et al., 2015) reported that significant correlation between estimated and observed sediment yield based on R^2 (0.99) and NSE (0.92) in north waste of Tehran Iran

Table 11: Runoff and sediment yield predicted by WEPP (watershed method) with hill slopes

Hill slopes	Runoff Volume (m^3)	Soil Loss (kg)	Sediment Yield(kg)

Hill 1	11790.8	1483888	1483890
Hill 2	15279.17	34605.46	34605.23
Hill 3	2736.38	1139.14	1139.15
Hill 4	2373.77	29951.9	29952.08
Hill 5	6420.29	750.4	750.4
Hill 6	7299.47	727416.2	727414.6
Hill 7	11749.94	42906.63	42906.73
Hill 8	8931.08	1157148	1157154
Hill 9	552.57	37972.83	37972.99
Hill 10	6.09	115.26	115.26
Hill 11	13347.32	1976416	1976424
Hill 12	30012.84	2579334	2579346
Hill 13	16857.5	18209.02	18209.16
Hill 14	1463.44	129132.4	129132
Hill 15	6643.65	407304.5	407304.1
Hill 16	477.02	10400.07	10400.17
Hill 17	3149.46	132630.9	132630.8
Hill 18	4506.73	7320.12	7320.15
Hill 19	7473.72	612663.1	612660.2
Hill 20	3207.42	60813.83	60813.85
Hill 21	9067.66	1201852	1201851
Hill 22	59.03	45.89	45.89
Hill 23	572.18	13093.63	13093.65

The relative soil erosion increases across the hill slope. WEPP model predicts 8.42 kg/m^2 was simulating at 51 m in the hill slope (Figure 17). The annual rainfall of 655.37 mm generates 63.04 mm of runoff and 43.014 t/ha sediment yield (Figure 17). The results showed that the soil losses increase along the hill slope. The result agrees with (Niguse et al., 2017) reported that the WEPP model predicts 8.11 kg/m^2 was observed at 20 m in the hill slope.

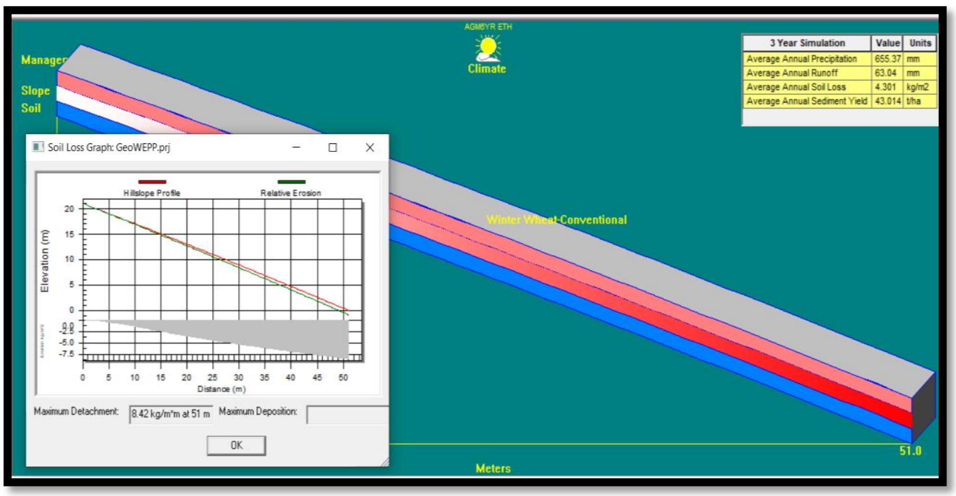


Figure 17: WEPP hill slope erosion

The sediment yield estimation of the WEPP model for the Agewu-Maryam watershed (43t/ha/yr) was in agreement with (Niguse et al., 2017) reported that the WEPP model predicts from the treated and untreated watershed (39.9 and 64.1 t/ha/yr) was a satisfactory result in the northern highland of Ethiopia.

4.4. Spatial Distribution Map of Sediment Yield

The degree of erosion hazard in the Agewu-Maryam watershed was reclassified into five (Table 12) different erosion hazard classes based on (Gebrehana et al., 2021). According to prioritization map, sediment loss categorized into five (5) classes, such that 0-11, 12-18, 19-30, 31-50 and >51 t/ ha/yr.

Table 12: Sediment yield loss and severity class of Agewu Maryam watershed

Annual sediment loss rate t/ha/yr	Sub-watershed	Severity class	Area covered	Area %	Priority class
0-11	7, 8, 10	lower	30.46	19.56	5
12-18	3, 4, 6, 11	moderate	65.88	42.32	4
19-30	9	high	5.23	3.36	3
31-50	5	Very high	25.03	16.08	2
>50	1, 2	sever	29.076	18.68	1
Total			155.685	100	

According to this study sub-watershed 9, 5, and 1, 2 are categorized as high, very high, and severe sediment loss and covered 38.12% of the watershed (Table 12 and figure17). The sediment losses from this sub-watershed are greater than the maximum tolerable soil loss rate (>18 t/ha/yr) and high surface runoff generated from these sub-watersheds and identified as an erosion-prone area in the Agewu Maryam watershed (Table 12 and figure 17). The main reason for generating more runoff and sediment yield could be land degradation, poor land cover, improper land management, and cultivating undulating slopes without conservation. The acceptable soil loss that can maintain the economy and a high level of production (Husen and Abate, 2020; Gebreyesus and Kirubel, 2009) ranges from 5 to 11 t/ha/yr (Foster et al., 2002). However, the sediment loss from these sub-watersheds is above this range and the area is more susceptible to soil loss.

From 11 sub-watersheds 4-sub watersheds (3, 4, 6, and 11) were categorized under moderate severity class and the annual sediment loss ranges from 12-18t/ha/yr, and the larger area of the watershed covered 42.32% and give moderate priority class shown in (Table 11). The result is in line with (Hurni, 1985) who reported that the range of soil loss tolerable levels for different agro-ecology of Ethiopia was found from 2 to18 t/ha/yr. However, the result from the four sub-watersheds above acceptable soil loss that can maintain the economy and a high level of production (FAO, 1986; Gebreyesus and Kirubel, 2009) ranges from 5 to 11 t/ha/yr and also above the range of soil formation rate in the study area ranges from 6-10 t/ha/yr (Hurni, 1983). These sub-watersheds were dominated by a moderately gentle slope, agriculture, and sandy clay loam dominant soil Hence soil type, topography, and agricultural activity is the principal factor for sediment loss and surface runoff.

The other 3 sub-watershed (7, 8 and 10) were categorized under lower sediment loss rate 0-11 t/ha/yr. the area classified under lower sediment loss covered 19.56% of the watershed shown in (Table 12). The result agrees with the finding of (FAO, 1986; Gebreyesus and Kirubel, 2009) who, report that acceptable soil loss that can maintain the economy and a high level of production ranges from 5 to 11 t/ha/yr (Foster et al., 2002; Renard et al., 1996). This sub-watershed was less susceptible to soil loss because the land use cove type dominantly covered with bush and forest are shown in (Figure 8). The main reason for this forest land area, it has a thick layer of old leaf residue on the surface that protects against soil erosion. The forest bush canopy was also reduced the raindrop power and detachment of soil. The result was also confirmed by (Oruk et al., 2012; Rizeei et al., 2016). Therefore, land cover took a greater share in reducing soil erosion and runoff potential by increasing infiltration capacity and reducing raindrop impact. The number (1-11) indicates the sub watershed number illustrated in (Figure 11).

