HYDRO-SEDIMENT RESPONSES TO MANAGEMENT OPTIONS UNDER CURRENT AND FUTURE CLIMATE CHANGE SCENARIOS IN MAYBAR SUB-WATERSHED, SOUTH WOLLO ZONE, ETHIOPIA

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MULUKEN LEBAY EGIGU

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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MAJOR ADVISOR: AWDENEGEST MOGES (PhD)

CO-ADVISOR: HAILU KINDIE (PhD)

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STATEMENT OF THE AUTHOR

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Name: Muluken Lebay Egigu Signature: ______________

Place: Hawassa University, Hawassa

Date of Submission: June, 2022

E-mail address: mulerbruk2016@gmail.com

BIOGRAPHICAL SKETCH

The author, Muluken Lebay was born in Oct 1991 from his father Kess Lebay Egigu and his Mother Mrs. Belaynesh Kebede in South Wello Zone, Delanta District in the village Abahaile warka. He attended his elementary education (grade 1-5) at Chegoma Elementary school, grade 6 at Tikurena Elementary School and grade 7-8 at Chewukutir Elementary School from 1998–2005. After completing his elementary education, he continued his Senior Secondary School (9^{th}-12^{th}) at Wogeltena Senior Secondary and preparatory School from 2005–2009. Then, he joined Samara University in 2009 and graduated with a BSc degree in Natural Resorce Management on June 2012. After completion of his studies, he was employed in North Wello Zone Dawunt wereda agricultural office as a natural resource management development agent for a few months and similarly in the South Wello zone Delanta wereda totally less than one year.

Then he joined Wogeltena Technical Vocational and Educational Training college (WTVET) as a Natural Resource Management instructor from November 2013 to June 2015. The author then has been employed by Amhara Agricultural Research Institute (AARI) at Sirinka Agricultural Research Center in June 2015 and served as junior and assistant soil and water conservation researcher in Soil and Water Management Division. He had also served as soil and water conservation research case team coordinator for two years. During this period, he prepared research proposals and carried out experimentation. Though least to mention, he presented some papers to different conferences and workshops in association with his colleagues, involved in different short term training opportunities and published around five research articles. After serving for more than 4 years in research, he joined the School of Graduate Studies, Hawassa University in 2019 to pursue his Master of Science in Soil and Water Conservation Engineering.

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ABBREVIATIONS AND ACRONYMS

ACRU	Agricultural Catchment Research Unit
AGNPS	Agricultural Non-point Source Model
ARARI	Amhara Regional Agricultural Research Institute
BMPs	Best Management Practices
C	Crop management factor
CORDEX	Coordinated Regional Downscaling Experiment
CREAMS	Chemicals, Flow and Erosion in Agricultural Management Systems
CRSP	Collaborative Research Support Program
DA	Development Agent
DEM	Digital Elevation Model
EPIC	Erosion/Productivity Impact Calculator
EUROSEM	European Soil Erosion Model
FAO	Food and Agricultural Organization
GCMs	General Circulation Models
GIS	Geographical Information System
HRU	Hydrologic Response Unit
HSPF	Hydrologic Simulation Program, Fortran
IPCC	Intergovernmental Panel on Climate Change
KML	Keyhole Markup Language
KYERMO	Kentucky Erosion Model
LULC	Land Use Land Cover

MUSLE	Modified Universal Soil Loss Equation
NSE	Nash-Sutcliffe Efficiency
P	support practice factor
PBIAS	Percent Bias
R2	Coefficient of Determination
RCM	Regional Climate Models
RCPs	Representative Concentration Pathways
RUSLE	Revise Universal Soil Loss Equation
S	Slope gradient factor
SARC	Sirinka Agricultural Research Center
SCRP	Soil Conservation Research Program
SDSM	Statistical Downscaling Method
SWAT	Soil and Water Assessment Tool
SWRRB	Simulator for Water Resources in Rural Basins
USA	United States of America
USGS	United States of Geological Survey
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project
WGEN	Weather Generator
WLRC	Water and Land Resources Center

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ABSTRACT

Climate change coupled with inappropriate land use management is a serious environmental challenge in the highland part of Ethiopia. The aim of this study was to investigate hydro-sediment responses to management options under current and future climate change scenarios in Maybar watershed, Northern Ethiopia. We employed soil and water assessment tool (SWAT) for hydrologic modeling and CORDEX-climate data under RCP 4.5 and RCP 8.5 emission scenarios was used for climate projections. Soil map was prepared by digitizing soil characterization map of the watershed generated by Weigel in 1986. DEM data with 2m spatial resolution was obtained from water and land resource center and land use classification was done through digitization of google earth images. Better agreement between calibrated SWAT simulation and observed variables was achieved. Delta change bias correction method was empolyed to improve the climate simulation in reproducing the observed climate variables. We found a considerable increase in annual precipitation by 18.71% and 22.33% for RCP 4.5 and RCP 8.5, respectively compared with the current climate conditions. Climate change induced hydro-sediment results were observed to be consistent with predicted precipitation. Under the current climatatic conditions, average sediment yield at the subbasin scale varies from negligible (under terrace complementation) to approximately more than 50 t $ha^{-1}yr^{-1}$ *with a basin average of 32 t* $ha^{-1}yr^{-1}$ *(under no-terrace conditions). The implementation of management alternatives gets the dry seasons hydrological behavior of the catchment improved and climate change induced sediment yield reduction. Generally, the information could possibly support decision makers and planners to implement best-fitted management options and thereby reduce current and expected aggressive sediment loss situations.*

Key words: Climate Change, Maybar watershed, Sediment yield, SWAT model

1. INTRODUCTION

1.1. Background

Climate change disproportionately affects sub-Saharan African countries such as Ethiopia because their economies are largely dependent on climate-sensitive activities such as rain-fed agriculture. In Ethiopia, agriculture contributes about 47% of the country's Gross Domestic Product (GDP) and more than 85% of the Ethiopian population depend on agriculture directly or indirectly for their livelihoods (Gebreegziabher *et al*., 2014). Soil and water are vital resources that agriculture is depend on and impacted by climate change. Climate change regarded as increasing temperature is able to affect precipitation regime and thus surface hydrology (Lu, 2013).

Soil degradation, as a result of water erosion is a serious threat to most parts of the world and more serious in the sub-Saharan African countries where the population livelihood is dependent on the soil (Erkossa *et al*., 2015; Nigussie *et al*., 2017). Soil erosion by water as a result of rapid population growth, clearing of vegetation, cultivation of steep slopes, and overgrazing is dramatically increased in Ethiopian highlands (Adimassu *et al*., 2014; Belay *et al*., 2014; Erkossa *et al*., 2015; Addis *et al*., 2016). About 35-40% of Ethiopia's total land was once covered by various types of forest, but this proportion had decreased to 16% in the 1950s and continued to decrease, reaching 11.2% in the 2010s (Hatsey, 2015). Observation in most parts of Ethiopia is shocking by the extent and severity of noticeable soil erosion from different agricultural areas (Tamene *et al., 2006*).

In Ethiopia, the soil formation rate is much lower than the annual rate of soil loss (Hurni, 1988). According to Tadesse (2001), erosion causes more than 1.5 billion tons of annual soil loss in the highlands of Ethiopia, which is estimated to be equivalent to 1.5 million tons of grain harvest in the country. In developing countries, the economic implication of soil erosion is more severe because of a lack of capacity to grip with it and also to substitute lost nutrients (Bekele, 2003). Therefore, the design and implementation of productive and sustainable agricultural systems are critical by understanding the basic processes and factors that are responsible for soil erosion and associated phenomena.

Climate change phenomenon and changes in land management are among the most important agents that greatly impact the hydrological cycle and cause soil erosion (Mahmood *et al.,* 2010; Tadesse *et al*., 2017; Bekele *et al*., 2019). The hydrological response of watersheds to climate change and different land management strategies is an important concern of soil and water resource management (Mango *et al.,* 2011). LULC changes due to settlement expansion and deforestation can be brought interruptions on the hydrological processes. It alters the flood frequency and annual mean discharge through affecting the evapotranspiration, soil infiltration capacity, and surface and subsurface flow regimes (Sun *et al*., 2009; Li *et al*., 2009). Climate change can also alter the flow routing time and peak flows (Li *et al*., 2009). Conservationists to achieve sustainable development of soil and water resources should understand these factors potential impact on the hydrological cycle and soil erosion as a consequence (Sun *et al*., 2009).

Global warming as a result of increased greenhouse gases is expected to lead to a more vigorous hydrological cycle, including more total rainfall and more frequent high-intensity rainfall events (Nearing *et al*., 2004). Rainfall intensity mainly drives extreme soil erosion event process and affects soil loss approximately by a power function (IPCC, 2001). In turn, these extreme erosion events increase the potential crisis of onsite and off-site damage (Nearing *et al*., 2005). Climate change greatly influences the response of soil erosion rates due to the most direct of which is the changes in the erosive power of rainfall

(Nearing, 2001; Pruski and Nearing, 2002a). The rise in temperature and precipitation patterns are noticeable features of change in climate that directly impact the hydrological responses (Azari *et al.*,2016). The timing and magnitude of streamflow, rainfall patterns and other hydrological processes might be altered through temperature fluctuations. Soil erosion will also be expected to remarkably influenced by Climate changes since rainfall and runoff are the factors governing it (Nilawar and Waikar, 2019). The global climate models (GCMs) driven information is currently the most applicable in evaluating both past and possible future changes in climate scenarios. Direct implementation GCMs to any hydrological models which is designed for impact evaluation is highly uncertain because of coarse resolution issues. So, long-term locally-observed climate data are required to validate climate model outputs to capture local settings (Chen *et al*., 2020). Downscaling the GCM to regional & local hydrologic scales to produce outputs of the more acceptable and realistic resolution for future hydrologic scenarios should also be employed (Dlamini *et al*., 2017; Worku *et al*., 2020).

Although the interaction is complex, more indirectly, climate change would also affect biomass by which biomass significantly changes the response to runoff and erosion (Pruski and Nearing, 2002b). Consequently, Climate and LULC changes are the most important factors highly governing the process of hydrologic cycles and the rate of soil erosion (Nearing *et al*., 2004). Appropriate land-use and land-management practices for improving soil to hold and infiltrate water and maintain good ground cover against the fall energy impact of rainfall are useful means to reduce soil loss and sediment delivery (Erskine and Saynor, 1995). Quantification of changing aspects of climate and land management on runoff and soil loss helps to understand interactive processes, substantiate investment in sustainable and proper planning of land management strategies to benefit land users (Telles *et al*., 2013). Globally, a modeling approach is a common and useful way to project runoff and soil erosion under a dynamic nature (Li and Fang, 2016).

Different hydrologic models can be used to simulate proposed management scenarios and to design alternative land use and conservation options targeted at specific locations that are better aimed at preventing soil erosion and its downstream delivery for the improvement of the natural resource (Jetten and Hessel, 2003). Soil and water assessment tool (SWAT) is widely used over the world; well known for its continuous-time, daily-based and a semi-distributed watershed simulation model developed to predict hydrological processes (Yen *et al*., 2014) and to identify better watershed management strategies. SWAT is selected as it has been proved as a very effective tool for soil erosion prediction, scenario analyses, and helps in decision-making processes for adopting best management practices (BMPs) to support watershed management initiatives and/or conservation programs in the Ethiopian highlands (Yesuf *et al*., 2015).

The Soil Conservation Research Program (SCRP) was launched in 1981 and continues to date with a meteorological station, and rainfall, runoff, and other climatic data have been generated. Therefore, using this information to address issues on future climate conditions and LULC change and their relation with runoff and sediment load accumulation, which could contribute to the sustainability of highland environments and the livelihoods of farming communities, is undoubtedly very important. Erosion rates are highly dependent on climatic conditions and human-induced land use management strategies (Ashagre, 2009). Watershed models (e.g., SWAT) that are capable of capturing these processes in a dynamic manner can be used to provide an enhanced understanding of the relationship between hydrological processes, erosion/sedimentation, and management options.

Therefore this research aims to investigate the effect of different management options on hydro-sediment responses under current and future limate change scenarios.

1.2. Statement of the Problem

Seriousness of land degradation in Ethiopia and the motivational efforts of Ethiopian governments to conserve soil and water for agricultural purposes, scientists and development specialists established the Soil Conservation Research Program (SCRP) in 1981. Their main objective was to collect long-term hydro-sediment data and contribute to the technical, ecological, economic, and social improvement of governmental efforts. The Maybar Research Station is one of SCRP's research sites, which was established in the same year (1981) in Wello, north central Ethiopia. Many researchers from governmental and non-governmental organizations have conducted different studies focusing mainly on hydro-sediment relations, soil fertility status, and land use/land cover dynamics (SCRP, 2000).

Huge data on agro-meteorological and erosion-related parameters was collected since 1981 to date; but little or no studies have been reported yet on the simulation of effective management practices under climate change conditions in response to hydrology of the watershed. Previous studies at Maybar research station have shown that bushlands were lost and converted to cultivated lands, grassland, and forest areas to homestead due to the population growth and settlement area expansion (Tesfaye, 2017; Tilahun and Awdenegest, 2021). The conversion of land use dynamics would unexpectedly affect soil erosion and hydrological conditions if their future effect is not properly analyzed. There is also a growing consensus in Earth system science that global temperature and aggressive rainfall events are increasing and will continue to do so over the next century, leading to changes in global climate regimes (Nunes and Nearing, 2010).

Consequently, climate change coupled with unevaluated land use land cover conversions greatly lead to a land degradation crisis. Complex interactions between land use and climate are reported to result in a highly impacted global change on runoff and soil erosion (Tomer and Schilling, 2009). Insufficient information on watershed hydrologic processes could lead to inefficient planning and inadequate design and operation of soil and water resource management projects. Most of the existing studies in the study region focused on observed effects of soil and water conservation practices on surface runoff and soil loss reduction at plot and field scales. Thus, assessing the effect of management practices on hydro-sediment responses at watershed scale is our interest.

The prediction and assessment of streamflow and sediment yield using a watershed model are important for agricultural watershed management in the Ethiopian highlands as watershed models are crucial tools to illustrate hydrological processes and to scale up the model results (Melaku *et al.*, 2018). Therefore soil erosion prediction from land use and future climate change scenarios must be focused to plan and arrange countermeasures and mitigate its effect on natural resource degradation. Using the baseline hydrologic, sediment, and agro-climatic data, the modeling approach is a common and convenient way to project runoff and soil erosion under the dynamic nature of the global environment. Therefore, before managing a watershed, it is advisable to assess the interaction between management practices, hydrology, and amount of sediment yield with respect to climate change conditions.

1.3. Objective of the Study

1.3.1. General Objective

The main objective of this study was to investigate hydro-sediment responses to management options under current and future climate change scenarios.

1.3.2. Specific Objectives

- To project future climate change conditions for different seasons over the periods of 2022 to 2070s.
- To quantify the impact of climate change on discharge and sediment yield of Maybar watershed over the periods of 2022 to 2070s.
- To quantify the impact of management options on discharge and sediment yield of Maybar watershed under current and future climate change conditions.
- To compare the potential roles of management options on minimizing eroded sediments in Maybar watershed

1.4. Research Questions

- How climate change will behave and impact the discharge and sediment yield of Maybar watershed over the periods of 2022 to 2070?
- What will be the effect of management options on hydro-sediment responses of Maybar watershed under current climatic conditions?
- What will be the effect of management options on hydro-sediment responses of Maybar watershed under future climate change scenarios?
- Which management option is effective on mitigating climate change induced soil erosion at Maybar watershed?

1.5. Significance of the Study

The information provided through the simulation of hydro-sediment output parameters could help for effective planning and decision making to implement watershed-based soil and water conservation activities. Implementing different soil and water management interventions can reduce the risk of flooding downstream areas and loss of important soil nutrients that support plant growth, thus it improves the recharge capacity of the aquifers and productivity of agricultural land.

Therefore, this study was intended to investigate the response of discharge and sediment yield to future climatic conditions and different land management scenarios. Undoubtedly, the study provides information to planners and decision-makers to have an efficient design and implement effective soil and water conservation interventions as a countermeasure to predicted climate and erosion phenomenon. In addition, simulation models have been proved to be a tool for evaluating the impact of different land management practices under anticipated climatic conditions on soil erosion and the output could serve as a reference for future similar studies.

1.6. Limitation of the Study

Our results demonstrate that the combination of SWAT and climate models employed have potentially predict future discharge and sediment yield of the Maybar watershed. The climate change scenarios and management alternatives evaluated in this study were found to impact the discharge and sediment yield of the catchment and potential conservation measures to mitigate the effects of climate were valued. Our study has a limitation on the impact of climate change on agricultural yields and the economic feasibility of conservation measures. The SWAT-cup parallel processing technology could enable the model efficiency improved further by employing large numbers of simulations that can be fastened through using eight parallel simulations at a time.

2. LITERATURE REVIEW

2.1. Global Overview of Soil Erosion

Sediment yield is one of the manifestation of soil erosion. Soil erosion is a physical process with considerable variation globally in its severity and frequency, where and when erosion occurs is strongly influenced by social, economic, political, and institutional factors (Morgan, 2009). Its rates are highly variable, depending on natural phenomena, such as climatic and topographic conditions, as well as local soil properties. Though wind, especially in arid and semi-arid regions can cause erosion, soil erosion associated with water (rain splash or runoff) is the most common (Boardman, 2006) and about 80 % of the world's agricultural land suffers from moderate to severe erosion (Ritchie *et al*., 2003).

Soil erosion has significant implications for land productivity and surface water quality, as sediment is the leading water pollutant worldwide (Holz *et al*., 2015). Although soil degradation occurs worldwide and its most widespread form is soil erosion (Panagos *et al*., 2014). Stavi and Lal (2015) reported that 23% (with an estimate of 5–10 million ha) of the Earth's land surface has been severely affected by soil erosion each year. At the beginning of the 21st century, the global average erosion rate was estimated to be 10.2 tons ha^{-1} yr^{-1} and the global loss of soil by erosional processes and sediment transport to oceans has been estimated in ranges between 24 (Lee and Heo, 2011) to 75 billion tons of fertile soil (Meybeck *et al*., 2003).

Although land degradation is a physical process, its underlying causes are firmly rooted in the socioeconomic, political, and cultural environment in which land users operate (Stocking and Murnaghan, 2001). Globally, Asia has the highest proportion of degraded land (31%), followed by Africa (27%) (Oldeman, 1994). It is due to rapid population growth and associated land-use changes, combined with inadequate land use planning and regulations to control soil erosion in Asia (Yang *et al*., 2005).