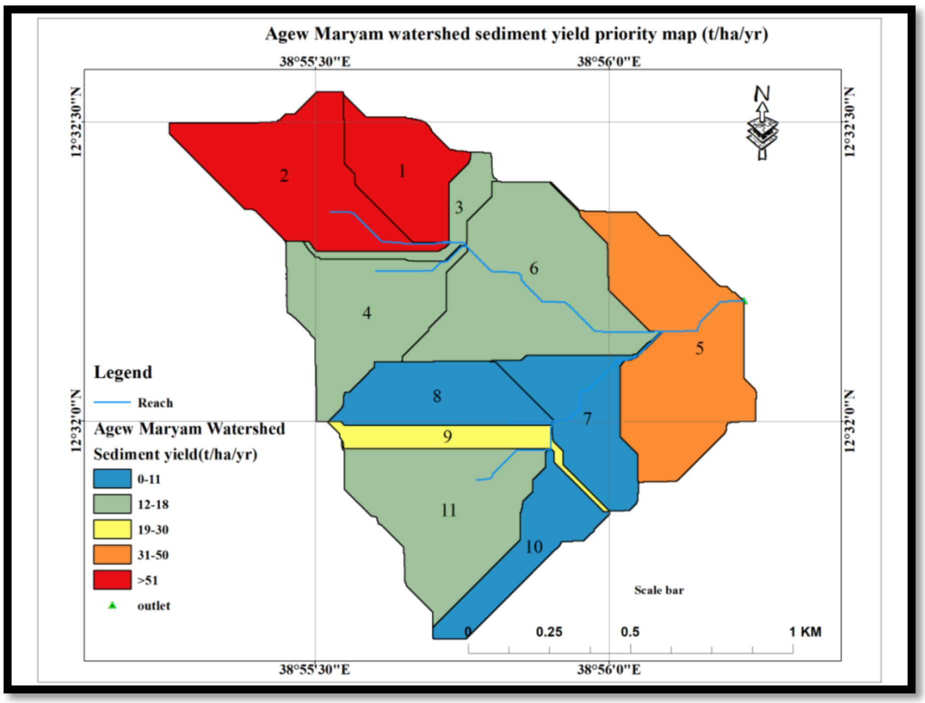
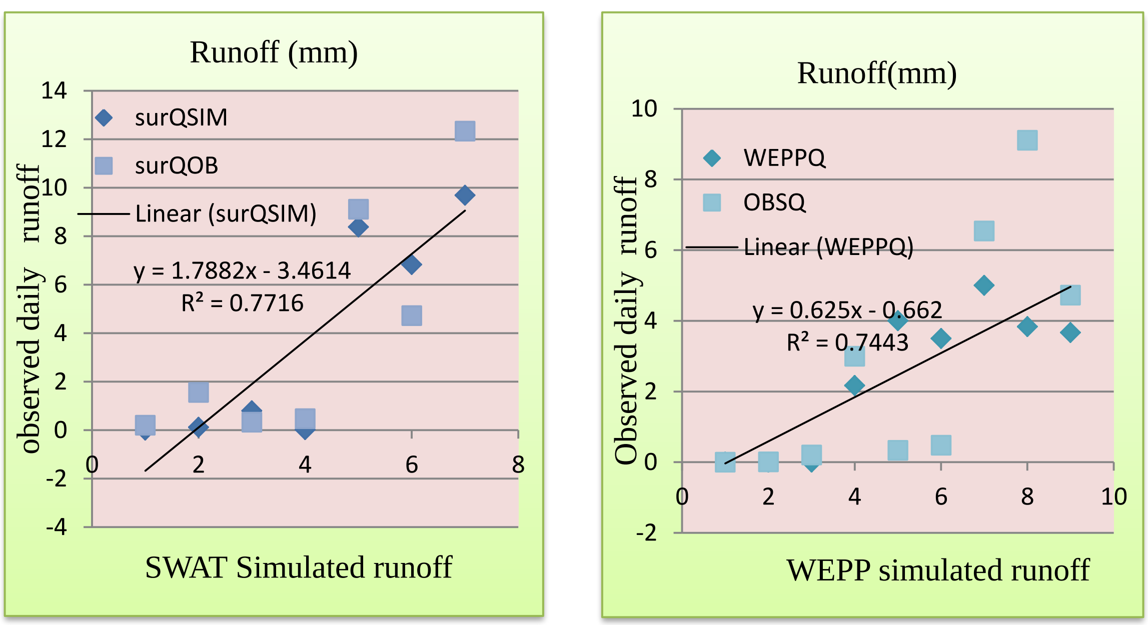


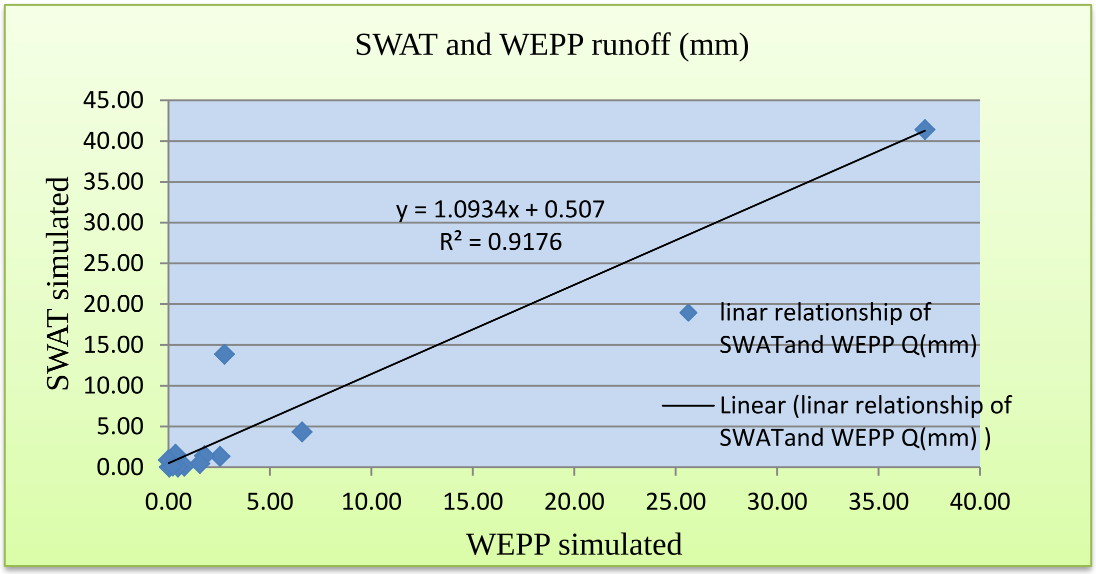
Figure 18: Sediment loss priority map for the planning of Agewu Maryam watershed

4.5. Comparison of simulated and observed annual runoff and sediment yield

The simulated monthly mean runoff values of the WEPP and SWAT models for the simulation periods were compared with observed values. The observed and simulated monthly mean runoff values along with the 1:1 line for the simulation periods are shown in (Figure19 and Figure20). The high coefficients of determination (Figure 19and Figure 20) indicate a positive relationship (how much, model explain observed variable) between the measured and simulated runoff for most selected days, months, and year. Furthermore, reasonably the regression R^2 values for the simulation periods selected days (0.74 and 0.77 for WEPP and SWAT, respectively) indicated the satisfactory performance of both models simulated daily runoff (Figure19 (a) and Figure 20 (a)). The simulated monthly mean runoff and sediment yield of the SWAT and WEPP model compared graphically (Figure19 (b) and Figure 20 (b)) the estimated result shows that SWAT and WEPP simulated very well with R^2 (0.91) for runoff and (0.88) for sediment yield. These results along with other criteria indicate a satisfactory overall prediction of monthly mean runoff by the WEPP and SWAT models during the simulation period. The simulated and observed value comparison result agrees with the finding (Niguse et al., 2017) reported that R^2 value 0.68 for untreated watershed and 0.61 for the treated watershed and (Aman et al., 2021) reported that R^2 0.73 and 0.82 for Maki watershed stream flow and sediment yield analysis using SWAT model.