In India, soil erosion occurs at a rate of approximately 0.16 tones km^{-1} yr^{-1}, of which approximately 10 % is deposited in reservoirs and 29 % is transported to the sea (Kirurhika *et al*., 2011). Currently, the Loess Plateau, also known as the Huangpu Plateau, located in north-western China is a dramatic indication for the global spreading of soil erosion; it is being a gully-hill dominated region from beyond 70 % of the once high, flat plain plateau (Zhao *et al*., 2013)

Soil erosion especially in the developing world has a severe negative impact on crop yield and damage to infrastructure (Ananda and Herath, 2003). Dubale (2001) reported that soil degradation in the form of soil erosion and soil fertility loss is a serious challenge to agricultural productivity and economic growth in Ethiopia. Nevertheless, it can drastically exceed 300 tons $ha^{-1}yr^{-1}$ on steep slopes where vegetation is denuded, the average annual rate of soil loss in Ethiopia is estimated to be 12 tons $ha^{-1}yr^{-1}$ (CRSPT, 2000). Poverty and food insecurity are concentrated in rural areas (Sewnet, 2015), because resource loss in the form of soil, nutrient, water, and agrobiodiversity costs the country every year in billions of birr (Dubale, 2001).

2.2. Processes and Mechanics of Erosion

Soil erosion, a complex phenomenon as it is, begins with a detachment of soil aggregates by impacting raindrops. Translocation of detached soil particles may be caused by raindrop impact as splash, through gravitational force downslopes as creep, or by overland flow (Lal, 1981). Soil Erosion, whether it is by water, wind, or tillage, involves three distinct actions – soil particles detachment from the soil mass, transport by erosive agents such as running water and wind or gravity, and a third phase, deposition (Morgan, 2009).

Raindrop energy, first impacts aggregates of soil particles to be deformed or disintegrated and detach soil particles from the surface. The remaining energy activates the second step of the erosion process, particle transport (Rose, 1960). Deposition, the final step in the erosion process, will occur simultaneously with the first two steps (Huang *et al*., 1999). When the sediment load of the moving agent is greater than its transport capacity, deposition occurs (Foster and Meyer 1972). Every single storm event can cause the detachment, transport, and deposition of individual soil particles several times. Re-detachment and transport are highly expected from recently deposited soil than residual soil because the original bonding forces have been broken (Zhang *et al*., 1998).

2.3. Factors and Conditions Governing Soil Erosion

Research on the various causal factors of soil erosion has been studied since the early 1920s (Smith and Wischmeier, 1962). Soil erosion issues in a given area and their influencing factors are one of the hot spots that currently cause global attention. The amount of soil erosion is mainly influenced by the natural factors, such as rains, the vegetation, the slope, and the soil character, and so on, as well as the human action (Vahabi and Nikkami, 2008). Earlier research by Dregne (1982) showed that accelerated erosion is the result of two factors: improper management of productive soils and exploitation of marginal lands, both reasons related to using lands without considering their suitability. In recent years, the trend of soil erosion has increased significantly due to improper land-use changes.

Several studies have focused on determining the driving forces that affect soil erosion, including precipitation, geomorphology, land use type, vegetation, and soil physical properties (Zhu *et al*., 2019). The splashing function of raindrops and the runoff generated by rainfall are the main driving factors of soil erosion (Zhao *et al., 2019*). As the slope increases, the amount of soil erosion and the rate of increase of soil erosion both increases. For vegetation, the canopy of vegetation can protect the surface soil from direct impact from raindrops and weaken runoff, thus eventually reducing soil erosion (Hassanin *et al*., 1993). The most important natural and human-induced driving factors of soil erosion are discussed below.

2.3.1. Rainfall as an Energy Factor

Many investigations either using indirect estimations (e.g., RUSLE), or with direct measurements (e.g. field plots) implied that soil erosion is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. This applies particularly to erosion by overland flow and rills, for which intensity is generally considered to be the most important rainfall characteristic (Morgan, 2009).

Although the magnitude of the erosion varies according to the storm characteristics, rainfall is a prerequisite for runoff and erosion of the soil water. Among the characteristics of the storms, the intensity of the rainfall is a very important factor. The close relationship between water erosion and rainfall intensity is due to (1) impact of raindrops on the soil surface in high intensity storms that causes increased soil particle detachment (Van Dijk *et al*., 2002) and (2) higher rainfall intensity results in higher rates of infiltration excess runoff and a much greater transport of suspended sediment load (Mohamadi and Kavian, 2015). Moreover, storms with the same average rainfall intensity likely do not have the same kinetic energy, since the relationship between rainfall intensity and its kinetic energy is not a linear relationship (Van Dijk *et al*., 2002).

Rainfall intensity, the parameter initially used in determining soil loss, is highly correlated with soil erosion, but it oversimplifies the problem (Miller and Daily, 1977). Panagos *et al.* (2017) proved that erosive power from intense rainfall is a major driver of sediment and nutrient losses worldwide, which may cause farmers vulnerable to crop failures and lead to landscape instability. The finding of Mohamadi and Kavian (2015) indicated that in low-intensity events, the effect of the storm on soil loss is linear. On the contrary, the effect of storm intensity on soil loss is nonlinear in high-intensity events. Finally, they concluded that high intensity and short duration storms lead to greater soil losss.

Appropriate planning of structures and agricultural practices aimed for soil conservation highly needs knowledge of the rainfall characteristics, which is a force full deriving cause to soil erosion (Wischmeier and Smith, 1978). To this effect, it is important to obtain the erosivity index (the potential rainfall has to cause soil erosion), which is exclusively a function of the physical characteristics of the rainfall, including the quantity, intensity, drop diameter, terminal velocity, and kinetic energy.

2.3.2. Soil Erodibility Factor

The nature of the soil plays an important role in erosion since some soils erode easily while others under the same conditions of rainfall, vegetation, and topography erode very little (Lutz, 1934). The amount of water absorbed by the soil is influenced by its mechanical composition and structure. In sands and other light-textured soils, the coarseness of the particles is probably the most important factor contributing to rapid water absorption and permeability and decreased erosiveness. In heavy soils, however, there apparently is a negative correlation between clay content and soil loss, since the presence of clay generally promotes aggregate stability (Lobo, 2004). Depending on the constituents making up the soil and their relative proportions, soils can behave differently to rainfall and have different amounts of runoff and erosion. In addition to soil properties, soil conditions as determined by antecedent moisture content, time at this moisture content (aging), and rate of prewetting determine the amount of runoff and erosion (Vahabi and Nikkami, 2008).

The chemical bonding of soil aggregates as a result of the high content of base minerals makes the soil more stable. Wetting the soil weakens the aggregates because it lowers their cohesiveness, softens the cement, and causes swelling as water is adsorbed on the clay particles. Rapid wetting can also cause aggregate collapse through slaking. The wetting-up of initially dry soils results in greater aggregate breakdown than if the soil is already moist because, in the latter case, less air becomes trapped in the soil, research by Truman *et al.* (1990) as cited by Morgan (2009).

The development organic matter will undoubtedly improve the aggregate stability of the soil and plays an important role in affecting the erosiveness of different soils (Nciizah and Wakindiki, 2015). An earlier experiment proved that soils high in organic matter contain from 15 to 30 % more granules than those low in organic matter and that the granules are three times more stable when shaken with water for 100 minutes (Lutz, 1934). The degree of aggregation and the size and stability of the aggregates, therefore, must have a pronounced effect upon the rate of percolation and, consequently, upon the amount of run-off and soil erosion.

2.3.3. Topography /Slope Length and Steepness/

Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff water enters a well-defined channel that may be part of a drainage network or a constructed channel (Smith and Wischmeier, 1957). The effects of length and degree of slopes on soil erosion were first investigated by F. L. Duley and M. F. Miller in 1925 (Krusekopf, 1943). Erosion would normally be expected to increase with increases in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff. Furthermore, while on a flat surface raindrops splash soil particles randomly in all directions, on sloping ground, more soil is splashed downslope than upslope, the proportion increasing as the slope steepens (Morgan, 2009).

In 1940 Zingg showed that soil loss increases exponentially with slope gradient; as the gradient increases, the kinetic energy of rainfall remains constant, but transport accelerates toward the foot as the kinetic energy of the runoff increases and outweighs the kinetic energy of the rainfall when the slope (S) exceeds 15%. Zingg concluded that doubling the degree of the slope increased the total soil loss in run-off 2.61 times, whereas doubling the horizontal length of the slope increased the total soil loss in run-off 3.03 times. The differential effects of slope length on runoff and erosion may be observed. This situation occurs when other influential factors like management and cover, take a predominant action on runoff velocity (Lal, 1988).

2.3.4. Land Use and Land Cover Conditions

Land use land cover which is known as C-factor, in the soil loss equation is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith, 1978). According to Coffey (2013), land use and land cover have some fundamental differences; land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture, whereas land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil, or other. Therefore, land use indicates how people are using the land, whereas land cover indicates the physical land type. Hence, understanding both the land use and land cover of land provides a comprehensive picture of a particular area and is a fundamental component of the planning and decision-making processes for many communities (Weldu and Edo, 2020).