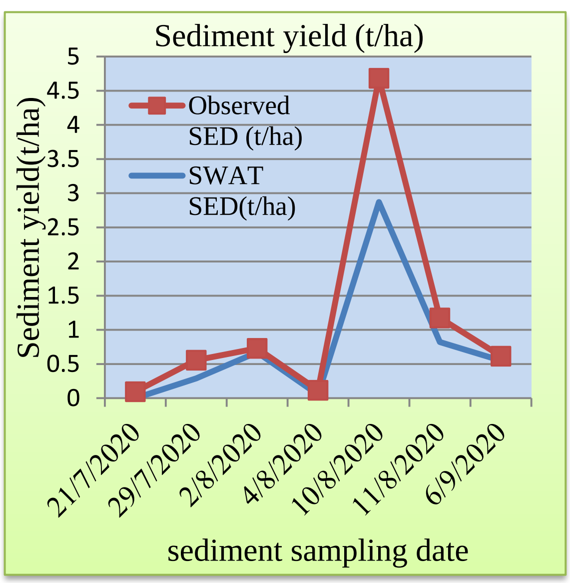
(a)

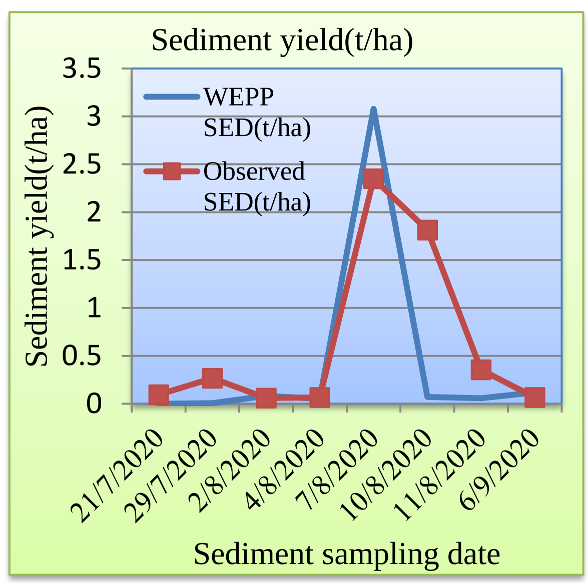


(b)

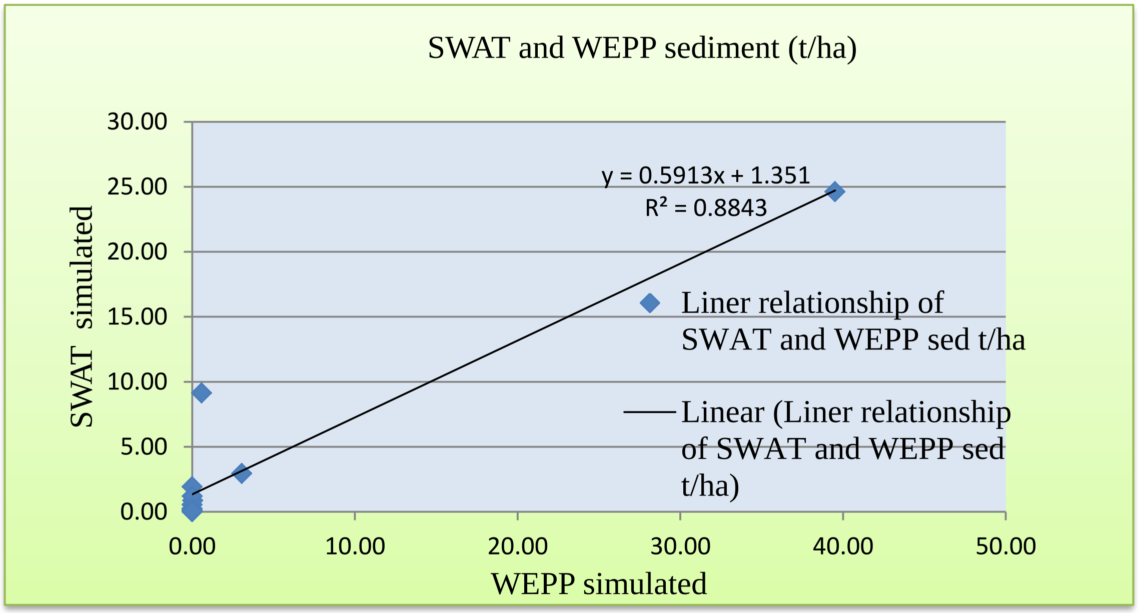
Where, surQSIM = surface discharge simulated, sur OBQ = surface observed discharge WEPPQ = WEPP discharge and OBSQ =observation discharge

Figure 19: Simulated and observed runoff (mm) SWAT and WEPP (a) and simulated SWAT and WEPP runoff (b)





(a)



(b)

Where SWAT SED = SWAT sediment yield, WEPP SED = WEPP sediment yield, and observed SED = observed sediment yield.

Figure 20: Simulated and observed sediment yield (t/ha) SWAT and WEPP (a) and simulated SWAT and WEPP runoff (b)

In addition, a t-test is done to compare the estimated long-term monthly runoff and sediment yield for both SWAT and WEPP models. The P-value is known as the probability value. It is defined as the probability of getting a result that is either the same or more extreme than the actual observations. The P-value is known as the level of marginal significance within the hypothesis testing that represents the probability of occurrence of the given event. The results of the t-test showed that there were no statistically significant differences ($P \geq 0.05$) between the SWAT and WEPP models estimated runoff and sediment yield with p-value = 0.84 and p-value = 0.97 respectively (Table 13).

Table 13: Comparison of SWAT and WEPP model runoff and sediment simulation with Observed value

Models	Precipitation (mm)	Runoff (mm)		R2	NSE	Sediment yield t/ha		R2	NSE
WEPP	782.2	146.14		0.86	0.54	43.1		0.85	0.64
SWAT	782.2	148.42		0.91	0.71	41.7		0.57	0.56
Observed	626.26	93.4				33.36			
Mean	730.22	129.27				39.35			
*SD	90.032	31.12				5.23			
CV	12.32	24.07				13.29			
Models	n	Mean	df	Std.	p-value	Mean	df	Std.	p-value
SWAT	12	5.46	22	11.96	0.84	3.59	22	11.3	0.97
WEPP	12	4.53		10.47		3.57		7.13	

The simulated monthly mean sediment yield values by the WEPP and SWAT models for the simulation periods were compared with observed values (Table 13). The observed and simulated monthly mean sediment yields for the simulation periods along with the 1:1 line are shown in (Figure19). The high coefficients of determination indicated a positive relationship between the simulated and measured sediment yields (Figure19 and Figure20). Reasonably the NSE values for runoff and sediment simulated periods for WEPP (0.54 and 0.64, respectively) and SWAT (0.71 and 0.56, respectively) showed that the models performed satisfactorily (Table 13). The NSE value of the WEPP model means annual sediment was higher than the SWAT model and WEPP had better sediment yield prediction performance than SWAT. However, the overall predictions of monthly mean sediment by the WEPP and SWAT models during the simulation period were satisfactory and so used for further analysis.

The Geo-WEPP model simulation results predict the monthly runoff and the sediment yield well with R^2 values of 0.86 and 0.85 for the watershed. The SWAT model simulation results predict the monthly runoff and sediment yield with R^2 0.91 and 0.57 for the Agewu Maryam watershed. In general, GeoWEPP and SWAT model performed with NSE satisfactorily in both surface runoff and sediment yield simulations in the watershed and with R^2 WEPP good perform for both runoff and sediment yield prediction and SWAT good perform only for runoff prediction for Agewu Maryam watershed.