Land use change is the conversion of land use due to human intervention for various purposes, such as agriculture, settlement, transportation, infrastructure and manufacturing, parks, recreation uses, mining, and fishery (Lambin and Geist, 2008). The change in land use types played a significant role in increasing the rate of soil erosion. Bout (2015) showed that soil loss is very high in cultivated land and bare soil than under forest and grassland conditions. Similarly, studies indicated that land use/land cover changes towards cultivated and degraded land increases the susceptibility of the soil for erosion (Gete and Hurni, 2001). The evaluation of scenarios with different vegetation cover in high-risk areas showed that greater vegetation cover can considerably reduce the loss of soil erosion (Zhou *et al*., 2008). Many findings proved that different land-use types in terms of area size and pattern influenced the soil erosion risk like areas with smaller land cover obviously showed the higher risk of soil erosion than the larger land cover did (Wijitkosum, 2012).

2.3.5. Management Practices

Soil erosion, the most severe process of soil degradation, is apparent in many areas of the world and can be severely aggravated by inappropriate soil management practices (Morgan, 2009). The universal soil loss equation (USLE) support practice factor (P) is defined as the ratio of soil loss under a specific soil conservation practice (e.g., contouring, terracing) compared to a field with upslope and downslope tillage. The P factor accounts for management practices that affect soil erosion by modifying the flow pattern, such as contouring, strip-cropping, or terracing (Renard *et al*., 1997).

Soil tillage highly influences the severity of erosion mainly due to the effect on surface roughness, soil permeability, soil resistance against destruction caused by raindrops and surface runoff, freezing of the soil and the mobilization of nutrients and water for plant growth (Kairis, 2013). Crop rotations with respect to growing patterns, minimum tillage, irrigation, and fertilization are basic soil conservation measures applied on agricultural land by means of which erosion on the land of low and medium erodibility may be reduced to a harmless level. In addition, mulching as a ground cover can also be an important factor in the reduction of erosion.

Generally, the potential tillage operations to cause soil erosion by water to depend on the depth, direction, and timing of plowing, the type of tillage equipment, and tillage frequency. The less the disturbance of vegetation or residue cover at or near the surface, the more effective the tillage practice in reducing water erosion ((Kairis, 2013)). Soil tillage reduces plant cover and disaggregates surface soil in conventional tillage, decreases water infiltration, and increases water erosion. No-tillage allows soil cover to remain more compact, promotes better water infiltration, and lessens erosion in comparison to conventional management (Castro *et al*., 2006). Research finding by Bagherzadeh (2014) concluded that the lower the P factor, the more effective the conservation practice is at mitigating soil erosion.

2.4. Sedimentation Problems and Management Strategies

The management of sediment in river basins and waterways has been an important concern for water resource managers throughout history. Water managers face many complex technical and environmental challenges (e.g, Reseroir sedimentation) in relation to sediment management due to the changing nature of sediment issues (Liu *et al*., 2018). The most significant physiographic factors that governs sedimentation process include the climate, topography, soil type, and land use of the river basin and its sub-basins. So sedimentation problems management starategies are emanated from understanding the interaction of one or more of these factors. Implementation of effective management practices in the high land areas of Ethiopia that are prone to soil erosion and sedimentation problems is a principal issue (Tibebe and Bewket, 2011).

Terracing, afforestation and vegetative filter strips are among the most common practices for areas susceptible to water erosion, and have been proven to be effective at retaining water and soil (Chen *et al*., 2017; Khatavkar and Mays, 2017). These soil and water resources management strategies can reduce the sediment yield significantly. The vegetative filter strips can make a barrier to reduce runoff discharge by promoting infiltration, increasing surfaceroughness, and slowing down the overland flow and peak runoff. Peak runoff rate can also be reduced after the slope gradient and slope length reduction by terracing on the hillside areas (Yang *et al*., 2009). In addition, terraced fields could have a certain storage capacity similar to a reservoir, which can intercept surface runoff and sediment and promote runoff infiltration, evaporation, and sediment deposition (Arnaez *et al*., 2015). The kinetic energy of rainfall can directly be intercepted by vegetation canopy and then it influences erosion rates. Covering an area with vegetation or alternate growing of vegetative strips can also reduce sediment yield by reducing surface flow volume and increasing sediment trapping (Berendse *et al*., 2015). In addition to this, both physical structures and biological measures can intercept the sediment yield from upstream and achieve sediment reduction in the valley by reducing runoff flowing from the slope into the valley.

2.5. Impact of Climate Change on Discharge and Sediment Yield

Climate change is one of the most significant challenge that affects all living matters on the Earth. Temperature and sea level rises may cause floods and salt water intrusion, thus may damage agriculture as well as pose risks to industries and socio-economic system. It is reported that climate change due to high level of greenhouse gas emission will cause changes in stream discharge (up to 11.4%) and sediment load (15.3%) (Phan, *et al*., 2011). Hydrologic cycle will directly be affected by changes in climatic conditions (i.e., temperature rise and rainfall alteration) through modifying actual evapotranspiration, infiltration, lateral flow, groundwater recharge, and surface runoff. Consequently, these alterations will influence the availability of freshwater resources, including surface water and groundwater, across many regions of the world (Ghimire *et al*., 2021). Change in climate directly causes soil erosion through the influence of the amount rainfall (Nearing *et al*., 2004), rainfall intensity (Zhang *et al*., 2012), and the spatial and temporal distributions of rainfall patterns. According to Kotir (2011) Sub-Saharan Africa in the near future is expected to experience stronger variations in hydrology owing to climate change causing increasing variability in duration and timing of wet and dry seasons. Consequently, the relationships of sediment and nutrient concentrations with river discharge will also be altered depending on the bio-physical components of the watershed (Whitehead *et al*., 2009).

A warming climate also indirectly influences soil erosion mainly through changes in vegetation cover and soil moisture (Nearing *et al*., 2004). According to Morgan (2009) when there is an increase in precipitation due to climate change so does the vegetation cover, resulting in better protection of the soil surface, then for annual precipitation between 450 and 650 mm, soil loss decreases as precipitation increases. However, the positive relationship between rainfall and soil erosion does not always exist. The volume and intensity of the rainfall resulted from above 1700 mm; outweigh the protective effect of the vegetation and erosion increases with precipitation. Generally, the impacts of climate change on soil erosion and the fate of eroded sediments have been observed as a worldwide phenomenon, and rainfall is suggested by many research findings to be the most direct influencing factor. The finding by Lu *et al.* (2013) proved that every 1% change in precipitation has led to a 2% change in sediment loads and a 1.3% change in water discharge.

2.6. Erosion Interms of Sediment Yield and Its Measurements

The United States was the largest contributor to global soil erosion studies, on the basis of a total number of publications. However, cooperative studies between research institutes seemed to be the main research pattern in soil erosion research (Zhuang *et al*., 2015). Scientists were developed a scientific procedure to conduct research on soil erosion and its effect on agricultural productivity during the 1930s in the USA (Gebremichael and Alamirew, 2012). On the other hand increasingly alarmed by the seriousness of land degradation in Ethiopia and encouraged by efforts undertaken by Ethiopian governments to conserve soils and water for agricultural purposes, scientists and development specialists created the Soil Conservation Research Program (SCRP) in 1981 (SCRP, 2000).

Soil erosion research is widely facilitated by erosion plots based on sediment yield measurement and rainfall simulators by scientists around the world (Sharpley and Kleinman, 2003). Rainfall simulation experiments are used to study erosion and contaminant transport in the overland flow. Small plots can be also used to observe and understand what is happening when splash, interrill, and rill erosions occur; the processes are not at all clear in larger field plots. Furthermore, small erosion plots in the laboratory allow for the control of most influences, such as slope, soil texture, and moisture content, and thus the impact of one specific factor can be investigated. Moreover, at least the relative effectiveness of various erosion control techniques can be assessed in a very efficient way (Morgan, 2005).

Soil erosion assessment can be performed either at a site (plot, field) level or in a landscape, catchment, or larger areas. Plot experiments to study the processes driving soil erosion have been the main way of assessing erosion at a site by measuring the mass of soil eroded from a plot under varying measured rainfall, soil, and crop conditions (Laflen and Moldenhauer, 2003). These plot-level experiments are the basis for models to assess erosion across the landscape scale (Panagos *et al*., 2015). The research goal is the basic issue of collecting data on soil erosion and its controlling factors, whether from the field or, from simulated conditions, in the laboratory. Although realistic data on soil loss, field measurements are most reliable, since conditions vary in both time and space, it is often difficult to determine the chief causes of erosion or to understand the processes at work (Morgan, 2005).

2.7. Prediction of Soil Erosion as a Function of Sediment Yield

Models are a simplified representation of the real world (Morgan, 2009). Modeling soil erosion is the process of mathematically describing soil particle detachment, transport, and deposition on land surfaces (Morgan and Nearing, 2016). It is very important to understand the processes governing soil erosion, predicting runoff and soil erosion rates, and identifying or choosing appropriate measures of erosion control strategies (Nearing *et al*., 1994; Blanco and Lal, 2008). Estimates of annual soil loss on a global or regional scale are unreliable and a lack of quantitative data is obvious. The extrapolation of erosion data based on sediment yield from specific sites to larger areas of countries may be completely misleading and erroneous. Sound estimates of soil losses, however, are the first step toward an effective cut-down of erosion by appropriate control measures. The starting point is the set-up of erosion plots and their size and location in the landscape, especially with respect to the adaptability of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (Ehlers, 1990).