The result agrees with the finding (Afshar and Hassanzadeh, 2017) reported that (0.667 and 0.809 for SWAT perform satisfactorily and good and 0.832 and 0.816 for WEPP) showed that the models performed well for runoff and sediment respectively. Another study in northern Ethiopia (Mamo et al., 2013) reported that runoff good perform with R^2 (0.84) for the SWAT model.

4.6. Nutrient and organic matter loss within the sediment

The runoff with suspended sediment sample was taken by the bottle at the hydrological weir on the outlet of the watershed. The runoff sample taken from the field was filtered by using a measuring beaker and filter paper. Drying the sediment at room temperature and preparing each sample for NPK and organic matter laboratory analysis. The average sediment loss per one litter of collected sample was 22.227gr and the average of N, P, K, and OM loss per sample was 0.044%, 0.025(gr/l), 0.79 (meq/ 100), and 2.12% respectively as shown (Appendix table 2). The amount of soil nutrient loss from the watershed in the study year was calculated using equations (3 and 4). The nutrient loss in the watershed is 33.74 kg/ha N 6.79kg /ha P1.52 kg/ha K nutrient and 642.5kg/ha/yr OM shown in (Table14) is loss at Agewumariyam watershed.

4.7. Nutrient loss severity

Most 17 essential nutrients are required for plant growth and lifecycle. N and P are the main nutrients that restore soil fertility, and together with Ca, Mg, K, and organic matter are lost by water erosion (Bertol and Miquelluti, 2003). It is impossible to stop all erosion completely but can be minimized; techniques to control erosion usually result in maintaining or increasing soil productivity. A decline in soil fertility (also described as a decline in soil productivity) is a deterioration in the chemical, physical and biological properties of the soil. The nutrient loss severity classification was based on (Stoorvogel and Smaling, 1990) (Appendix table 2) for available nutrient loss due to soil erosion. The result of classification signifies how much sediment yield alone is contributing to very high nutrient loss.

Table 14: Nutrient loss rate within the sediment samples in Agewu Maryam watershed

Nutrients	Average nutrient loss rate (Kg/ha/yr)	Severity Class
N	33.74	High
P	6.79	Moderate
K	1.52	Low
OM	642.5	-

The amount of nutrient loss due to soil erosion result is in line with the finding of (Stoorvogle and Smaling, 1990) estimated nutrient losses through erosion at 30.3 kg N / ha/ yr, 5 kg p /ha/ yr, and 19 kg K /ha/ yr and other scholars (Hileselasie et al., 2015) reported that nutrient loss due to erosion estimated by USLE at national scale is 79 kg/ha/yr N 15 kg/ha/yr P and 50.3 kg/ha/yr K.

5. SUMMARY AND CONCLUSION

5.1. Conclusion

Land resources are finite in extent, unequally distributed geographically unevenly distributed, prone to degradation by land misuse and mismanagement, but essential to all terrestrial life and human wellbeing. Reducing soil erosion and fertility management are among the key factors for the sustainability of agricultural production. In this research, Soil and Water Assessment Tool (SWAT) and geo-reference water erosion prediction project (Geo-WEPP) models have been used to predict annual runoff and sediment yield for the Agewu Maryam watershed in the eastern Amhara, the northern part of Ethiopia. In addition, prioritized sub-watershed interims of sediment yield for management planning and the NPK nutrient and organic matter loss in the suspended sediment has been quantified in the entered watershed.

In this study, three year rainfall, runoff and sediment data were used for observed data analysis. 30 storm events occurring from June2018 to September in 2020 rainfall seasons. The mean average runoff depth, peak discharge and sediment yield for 3 observed yeas was 93.47mm, 1.39 m3/s and 33.36 t/ha for the Agewu Maryam watershed. The model simulated mean monthly runoff and sediment yield result was 54.56mm, 43.1t/ha for WEPP model and 65.1mm 41.7 t/ha for SWAT model for 24 simulation year.

The results of the SWAT simulation study showed good model performance for monthly runoff prediction at the watershed with acceptable R^2 (0.91) and satisfactory NSE (0.71) values. However, the model performance was poor in terms of predicting sediment loss with lower R^2 (0.57) and satisfactorily NSE (0.56) values. Similarly, the results of the Geo-WEPP simulation study showed satisfactory model performance for runoff prediction at the watershed with acceptable R^2 (0.86) and NSE (0.54) values. Additionally t- test statistics was done to comparison result for both model simulated result for runoff and sediment yield using p- value, the result shows that there was no statistically significant different between both models runoff and sediment prediction result.

Overall, the watershed modeling results indicated that the sediment yield in the entered watershed is above the soil loss tolerable limit (18t/ha/yr). Both the SWAT and Geo-WEPP simulated and the observed results showed that soil erosion is still severe and above the soil loss tolerable limit in the Agewu Maryam watershed. Identifying and prioritizing erosion susceptible areas map for intervention are quite essential for this study area. Sub-watershed 9, 5, 1, and 2 were identified and more susceptible to soil erosion, and more attention has to be given to this area and the required treatments should be used on these areas. The quantity of NPK and organic matter delivered to the outlet of the watershed is 33.74 kg/ha N, 6.79kg/ha of P_2O_5, 1.52 K_2O, and 642.5 kg/ha of OM is loss in the watershed. The severity class for nutrient loss NPK in the watershed has high, moderate, and low respectively. The result indicates soil fertility status of the Agewu-Maryam watershed has been highly depleted by soil erosion. As a result, the agricultural production and household incomes were low in the study area. Finally, these problems may cause water pollution and other socio-economic problems. This has been a major concern for sustaining agricultural production.

5.2. Recommendation

Based on the above conclusion the following recommendation are drawn

Generally, land management strategies and SWC structures should be improved to achieve more sustainable soil erosion protection for sustainable agricultural production in the Agewu-Maryam watershed.

To sustain agricultural production and minimize the risk of soil erosion and sediment yield in the watershed should be an implementation biological SWC measures (in-situ moisture conservation, intercropping with nitrogen-fixing legumes, mulching, hillside terraces, and bund with multi-purpose grass) and Slope greater than 30% no need of conducting any agricultural activities, rather the area should be protected and conducting rehabilitation such as afforestation and area closure.

- Soil fertility should be improved by adding organic and inorganic source of fertilizers.
- Silt trap mechanism could be considered during the construction of any water harvesting structure, pond, and dam in Wag-himra areas.
- To increase the accuracy of the model could be calibrated and validated with more observed hydrological data and an automatic weather station and flow meter could be installed for continuous monitoring climatic and hydrologic data of the watershed.
- The SWAT and Geo-WEPP model can be used as decision-making tools in Agewu-Mariyam watershed and other watersheds with similar agro-ecologies in the eastern Amhara to predict runoff and sediment yield.

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APPENDIXES

Appendix Table 1: Soil sampling point for soil physicochemical analysis

	Sampling location		**Soil texture (%)**				**soil structure**		**Organic matter and nutrients**			**Rock and stoniness (%)**
No	Easting	Northing	sand	clay	silt	textural class	shape	size	%OM	%TN	Avi. P	Fcrg
1	491396	1386198	70	12	18	Sandy Loam	granular	fine	0.84	0.09	9.85	0.0075
2	491406	1386102	74	10	16	Sandy Loam	granular	moderate	0.81	0.03	3.37	0.01
3	491505	1386203	66	14	20	Sandy Loam	granular	moderate	0.71	0.03	9.79	0.015
4	491498	1386093	70	12	18	Sandy Loam	granular	moderate	1.51	0.02	4.40	0.01
5	491508	1386003	66	12	22	Sandy Loam	granular	moderate	0.84	0.04	10.75	0.0075
6	491612	1386203	64	13	23	Sandy Loam	granular	moderate	0.61	0.03	9.42	0.01
7	491597	1386093	76	10	14	Sandy Loam	granular	moderate	2.15	0.02	7.06	0.005
8	491607	1385998	66	12	22	Sandy Loam	granular	fine	1.14	0.15	12.45	0.005
9	491594	1385905	68	10	22	Sandy Loam	granular	moderate	0.77	0.03	11.36	0.0025
10	491714	1386278	72	10	18	Sandy Loam	granular	moderate	0.77	13.96	4.34	0.0025
11	491699	1386194	56	20	24	Sandy Clay Loam	granular	moderate	0.71	0.03	4.21	0.01
12	491693	1386107	76	6	18	Sandy Loam	granular	moderate	2.22	0.03	12.45	0.006
13	491699	1385939	59	12	29	Sandy Loam	granular	fine	1.14	0.00	7.77	0.0125
14	491699	1385911	55	26	19	Sandy Clay Loam	granular	fine	0.77	0.03	15.88	0.011
15	491710	1385787	59	21	20	Sandy Clay Loam	granular	fine	1.11	0.02	5.32	0.0015
16	491800	1386300	74	10	16	Sandy Loam	granular	moderate	1.51	0.15	4.98	0.0325
17	491803	1386195	66	10	24	Sandy Loam	granular	fine	2.72	0.87	9.79	0.02

18	491804	1386113	58	18	24	Sandy Loam	granular	fine	0.10	0.03	4.40	0.005
19	491803	1386009	52	18	30	Loam	granular	moderate	0.30	0.02	18.50	0.0125
20	491797	1385893	55	28	17	Sandy Clay Loam	granular	fine	2.25	0.06	6.12	0.0015
21	491809	1385798	54	30	16	Sandy Clay Loam	granular	fine	1.28	0.02	4.63	0.0125
22	491788	1385714	51	31	18	Sandy Clay Loam	granular	fine	1.41	0.02	7.32	0.015
23	491793	1385587	82	6	12	Loamy Sand	granular	moderate	1.14	0.18	5.01	0.0065
24	491796	1385510	87	4	9	Loamy Sand	granular	moderate	0.37	0.16	3.97	0.004
25	491802	1385405	75	10	15	Sandy Loam	granular	moderate	4.10	0.05	13.14	0.0325
26	491811	1385303	79	7	14	Loamy Sand	granular	moderate	0.30	0.05	3.60	0.0065
27	491892	1386299	79	8	13	Loamy Sand	granular	moderate	1.11	0.04	5.61	0.0325
28	491896	1386202	68	10	22	Sandy Loam	granular	fine	2.99	6.15	7.95	0.0025
29	491908	1386104	59	16	25	Sandy Loam	granular	fine	1.58	0.04	4.76	0.004
30	491906	1386011	56	22	22	Sandy Clay Loam	blocky	coarse	0.47	0.02	7.95	0.004
31	491883	1385898	57	14	29	Sandy Loam	granular	fine	0.91	0.04	9.37	0.015
32	491889	1385806	64	14	22	Sandy Loam	granular	fine	0.61	0.05	6.52	0.01
33	491894	1385709	62	18	20	Sandy Loam	granular	fine	1.24	0.03	5.32	0.01
34	491896	1385591	83	6	11	Loamy Sand	granular	moderate	0.97	0.04	2.25	0.0075
35	491900	1385493	90	4	6	Sand	granular	moderate	0.37	0.00	5.26	0.01
36	491892	1385393	79	6	15	Loamy Sand	blocky	coarse	0.34	0.04	3.64	0.004
37	491905	1385294	74	8	18	Sandy Loam	granular	moderate	0.40	0.14	4.87	0.006
38	491891	1385200	81	6	13	Loamy Sand	granular	moderate	0.84	0.10	3.86	0.01
39	491910	1385093	83	4	13	Loamy Sand	granular	fine	0.03	0.05	4.68	0.005
40	492003	1386191	66	10	24	Sandy Loam	granular	moderate	0.61	0.01	5.61	0.0025
41	492030	1386070	63	15	22	Sandy Loam	granular	fine	1.88	0.05	6.64	0.035
42	492013	1385998	68	10	22	Sandy Loam	granular	fine	3.60	0.05	6.46	0.0275
43	492001	1385907	72	10	18	Sandy Loam	granular	moderate	0.77	0.04	3.49	0.01
44	492005	1385806	65	14	21	Sandy Loam	granular	fine	4.30	0.08	23.76	0.03
45	492018	1385723	72	10	18	Sandy Loam	granular	moderate	2.15	0.06	2.42	0.04