Numerous models of different prediction capabilities and utilities have been developed. The advent of technological tools such as remote sensing and GIS has significantly enhanced the usefulness of soil erosion models. Remote sensing and GIS tools also allow the scaling up of modeled data from small plots (e.g., USLE) to large areas. Modeling soil erosion involves the integration of complex and variable hydrological processes across large areas to understand the magnitude of soil erosion (Blanco and Lal, 2008). Although the distinction between models is somewhat subjective as there is no sharp difference among them, there are empirical, conceptual, and physically-based models to estimate soil erosion at various scales (Bobe, 2005).

2.7.1. Empirical Models

Empirical models are the simplest of all models as they tend to require fewer data, are easier to apply, particularly over large areas, and are useful as a first step in identifying sources of sediment and nutrient generation (Tesfahunegn, 2011). However, the models suffer from a lack of specificity and do not incorporate a mechanism. Empirical models are based primarily on observations and are usually statistical in nature. Three types of analysis are recognized: (i) black-box, where only main inputs and outputs are studied; (ii) grey-box, where some detail of how the system works is known; (iii) white-box, where all details of how the system operates are known (Nearing *et al.*, 1994). They are based on identifying statistically significant relationships between assumed important variables where a reasonable database exists, and generally are applicable only to those conditions for which the parameters have been calibrated (Merritt *et al*., 2003).

The main emphases of empirical models have been in predicting average soil loss although some extensions to sediment yield have been developed (Nearing *et al*., 1994). They are not event-responsive and ignore the process of rainfall-runoff in the catchments being modeled. They make no inferences as to the processes involved in the work. However, as they can be implemented in situations with limited data and parameter inputs, empirical models are frequently used in preference to the more complex models (Merritt *et al*., 2003). Tesfahunegn (2011) in his article described that the most widely used empirical soil erosion models include the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), RUSLE (Renard *et al*., 1994), and the Soil Loss Estimation Model for Southern Africa (SLEMSA) (Elwell, 1978).

2.7.2. Conceptual Models

Conceptual models are placed somewhere in between empirical and physically based models (Beck, 1987). They reflect the physical processes governing the system, but describe them with empirical relationships. Conceptual models have the inherent limitations of empirical models and also require relatively detailed data for calibration (Tesfahunegn, 2011). In these models, sediment yield is an output while sediment producing factors such as rainfall and runoff are treated as inputs to the system.

Conceptual models are mainly distinguished from empirical models by the feature that conceptual models tend to be aggregated, and they still reflect the hypothesis about the processes governing the system. They usually include a general description of catchment processes, without including the specific details of process interactions, which would require detailed catchment information (Merritt *et al*., 2003). These models can therefore provide an indication of the qualitative and quantitative effects of land-use changes, without requiring large amounts of spatially and temporally distributed data. According to Merritt *et al.* (2003) the Agricultural Non-point Source Model (AGNPS), Agricultural Catchment Research Unit (ACRU), Hydrologic Simulation Program, Fortran (HSPF), and Simulator for Water Resources in Rural Basins (SWRRB) are among the conceptual models used in erosion assessment studies.

2.7.3. Physically-Based Models

Physically based models are scientifically flexible and are applied to a wide range of soils, climatic, and land use conditions. (Schmidt, 2013). These models incorporate the laws of conservation of mass and energy. Most of them use a particular differential equation known as the continuity equation, which is a statement of the conservation of matter as it moves through space over time (Nearing *et al*., 1989). There is an input of material into the segment as a result of the detachment of soil particles on the segment itself and an influx of sediment from the slope above. If the material removed can be transported by the flow there is soil loss, and there is deposition when the transport capacity of the flow is less than detachment (Nearing *et al*., 1990).

The trend of the wide use of empirically-based models for erosion research is declining. After the mid-20th century, the emphasis on erosion prediction technology is toward the development of process-based simulation models (Morgan, 1980). Though these models may be complex and data-intensive (Ganasri and Ramesh, 2016), they enable users 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. The Soil and Water Assessment Tool (SWAT) is one commonly used in practice to simulate water and sediment fluxes in watersheds among physically based models (Salah and Abida, 2016), others physically-based models reported in the literature include Erosion/Productivity Impact Calculator (EPIC) (Sharpley and Williams, 1990), Water Erosion Prediction Project (WEPP) (Nearing *et al*., 1990), Chemicals, Flow and Erosion in Agricultural Management Systems (CREAMS) (Line and Meyer, 1988), European Soil Erosion Model (EUROSEM) (Morgan *et al*., 1992) and Kentucky Erosion Model (KYERMO) (Hirschi and Barfield, 1988). In any of the cases, that is, whatever the option for the model to be used, the important thing is that it be validated for the intended purposes at places under study, according to the existing data.

2.8. Performances of Climate Models for Ethiopia

Climate models due to their extensive simulation of precipitation and temperatures are very important in predicting and forecasting current and future climate impacts on water resources (Matiu *et al*., 2020). Although, many climate models are developed and available right now they have different performances for simulating precipitation, temperatures, and other climate variables. Dynamically downscaled Regional climate models are a credible and more alternative solution than GCMs in identifying and evaluating climate impact generated from rainfall and surface temperature on stream flow and surface runoff during in use of hydrological models (Crop *et al*., 2012). The performance of climate models is most of the time evaluated by using distinguished statistical parameters which are capable of estimating the difference between observed data and simulated.

Performance study by Endris *et al*. (2013) reported that the characteristic of ethiopian rainfall is highly dependent on topography which varies with the complexity of the landscape of the region. The performance of some RCMs around awash river basin in attaining observed climate variables were not shown complete variation. But there was a certain difference among RCM in simulating precipitation and temperature against the observed variables (Tumsa, 2021). An other performance assessment around South West Ethiopia by Demissie and Sime (2021) found that RCMs can simulated the seasonal rainfall, but not the peak rainfall, with all models including their ensemble underestimating the peak rainfall. The ensemble was showed better in Upper Blue Nile Basin than the individual RCMs in simulating both rainfall and air temperature (Dibaba *et al*., 2019). Moreover, despite their performance, it was recognized that all RCM simulated values assessed in different parts of Ethiopia show reasonable bias that needs correction before use for hydrological modeling (Demissie and Sime, 2021; Worku *et al*., 2018).

2.9. Climate Scenarios and Data Exploration

Scenarios are consistent and coherent descriptions of alternative hypothetical futures that reflect different perspectives on past, present, and future developments, which can serve as a basis for action. (Van Notten, 2005). Developing scenario functions to promote learning, communication, and improving observational skills. The learning/educative function is about informing people by interpreting the often confusing overload of information and integrating possible future events and developments into consistent pictures of the future (Duncan and Wack, 1994). The most common method of developing climate scenarios for quantitative impact assessments is to use results from GCM experiments. Many researches used GCMs for simulating the response of the global climate system to changing atmospheric composition (Lal and Harasawa, 2000). Though climate change studies are conducted using data from general circulation models (GCMs); GCMs have a coarse resolution, they are not suitable forregional climate change impact studies. Instead, regional climate models (RCMs) have been used to dynamically downscale the GCM output to scales more suitable for end-regional applications. Using GCM-driven RCM output is therefore, relatively better to provide valuable information for climate adaptation practices or risk assessment studies. Impacts of climate change in local environments that are influenced by complex topographies and landscapes can be understood with the application of RCM outputs (Giorgi *et al*., 2009).

The choice of baseline period for climate change simulation has often been governed by the availability of the required climate data (Smith and Pitts, 1997). Whereas, choosing which GCM(s) or RCM to use as the basis for climate scenario construction, one of the criteria that have often been used is the ability of the model to simulate present-day climate. Many climate scenarios have used this criterion to assist in their choices, arguing that climate models that simulate present climate more faithfully is likely to simulate more plausible future climates (Smith and Hulme, 1998; Lal and Harasawa, 2000). Nowadays, the Coordinated Regional Climate Downscaling Experiment (CORDEX) program, initiated by the World Climate Research Program, provides an opportunity for generating high-resolution regional climate projections. Impacts of climate change in the future at regional scales can be assessed by the so called climate model (Giorgi *et al*., 2009). Performance evaluation studies for Ethiopia showed that the simulation results of CORDEXAfrica can reproduce the shape of the monthly rainfall distribution and temperature states (Endris *et al*., 2013; Fentaw *et al*., 2018). However, bias correcting the RCMs has to be done before they are applied for future climate change analsis.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location and Topography

Maybar (also called the Kori Sheleko basin) is located in Amhara National Regional State, South Wollo Zone, Albuko district, Ethiopia. It is situated at about 20 km from Dessie town in the south- eastdirection and about 422 km north of Addis Ababa (Fig. 1). It is one of the Research Units of the Soil Conservation Research Project (SCRP), where the standard research program has been operational since 1981. The watershed area covers 113.41 ha based on an ArcSWAT watershed delineation using a 2 m resolution digital elevation model (DEM). The study site is geographically lies between 10^0 59' 45" N to 11^0 30' 45" N and 39^0 39' 15" E to 39^0 39' 45" E (Fig. 1).

According to Tena (2018), it is stated that the watershed's name is derived from Lake Maybar, which is a small lake caused by tectonic uplift, but the spe-cific observatory stream is called Kori Sheleko. The catchment is characterized by highly rugged topography with an altitude of 2530 to 2858 above mean sea level (a.m.s.l.). The Maybar watershed consists of Kori Sheleko subcatchment that feeds Lake Maybar, which then drains to Borkenna river and ultimately to Awash river.