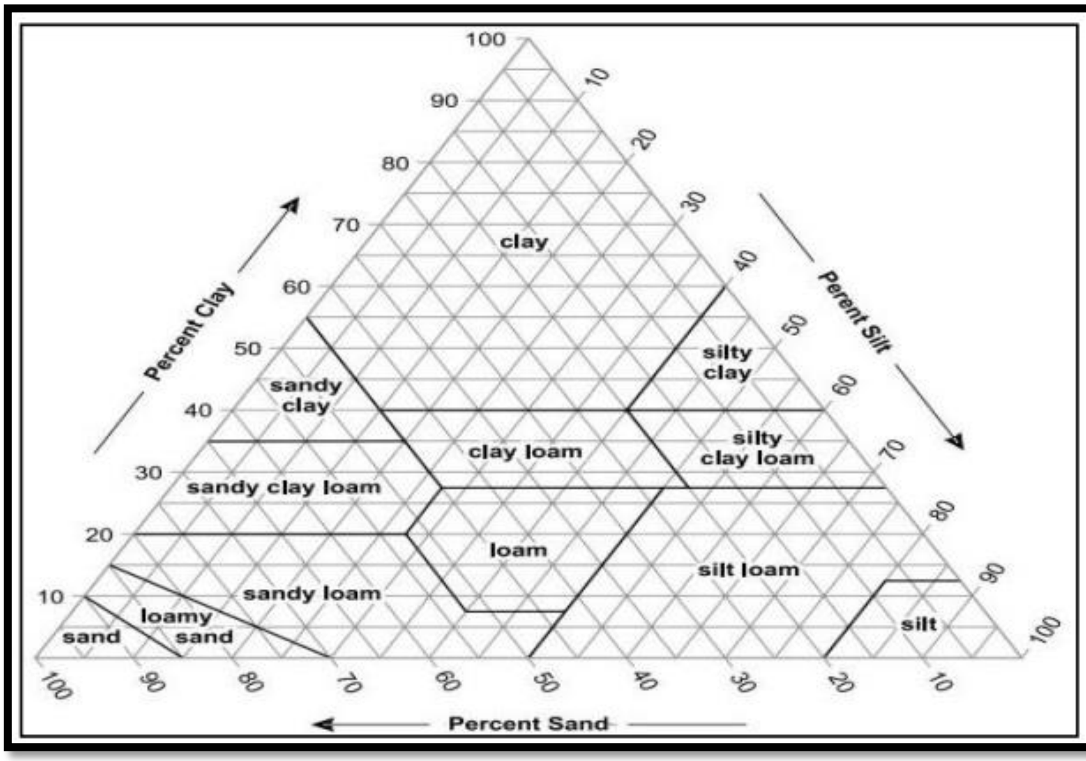
46	491998	1385609	80	4	16	Loamy Sand	blocky	coarse	1.38	0.01	4.24	0.009
47	492001	1385486	73	8	19	Sandy Loam	granular	moderate	0.47	0.03	3.51	0.005
48	492007	1385397	67	14	19	Sandy Loam	granular	fine	1.61	0.05	2.54	0.0075
49	492007	1385290	76	8	16	Sandy Loam	granular	moderate	1.75	0.11	6.57	0.009
50	491987	1385196	78	6	16	Loamy Sand	granular	moderate	1.82	0.03	3.77	0.006
51	491997	1385112	79	6	15	Loamy Sand	granular	fine	0.54	0.05	5.01	0.005
52	492099	1386189	49	28	23	Sandy Clay Loam	granular	moderate	0.87	0.00	8.97	0.002
53	492106	1386109	63	18	19	Sandy Loam	granular	fine	1.71	0.02	4.40	0.02
54	492103	1386007	62	16	22	Sandy Loam	granular	fine	3.13	0.08	10.09	0.03
55	492083	1385906	69	11	20	Sandy Loam	granular	fine	2.32	0.05	2.54	0.015
56	492111	1385803	61	18	21	Sandy Loam	granular	fine	1.82	0.06	2.84	0.02
57	492094	1385695	67	15	18	Sandy Loam	granular	fine	1.51	0.03	8.24	0.0175
58	492091	1385601	70	12	18	Sandy Loam	granular	moderate	0.61	0.04	4.06	0.004
59	492101	1385515	65	17	18	Sandy Loam	granular	fine	1.58	0.04	6.40	0.015
60	492107	1385414	60	21	19	Sandy Clay Loam	granular	fine	1.21	0.05	6.91	0.0175
61	492105	1385292	69	10	21	Sandy Loam	granular	fine	0.84	0.04	5.83	0.0075
62	492107	1385188	72	10	18	Sandy Loam	granular	fine	0.94	0.07	4.10	0.004
63	492102	1385116	79	9	12	Sandy Loam	granular	moderate	0.97	0.11	4.75	0.001
64	492089	1384999	63	17	20	Sandy Loam	granular	fine	1.28	0.02	7.42	0.015
65	492091	1384895	85	6	9	Loamy Sand	granular	moderate	1.28	0.06	3.02	0.005
66	492102	1384809	79	6	15	Loamy Sand	granular	moderate	2.96	0.13	12.67	0.004
67	492206	1386096	63	10	27	Sandy Loam	granular	fine	0.17	0.02	3.25	0.0015
68	492202	1385990	60	18	22	Sandy Loam	granular	fine	2.29	0.13	3.55	0.02
69	492208	1385892	60	18	22	Sandy Loam	granular	fine	4.57	0.08	5.81	0.03
70	492193	1385799	57	22	21	Sandy Clay Loam	granular	fine	4.67	0.04	5.00	0.01
71	492189	1385699	55	20	25	Sandy Clay Loam	granular	fine	3.26	0.06	3.37	0.015
72	492198	1385609	65	8	27	Sandy Loam	granular	fine	3.53	0.06	2.84	0.015

73	492200	1385500	67	12	21	Sandy Loam	granular	fine	0.77	0.05	3.71	0.01
74	492197	1385394	70	10	20	Sandy Loam	granular	fine	2.89	2.27	15.66	0.015
75	492199	1385301	71	10	19	Sandy Loam	granular	moderate	3.93	0.11	3.14	0.015
76	492195	1385201	64	11	25	Sandy Loam	granular	fine	4.00	0.06	11.05	0.0325
77	492200	1385102	63	8	29	Sandy Loam	granular	fine	2.15	0.06	3.55	0.0075
78	492208	1385027	74	11	15	Sandy Loam	granular	moderate	3.23	3.55	6.72	0.045
79	492223	1384957	57	21	22	Sandy Clay Loam	granular	fine	0.87	0.04	5.07	0.0025
80	492200	1384808	72	10	18	Sandy Loam	granular	fine	4.10	0.06	6.08	0.01
81	492303	1386093	62	10	28	Sandy Loam	granular	fine	1.18	18.45	63.65	0.005
82	492311	1386006	65	13	22	Sandy Loam	granular	fine	0.30	0.21	5.91	0.0125
83	492303	1385895	66	10	24	Sandy Loam	granular	moderate	4.27	0.10	4.74	0.0275
84	492308	1385805	74	11	15	Sandy Loam	granular	moderate	1.88	0.04	9.55	0.0375
85	492294	1385693	56	19	25	Sandy Loam	granular	fine	3.87	0.08	2.78	0.0175
86	492295	1385599	66	16	18	Sandy Loam	granular	fine	3.46	0.04	15.26	0.015
87	492308	1385508	70	8	22	Sandy Loam	granular	moderate	3.43	0.17	5.95	0.015
88	492306	1385406	72	10	18	Sandy Loam	granular	moderate	1.92	0.07	3.91	0.0175
89	492297	1385309	83	8	9	Loamy Sand	granular	moderate	1.82	0.02	5.01	0.01
90	492302	1385204	60	19	21	Sandy Loam	granular	fine	1.34	0.09	5.32	0.015
91	492301	1385096	63	16	21	Sandy Loam	granular	fine	1.01	0.06	3.97	0.025
92	492281	1385045	59	14	27	Sandy Loam	granular	fine	3.70	3.64	8.78	0.02
93	492305	1384944	60	22	18	Sandy Clay Loam	granular	fine	1.61	0.05	6.40	0.005
94	492399	1385995	62	18	20	Sandy Loam	granular	fine	0.67	0.03	15.30	0.0075
95	492400	1385900	68	13	19	Sandy Loam	granular	fine	2.79	0.03	7.09	0.015
96	492394	1385794	66	15	19	Sandy Loam	granular	fine	2.62	0.11	7.35	0.02
97	492406	1385704	69	12	19	Sandy Loam	granular	fine	2.02	0.03	6.02	0.0175
98	492394	1385603	69	13	18	Sandy Loam	granular	fine	1.58	0.03	4.09	0.0125
99	492400	1385498	86	8	6	Loamy Sand	granular	moderate	1.88	0.06	3.12	0.0075
100	492408	1385410	77	7	16	Sandy Loam	granular	moderate	1.78	0.05	2.60	0.02