3.1.2. Soils of the Catchment

The dominant soils in Maybar catchment are those shallow Phaeozems, associated with Lithosols, i.e. extremely shallow to shallow (soil depth 0-50 cm, with an average depth of around 15 cm), stony darkbrown clay loam soils, mostly excessively drained and well structured. Most of these soils are not suitable for permanent crop cultivation because of their very low soil moisture and nutrient storage capacity. Maybar also features hydromorphic soils, so-called mollic Gleysols that have a very high water table and are often waterlogged and swampy (SCRP, 2000). The soil textural classes of the watershed is mostly dominated by sandy clay loam covering 80% of the watershed, and the rest is clay loam (Tilahun and Awdenegest, 2021).

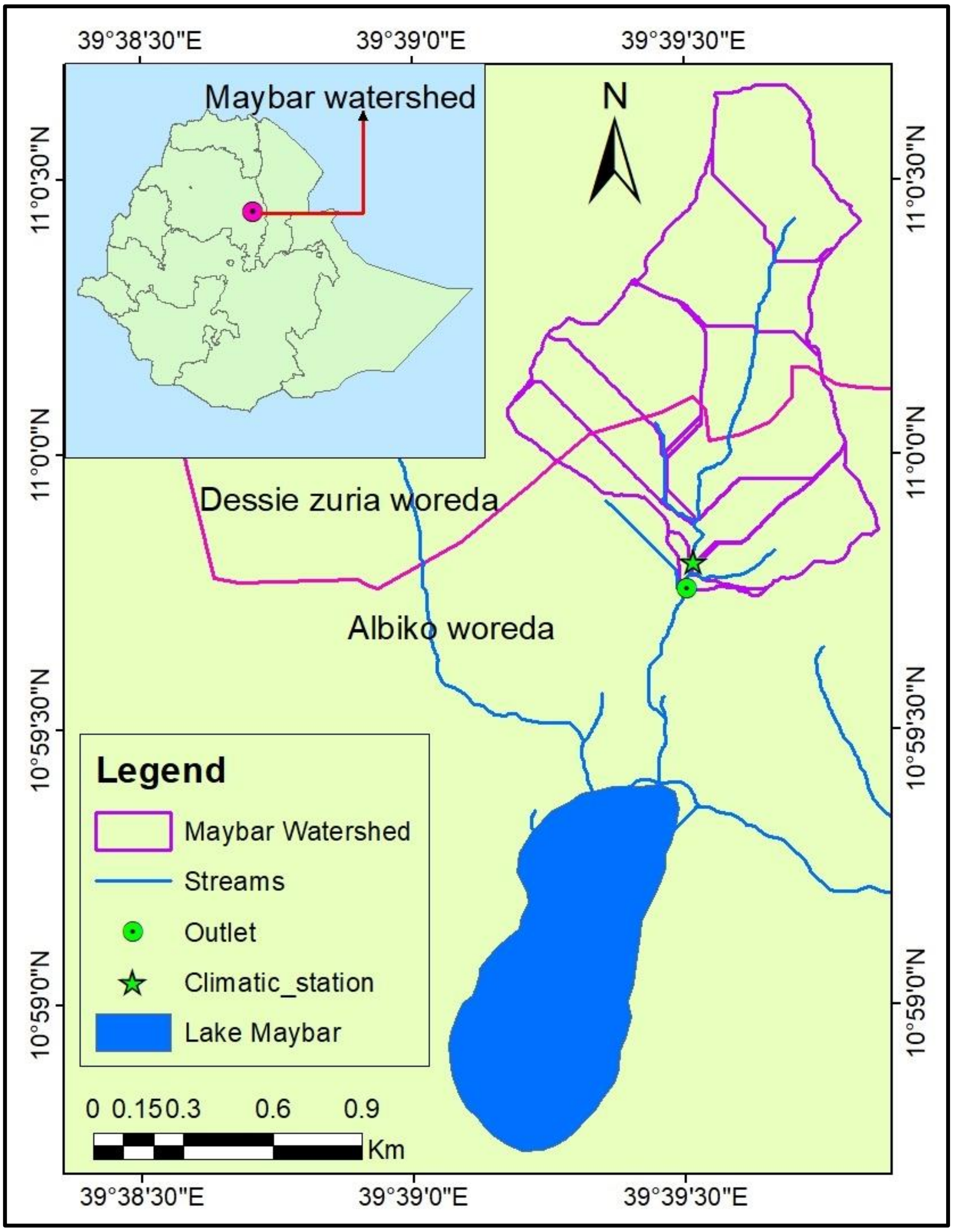


Figure 1. Location map of Maybar observatory watershed with its stream networks & hydro-meteorological stations

3.1.3. Climate

The Maybar research watershed receives an average annual rainfall of 1211.62 mm and the annual mean, minimum and mean maximum temperatures in the study area varies between 10.39 and 21.90 °C respectively (Fig. 2). Maybar area is characterized by a bimodal rainfall pattern with the erratic distribution. The small rainy season (Belg) occurs from March to May, while the main rainy (Kiremt) season occurs from June to September with a dry season from October end to February. The climate of the watershed is characterized by Moist Woina Dega agroecological zone based on the classification of Hurni *et al*. (2016).

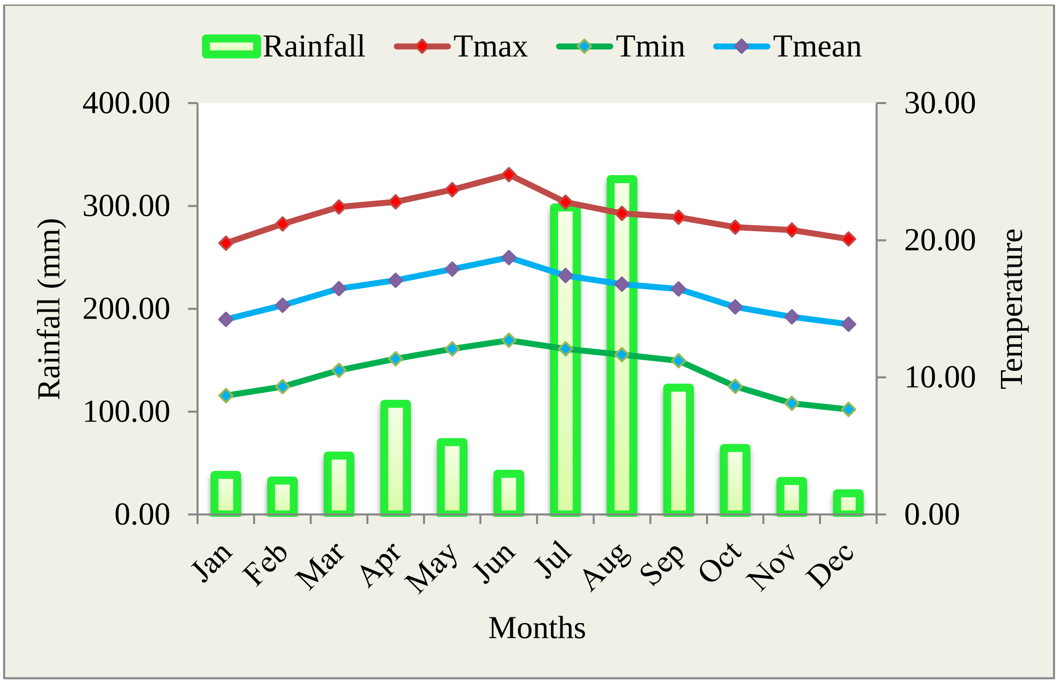


Figure 2. Mean monthly rainfall and maximum/minimum/mean temperatures for the study area

3.1.4. Agricultural Production and Economy /Agricultural Activities/

The study area is characterized as intensively cultivated, erosion prone, low potential, and oxen-plowed cereal belt of the north-eastern escarpment of the Ethiopian highlands (SCRP, 1982; Bosshart, 1997). From the total size of the Maybar catchment approximately 60 % of the entire area is cultivated. Predominant crops are cereals and maize; they cover about 30 % of the total catchment area.There are two cropping seasons in Maybar: the first, Belg, by the small rainy season in spring and the second is Kremt, the main rainy season. With its smaller amounts of rainfall, the belg season is predominantly used to plant cereals; in the Kremt season the agricultural environment of Maybar, would be dominated by pulses, which require more water. Maize is planted during Belg and grows over both cropping seasons. The percentage of fallow land is generally low (Tilahun and Awdenegest, 2021).

3.2. SWAT Model Description

SWAT widely used over the world is a river basin, or watershed scale model developed to predict the impact of land management practices on runoff and sediment yields with varying soils, land use, and management conditions over long periods of time. The model is physically based and computationally efficient, uses readily available inputs, and enables users to study long-term impacts (Di Luzio *et al.*, 2002). SWAT simulates hydrology, and sediment at the HRU level. Water and sediment from each HRU are summarized in each sub-basin and then routed through the stream network to the watershed outlet (Neitsch *et al.*, 2011). The SWAT model, which has already been integrated with ArcGIS software, is the most commonly used hydrological model capable of simulating the hydrology and sediment loads of watersheds with acceptable accuracies, and therefore it was implemented for this study.

SWAT model uses the Modified Universal Soil Loss Equation (MUSLE) to compute soil erosion at hydrologic response units (HRU) level. The MUSLE (Williams, 1977) can be expressed as:

$$Sed = 11.8 * (Q_{surf} * q_{peak} * area_{hru})^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG \text{ .... } 1$$

Where S*ed* is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm H_2O/ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m^2 hr/(m^3-metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and *CFRG* is the coarse fragment factor.