101	492389	1385310	67	11	22	Sandy Loam	granular	fine	1.68	2.56	5.83	0.005
102	492384	1385193	76	6	18	Sandy Loam	granular	moderate	0.77	0.04	5.32	0.0075
103	492476	1385141	61	16	23	Sandy Loam	granular	fine	2.32	0.03	10.79	0.015
104	492406	1384990	70	9	21	Sandy Loam	granular	moderate	4.37	7.68	7.80	0.01
105	492489	1386002	64	16	20	Sandy Loam	granular	fine	1.65	0.04	3.73	0.02
106	492499	1385895	65	14	21	Sandy Loam	blocky	coarse	0.17	0.04	3.79	0.0225
107	492498	1385794	64	10	26	Sandy Loam	granular	fine	1.45	0.09	13.08	0.03
108	492503	1385696	64	14	22	Sandy Loam	granular	fine	0.91	5.85	30.78	0.01
109	492493	1385591	83	8	9	Loamy Sand	granular	moderate	1.41	0.04	4.62	0.01
110	492494	1385507	82	6	12	Loamy Sand	granular	moderate	1.88	0.03	2.01	0.005
111	492503	1385396	62	16	22	Sandy Loam	granular	fine	0.37	0.06	6.69	0.0275
112	492500	1385284	60	12	28	Sandy Loam	granular	moderate	0.44	0.02	6.12	0.004
113	492509	1385194	82	6	12	Loamy Sand	granular	moderate	1.95	0.05	6.92	0.009
114	492566	1385187	92	4	4	Sand	granular	moderate	0.13	0.03	2.86	0.001
115	492499	1385003	70	8	22	Sandy Loam	granular	moderate	1.68	0.10	6.11	0.02
116	492593	1385908	74	6	20	Sandy Loam	granular	moderate	0.20	0.02	1.79	0.0225
117	492612	1385804	75	10	15	Sandy Loam	granular	fine	0.24	0.04	2.22	0.02
118	492600	1385696	85	4	11	Loamy Sand	granular	moderate	0.17	0.03	1.61	0.015
119	492599	1385600	72	6	22	Sandy Loam	granular	fine	0.61	0.04	5.26	0.0075
120	492613	1385498	76	9	15	Sandy Loam	granular	moderate	1.34	0.03	4.46	0.004
121	492606	1385407	82	8	10	Loamy Sand	granular	moderate	1.95	0.02	4.98	0.0025
122	492596	1385310	84	8	8	Loamy Sand	granular	moderate	1.34	0.03	4.69	0.0075
123	492605	1385208	68	10	22	Sandy Loam	granular	fine	0.94	0.09	6.69	0.0125
124	492605	1385091	72	9	19	Sandy Loam	granular	moderate	5.11	0.03	6.46	0.03
125	492657	1385036	63	13	24	Sandy Loam	granular	fine	2.25	0.04	5.40	0.0005
126	492696	1385692	68	10	22	Sandy Loam	granular	fine	0.44	0.02	6.97	0.0125
127	492704	1385597	70	10	20	Sandy Loam	blocky	coarse	0.61	0.05	6.75	0.015
128	492697	1385487	67	13	20	Sandy Loam	granular	fine	1.04	0.07	5.89	0.005

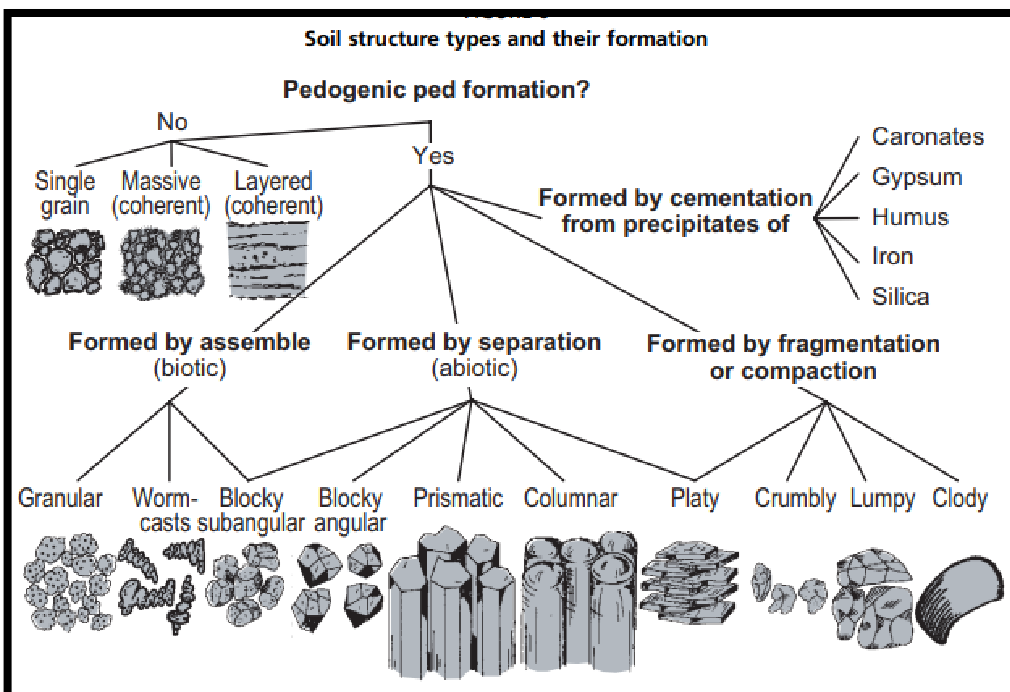
129	492711	1385409	83	6	11	Loamy Sand	granular	moderate	0.87	0.04	6.70	0.0025
130	492692	1385296	69	11	20	Sandy Loam	granular	moderate	0.40	0.03	3.45	0.01
131	492700	1385205	77	7	16	Sandy Loam	granular	moderate	3.97	0.08	4.56	0.015
132	492694	1385100	65	11	24	Sandy Loam	granular	fine	2.19	0.04	5.95	0.005
133	492800	1385700	78	8	14	Sandy Loam	granular	moderate	0.61	0.03	5.95	0.0125
134	492811	1385603	74	10	16	Sandy Loam	granular	moderate	0.97	0.02	3.25	0.015
135	492817	1385499	77	8	15	Sandy Loam	granular	fine	0.71	0.02	5.51	0.004
136	492802	1385410	80	6	14	Loamy Sand	granular	moderate	0.64	0.07	4.68	0.005
137	492811	1385301	80	8	12	Loamy Sand	granular	fine	1.01	0.02	4.94	0.0065
138	492850	1385250	86	6	8	Loamy Sand	granular	fine	1.51	7.45	11.74	0.005
139	492803	1385125	69	6	25	Sandy Loam	granular	fine	5.48	0.06	4.80	0.005
140	492929	1385700	82	8	10	Loamy Sand	granular	moderate	1.92	0.04	5.36	0
141	492905	1385601	84	6	10	Loamy Sand	granular	moderate	0.84	0.02	6.52	0
142	492912	1385513	90	4	6	Sand	blocky	coarse	0.47	0.05	4.81	0.005
143	492905	1385394	86	4	10	Loamy Sand	granular	moderate	0.27	0.04	3.25	0.0075
144	492904	1385304	90	4	6	Sand	granular	moderate	0.61	0.02	3.86	0.015
145	492931	1385256	90	4	6	Sand	granular	moderate	1.31	0.03	2.41	0.0025
146	493009	1385697	66	16	18	Sandy Loam	granular	moderate	0.57	0.04	7.26	0
147	493006	1385613	87	8	5	Loamy Sand	granular	moderate	0.34	0.08	9.04	0.0025
148	493004	1385513	92	5	3	Sand	granular	fine	1.75	0.01	3.72	0.0025
149	492996	1385408	83	6	11	Loamy Sand	granular	fine	0.34	0.05	5.72	0.0015
150	493007	1385302	88	5	7	Sand	blocky	coarse	0.57	0.06	4.11	0.015
151	493097	1385590	81	5	14	Loamy Sand	granular	moderate	0.87	0.50	4.30	0.005
152	493104	1385491	89	4	7	Sand	granular	moderate	0.47	0.05	2.19	0.0025
153	493076	1385410	84	4	12	Loamy Sand	granular	moderate	0.97	0.05	2.99	0.0025
154	491412	1386139	86	4	10	Loamy Sand	granular	fine	0.37	0.03	2.52	0.025
155	491293	1386201	74	10	16	Sandy Loam	granular	moderate	0.81	0.03	3.37	0.01
156	491776	1386376	74	10	16	Sandy Loam	granular	moderate	1.51	0.15	4.98	0.0325

157	492147	1384702	72	10	18	Sandy Loam	granular	fine	4.10	0.06	6.08	0.01
158	493160	1385408	84	4	12	Loamy Sand	granular	moderate	0.97	0.05	2.99	0.0025
159	492069	1384974	60	19	21	Sandy Loam	granular	moderate	1.38	0.02	4.21	0.0025



Appendix Figure 1: USDA textural triangle used to identify basic textural classes

Source: USDA Handbook 18, *(2020)*



Appendix Figure 2: Soil structure determination on fieldwork guideline

Source: FAO guideline soil description fourth edition, (2006)