Surface runoff can be estimated using the Soil Conservation Service (SCS)
curve number method as follows:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \text{ .... } 2$$

Where Q_{surf} is the accumulated runoff or rainfall excess (mm H_2O), R_{day} is the rainfall depth for the day (mm H_2O), I_a is the initial abstractions, which includes surface storage, an intercept and infiltration prior to runoff (mm H_2O), and *S* is the retention parameter (mm H_2O). The retention parameter varies spatially due to changes in soils, land use, management, and slope, and temporarlly due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4 \left[\frac{1000}{CN} - 10\right] \text{ .... } 3$$

Where *CN* is the curve number for the day.

The modified rational method will be applied to estimate peak runoff rate based on the idea that if rainfall of intensity begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration, t_{conc}, when all of the sub-basins are contributing flow at the outlet. q_{peak} is calculated as (Neitsch *et al*., 2011):

$$\boldsymbol{q_{peak}} = \frac{\boldsymbol{a_{tc} * Q_{surf} * Area}}{(\boldsymbol{3.6 * t_{conc}})} \ldots\ldots\ldots\ldots 4$$

Where, q_{peak} is the maximum runoff rate (m^3 s^{-1}), a_{tc} is the fraction of daily rainfall that occurs during the concentration time, Q_{surf} is the surface runoff (mm), Area is the sub-basin area (km^2), t_{conc} is the concentration time for the subbasin (hr), and 3.6 is the unit conversion factor.

The soil erodibility factor (K_{USLE}) will be generated using the equation proposed by Williams (1995):

$$\left(\boldsymbol{K_{USLE}} = f_{csand} * f_{cl-si} * f_{org} * f_{hisand}\right) \ldots\ldots\ldots\ldots 5$$

where f_{csand} is a factor that gives low soil erodibility factors for soils with high coarse sand contents and high values for soils with little sand, $f_{cl\text{-}si}$ is a factor that gives low soil erodibility factors for soils with high clay to silt ratios, f_{orgc} is a factor that reduces soil erodibility for soils with high organic carbon content, and f_{hisand} is a factor that reduces soil erodibility for soils with extremely high sand contents. The detail on the factors calculation procedure is available in SWAT theoretical documentation, version 2009.

The daily cover and management factor, C_{USLE}, which is defined as the ratio of soil loss from land cropped land under specified conditions to the corresponding loss from clean-tilled, continuous clean-tilled fallow (Wischmeier and Smith, 1978) can also be expressed in SWAT using the equation:

$$\boldsymbol{C_{USLE}} = \boldsymbol{exp}\left(\left[\boldsymbol{ln}(\boldsymbol{0.8}) - \boldsymbol{ln}\left(\boldsymbol{C_{USLE,mn}}\right)\right] * \boldsymbol{exp}\left[-\boldsymbol{0.00115} * \boldsymbol{rsd_{surf}}\right] + \boldsymbol{ln}\left[\boldsymbol{C_{USLE,mn}}\right]\right) \ldots\ldots\ldots\ldots 6$$

where $C_{USLE,mn}$ is the minimum value for the cover and management factor for the land cover, and rsd_{surf} is the amount of residue on the soil surface (kg/ha).

The $C_{USLE,mn}$ can be estimated from a known average annual C factor using the following equation:

$$\boldsymbol{C_{USLE,mn} = 1.463 * ln[C_{USLE,aa}] + 0.1034} \text{ .... } 7$$

Where $C_{USLE,aa}$ is the average annual C factor for land cover.

The support practice factor, $\boldsymbol{P_{USLE}}$, is defined as the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down slope culture. Support practices include contour tillage, strip-cropping on the contour, and terrace systems (Wischmeier and Smith, 1978). $\boldsymbol{P_{USLE}}$ factor will be adapted and extrapolated from look-up tables of various documents for Ethiopian conditions based on thorough field observations and data collections.

Topographic factor, LS_{usle}, is a combination of slope length and angle of slope. Slope length and angle of slope will automatically be calculated by SWAT since the geomorphic parameters are going to be generated by the DEM.

$$\boldsymbol{LS_{USLE} = \left(\frac{L_{hill}}{22.1}\right)^{m} * (65.41 * sin^{2}(a_{hill}) + 4.56 * sin\, a_{hill} + 0.065)} \text{ .... } 8$$

Where L_{hill} is the slope length (m), m is the exponential term and α_{hill} is the angle of the slope. The exponential term, m, is calculated:

$$\boldsymbol{m = 0.6 * (1 - \exp[-35.835 * slp])} \text{ .... } 9$$

Where slp is the slope of the HRU expressed as the rise over the run (m/m). The relationship between α_{hill} and slp is:

$$\boldsymbol{slp} = \mathbf{tan}\boldsymbol{a}_{\boldsymbol{hill}} \ldots\ldots\ldots\ldots 10$$

The coarse fragment factor is calculated as:

$$\boldsymbol{CFRG} = \boldsymbol{exp}(-\mathbf{0.053} * \boldsymbol{rock}) \ldots\ldots\ldots\ldots 11$$

Where rock is the percent rock in the first soil layer (%).

3.3. Methods of Data Collection, Analysis and Data Sources

3.3.1. SWAT Model Parameters

This study was conducted using SWAT (vers.2012) which was built on the ARCVIVEW platform (Fig. 3). The SWAT watershed simulation process begins with partitioning the watershed into differenet sub-units. Sub-basins are the first level of subdivisions. These units possess a geographic position in the watershed and are spatially related to one another (Neitsch *et al*., 2002). The next step is to integrate the digital elevation model, the soil map, and the land use map that results the watershed further divided into hydrological response units (HRUs). The delineation of HRUs allows SWAT to consider the spatial heterogeneity of landuses, soils, and slopes that increases the accuracy of sediment yield prediction and provides a much better physical description of sediment routing.

It is important to note at this stage that the quality of outputs of the model is largely dependent on the accuracy and the reliability of the input data in terms of spatial resolution. In the ArcSWAT interface, HRUs were defined based on a combination of land use, soil, and slope maps using multiple HRUs options in which more than one HRUs are created within a sub basin. A 0% (land use), 0% (soil) and 0% (slope) thresholds are used to define HRUs, which means no areas of land uses, soils and slope are eliminated from HRU formation within each sub basin. As a physically based hydrological model, SWAT requires a great deal of input/output data in order to derive sensitive parameters that control the flow and sediment routing processes in the study watershed. Major input datasets required by SWAT include slope, soils, land use/land cover, and Weather stations and their associated rainfall and temperature time series data.

3.3.1.1. Slope

The digital elevation model (DEM) was used to create slope map and discretize stream networks, sub basin and watershed characteristics including HRUs creations. This digital elevation model data with 2m by 2m resolution was obtained from Soil Conservation Research Project (SCRP, 2000); Water and Land Resources Center (WLRC), Addis Ababa, Ethiopia.

3.3.1.2. Soils

Weigel (1986) was carried out the soil characterization of Maybar watershed. So, the soil map of the watershed has been georeferenced and digitized on-screen in ArcGIS10.7 software and it has been further edited; overlay analysis, and topological checks with the rules of *must not have gaps and must not overlap*. Soil characteristics required by the model such as texture, organic carbon and bulk density from each type of soil was collected through opening different profiles considering soil types as a sampling unit. Then a total of 17 soil samples for chemical anlysis were transferred to plastic bags and placed in an air drying sample storage room, mixed well and passed through a 2 mm sieve for the analysis of parameters. Undisturbed soil samples were taken by core sampler for bulk density analysis and it was determined by drying the soil samples in an oven dry at 105 ^{o}C until constant weight is recorded (Hillel, 2003) and calculated as follows:

$$\boldsymbol{\rho b} = \frac{\boldsymbol{Ms}}{\boldsymbol{Vt}} \ldots\ldots\ldots\ldots \quad 12$$

Where, ρb = soil bulk density; Ms = mass of solid; Vt= total volume of the soil

The organic carbon content of the soil was analyzed by following the wet digestion method (Walkley and Black 1934). It allows the back titration of potassium dichromate in which the amount of reduced dichromate is considered to be quantitatively linked to the organic C content of the sample. Soil texture was also determined by hydrometric method (Bouyoucos, 1962) which estimates percentage of sand (0.05 - 2.0 mm), silt (0.002 - 0.05 mm), and clay (<0.002 mm) fractions in the soils; after destroying OM using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium phosphate ($NaPO_3$) and sodium carbonate (Na_2CO_3). These collected parameters were analyzed in sirinka agricultural research center soil laboratory. The remaining soil physico-chemical properties required by the SWAT model Such as available water capacity (SOL_AWC), saturated hydraulic conductivity (SOL_K), Hydrologic soil groups (HDRGRP) Soil rock fragment content (SOL_ROCK, which is used to estimate CFRG, and soil erodibility factor (USLE_K) were calculated by Saxton and Rawls (2006) pedo-transfer function using the collected soil data from the watershed. Finally, the user soils were edited, imported and appended into SWAT soil database to incorporate the soil parameters in SWAT2012 geodatabase.

3.3.1.3. Land Use/Land Cover Data

The land use land cover map was prepared by digitizing images from Google Earth in a very detail way using ArcGIS 10.7. software. The year of Google earth image used was similar with simulation periods for real representation of the systems. Previous studies have reported that land use/land cover mapping using pixel-based classificationon, Google Earth images, their fine spatial resolution with high level of detail could lead to lower accuracy. One possible solution to overcome this drawback is to practice on-screen digitisation instead of pixel-based classification (Myint *et al*., 2011). On-screen digitization could help to accurately represent the area in land use mapping, although it is more time consuming than pixel-based classification when large areas are taken for the classification (Shalaby, 2012).