Classification of types of soil structure

Blocky	Blocks or polyhedrons, nearly equidimensional, having flat or slightly rounded surfaces that are casts of the faces of the surrounding aggregates. Subdivision is recommended into angular, with faces intersecting at relatively sharp angles, and subangular blocky faces intersecting at rounded angles.
Granular	Spheroids or polyhedrons, having curved or irregular surfaces that are not casts of the faces of surrounding aggregates.
Platy	Flat with vertical dimensions limited; generally oriented on a horizontal plane and usually overlapping.
Prismatic	the dimensions are limited in the horizontal and extended along the vertical plane; vertical faces well defined; having flat or slightly rounded surfaces that are casts of the faces of the surrounding aggregates. Faces normally intersect at relatively sharp angles. Prismatic structures with rounded caps are distinguished as Columnar.
Rock structure	Rock structure includes fine stratification in unconsolidated sediment, and pseudomorphs of weathered minerals retaining their positions relative to each other and to unweathered minerals in saprolite from consolidated rocks.
Wedge-shaped	Elliptical, interlocking lenses that terminate in sharp angles, bounded by slickensides; not limited to vertic materials.
Crumbs, lumps and clods	Mainly created by artificial disturbance, e.g. tillage.

Appendix Table 2: nutrient loss rating class

Classes of nutrient loss rates in sub-Saharan Africa (kg/ha/yr)			
Class	**N**	**P_2O_5**	**K_2O**
Low	<10	<4	<10
Moderate	10 - 20	4 - 7	10 – 20
Strong	21 - 40	8 - 15	21 – 40
Very strong	> 40	> 15	> 40

Source: Stoorvogel and Smaling, 1990

Appendix Table 3: sediment sample analysis result from suspended sediment

S/DATE	Sediment (gr/l)	%OM	%TN	Avi. P (ppm)	K(meq /100)
10-9-2012	14.52	3.3618	0.0336	49.514321	1.52
12-9-2012	50.27	2.85753	0.0294	22.739726	0.52
13-09-12	25.57	2.6222	0.0588	38.430884	0.81

6-11-2012	46.85	3.3618	0.0308	22.366127	1.09
14-11-12	8.89	2.6222	0.0392	21.494396	0.90
17-11-12	17.99	1.17663	0.0322	26.600249	0.66
19-11-12	13.81	2.95838	0.0336	25.977584	0.66
24st-11-12	35.9	1.51281	0.0294	22.864259	0.52
24nd-11-12	24.96	2.0507	0.6958	20.124533	0.47
26-11-12	19.91	1.17663	0.0588	25.479452	1.82
27-11-12	7.52	2.28602	0.0434	22.49066	0.27
8st-12-12	35.68	1.47919	0.049	26.351183	1.03
8nd-12-12	12.72	1.58005	0.0714	33.574097	0.37
22-12-12	13.97	0.67236	0.0448	23.73599	0.47

Appendix Figure 3: Flow depth and velocity measurement at hydrological weir using stage reading and current meter

Appendix Figure 4: Filtering and drying sediment sample in the laboratory

Appendix Table 4: Criteria for R^2 and Nash-Sutcliffe coefficient of efficiency (Moriasi et al., 2015)

Table 8. Initial performance evaluation criteria for recommended statistical performance measures for watershed- and field-scale models based on the distribution of existing data.

Measure	Component	Temporal Scale	*n*	Very Good	Good	Satisfactory	Not Satisfactory
Watershed scale							
R^2	Flow	Annual	84	>0.75	$0.70 \le R^2 \le 0.75$	$0.60 < R^2 < 0.70$	≤0.60
		Monthly	87	>0.85	$0.80 \le R^2 \le 0.85$	$0.70 < R^2 < 0.80$	≤0.70
		Daily	27	>0.85	$0.70 \le R^2 \le 0.85$	$0.50 < R^2 < 0.70$	≤0.50
	Sediment	Annual	3	-	-	-	-
		Monthly	46	>0.80	$0.65 \le R^2 \le 0.80$	$0.40 < R^2 < 0.65$	≤0.40
		Daily	0	-	-	-	-
	N	Annual	2	-	-	-	-
		Monthly	31	>0.70	$0.60 \le R^2 \le 0.70$	$0.30 < R^2 < 0.60$	≤0.30
		Daily	0	-	-	-	-
	P	Annual	0	-	-	-	-
		Monthly	31	>0.80	$0.65 \le R^2 \le 0.80$	$0.40 < R^2 < 0.65$	≤0.40
		Daily	0	-	-	-	-
	General		311	>0.80	$0.70 \le R^2 \le 0.80$	$0.50 < R^2 < 0.70$	≤0.50
NSE	Flow	Annual	71	>0.75	0.60 ≤ NSE ≤ 0.75	0.50 < NSE < 0.60	≤0.50
		Monthly	109	>0.85	0.70 ≤ NSE ≤ 0.85	0.55 < NSE < 0.70	≤0.55
		Daily	79	>0.80	0.70 ≤ NSE ≤ 0.80	0.50 < NSE < 0.70	≤0.50
	Sediment	Annual	4	-	-	-	-
		Monthly	31	>0.80	0.70 ≤ NSE ≤ 0.80	0.45 < NSE < 0.70	≤0.45
		Daily	3	-	-	-	-
	N	Annual	0	-	-	-	-
		Monthly	31	>0.70	0.60 ≤ NSE ≤ 0.70	0.35 < NSE < 0.60	≤0.35
		Daily	6	>0.55	0.40 ≤ NSE ≤ 0.55	0.25 < NSE < 0.40	≤0.25
	P	Annual	10	>0.65	0.60 ≤ NSE ≤ 0.65	0.50 < NSE < 0.60	≤0.50
		Monthly	33	>0.65	0.50 ≤ NSE ≤ 0.65	0.40 < NSE < 0.50	≤0.40
		Daily	1	-	-	-	-

Appendix Table 5: Permeability classes corresponding to the hydraulic conductivity

Textural class name	Profile Permeability Class Code	Permeability Class	Saturated hydraulic conductivity (in/hr.)
Clay, silty clay	6	Very slow	< 0.04
Silty clay loam, sand clay	5	Slow	0.04-0.08
Sand clay loam, clay loam	4	Slow to mod	0.08-0.2
Loam, silt loam	3	Moderate	0.2-0.8
Loamy sand, sandy loam	2	Mod to rapid	0.8-2.4
Sand	1	rapid	>2.4

Source: (Renard *et al.*, 1997)

Appendix Figure 5: Misuse of land (Slope cultivation) in Agewu Maryam watershed

(a) Bilbala, Lalibela areas

(b) sekota

Appendix Figure 6: Sediment filling of water harvesting small dam structure in wag-lasta areas

BIOGRAPHICAL SKETCH

The author was born on 14 December 1993 G.C in North Mecha woreda, west Gojjam zone, Amhara regional state. He attended his primary education in Dagi Elementary School in Dagi kebele and secondary and preparatory education were completed Gomata Secondary School and Merawi preparatory school in Merawi town from 2008 to 2011. For three years, from 2012 to 2014, he studied BSC in soil and water resource management at Wollo University and graduated with a BSC degree in 2015. After graduating, he was employed in the central statistical agency Bahirdar sub- center as a data collector in Jabitsehnan woreda for 10 months and then shifted to Amhara Agricultural Research Institute as an Assistance Researcher of soil and water conservation at Sekota Dry-land Agricultural Research Center. During his service years, the Author had gained lots of practical experiences and knowledge through technical training on Soil and water conservation and others. After three years of service in various capacities, he joined the school of graduate studies at Hawassa University, institute of technology in 2019 to pursue his MSC studies in Soil and Water conservation Engineering.