Therefore, we made the watershed boundary buffered by 20 m in ArcGIS software and imported to Google earth pro as a shape file; it enables us to see the domain of our image digitization task. After importing the shapefile to Google earth pro what we did was zooming the whole area of our interest and identifying the major land use land cover of the area. This helps us to delineate the minor land cover areas and later overlaying with the boundary of our area of interest on ArcGIS environment. Finally, after finishing digitization of all land features and land covers inside the catchment, we exported digitized features on google earth to GIS environment and extracted necessary information through saving the project with KML file format and later convert it from KML to layer formats on ArcGIS. While digitizing the land use types we take care of the ground reality through having discussion with senior hydrologic observer who spend more than a decade in the watershed. The discussion would, in fact, support us to verify images and represent what is where in the watershed nicely. Land use defines the standing purpose of the land to serve, and land cover refers to the surface cover on the ground.

3.3.1.4. Climate Data

Daily climate data including maximum and minimum temperatures and precipitation of the gauge station was obtained from Water and Land Resource Center, Maybar database for the periods 1986 to 2018. The period from 2018 to 2020 is accessed from Hobo rainguge and Hoboware climatic station (Appendix Fig. 1) recently installed in the cachment. We used a WGN Parameters Estimation Microsoft Access tool to store and process daily weather data suitable for SWAT weather input (Essenfelder, 2016). This Weather Database is designed to be a friendly tool to store and process daily weather data to be used with SWAT projects. It is capable of Storing relevant daily weather information; Easily creating .txt files to be used as input information during an ArcSWAT project setup; Efficiently calculating the WGEN statistics of several weather stations in one-step run.

3.3.1.5. Discharge and Sediment Yield Data

In addition to climatic data discharge and sediment loss of monthly data at the watershed outlet for the periods of 1981 up to 2014 was obtained from the Maybar station database. These values were used to compare the observed and simulated values in the calibration and validation periods of the SWAT model. In this research article, the term ‘Discharge’ is used for the volume of water that passes through the gauge station at the outlet of the catchment and the term ‘Sediment Yield’ refers to the suspended sediment passing the gauge station at the outlet of the catchment. The discharge rate at the outlet of Maybar watershed, in liters per second, was calculated from the water level height in the main channel which is measured in each event. To do this the rating curve equation developed by Bosshart (1997) for Maybar watershed was used as follows:

$$Q = Q(H \leq 21) = 2.016H^{1.211} \quad \ldots\ldots\ldots\ldots 13$$

$$Q(21 < H \leq 49) = 0.003H^{3.356}$$

$$Q(49 < H \leq 180) = 1.023H^{1.862}$$

Where, H is stage (cm) and Q is discharge (l/s)

3.4. SWAT Model Calibration and Validation Procedures

Model calibration is the process of optimizing model parameters by adjusting them within their absolute values till the model is considered to successfully replicate observed data within an adequate level of accuracy and precision (Daggupati *et al*., 2015). In this process, the first step was to breakdown the observed discharge and sediment yield into calibration and validation periods. Considering 3 years warm up period (1998 to 2000), The period from 2001 to 2006 have been used to calibrate the model and the period from 2009 to 2014 was used for validation. The SWAT model has many input parameters to calibrate the streamflow, sediment, and other environmental purposes. To run this analysis procedure, SWAT- CUP, which is a SWAT Calibration Uncertainties Program, developed to analyze the prediction uncertainty of SWAT model calibration and validation results was employed . SWAT-CUP can integrate Sequential Uncertainty Fitting ver.2 (SUFI-2) calibration and uncertainty algorism (Abbaspour *et al*., 2007) used to perform a sensitivity analysis of parameters.

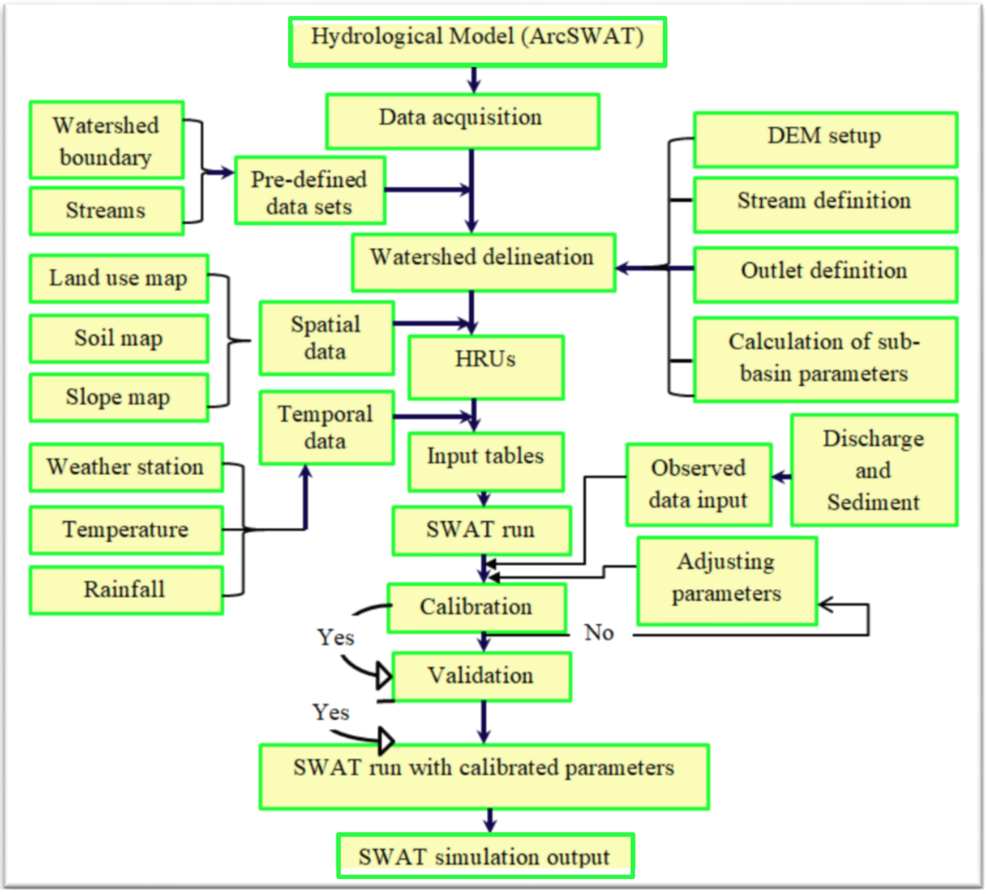


Figure 3. Methodological framework of SWAT Model simulation

3.4.1. Model Performance Evaluation Techniques

After proceeding the necessary steps of model calibration using monthly flow rates, observed at the outlet of Maybar gauge station, there was the model performance test. The model performance was tested based on visual inspection of the agreement between simulated and observed time series and by using the most commonly suggested Statistical and graphical model evaluation statistics as follows:

(i) Coefficient of determination (**R^2**): as a standard regression, it describes the degree of linearity between simulated and measured values.

$$\boldsymbol{R^2} = \left\{ \frac{\sum_{i=1}^{n}(O_i-\bar{O})*(P_i-\bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})^2} * \sqrt{\sum_{i=1}^{n}(P_t-\bar{P})^2}} \right\}^2 \text{ .... 14}$$

Where O_i is the i^{-th} observed value and P_i is the i^{-th} predicted value, $\bar{O}$ is the mean observed value for the entire evaluation period, and $\bar{P}$ is the mean of model-predicted value for the entire evaluation period and n is the total number of observations.

(ii) Nash–Sutcliffe efficiency (**NSE**): it is a normalized dimensionless statistic that determines the relative magnitude of the residual variance compared to the variance of the measured data (Nash and Sutcliffe, 1970).

$$\boldsymbol{NSE} = \left[1 - \frac{\sum_{i=1}^{n} (O_i-P_i)^2}{\sum_{i=1}^{n} (O_i-\bar{O})^2} \right] \text{........... 15}$$

Where symbols are as stated in Eq. (12) above.

(iii) Percent bias (**PBIAS**), measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta *et al*., 1999). PBIAS is calculated as:

$$\boldsymbol{PBIAS} = \left[\frac{\sum_{i=1}^{n} (O_i - P_i) * 100}{\sum_{i=1}^{n} (O_i)}\right] \ldots\ldots\ldots\ldots 16$$

Where PBIAS is the deviation of data being evaluated, expressed as a percentage.

3.5. Scenario Development Approaches

Prospects description through scenario development is a way of predicting the consequences of a prediction phenomenon or a situation that may occur if a trend or a phenomenon is assumed to be sustained or changed to the future, which is considered to be a planning and screening method for system designing ((Van Notten, 2005). So, here soil erosion was quantified under different land use management and climatic scenarios. Hence, a comparison of the advantages and disadvantages of each scenario with respect to providing suggestions on pre-verified soil erosion management strategies.

3.5.1. Management Scenarios

Now a days, the main ways of comprehensive management of soil erosion are to adjust the land use, rational allocation, and implementation of soil and water conservation measures (Mitasova and Mitas, 2001; Xu *et al.*, 2008). Under this scenario setting, factors of soil and water management under human action will most importantly be considered since the natural factors such as soil and slope will not change greatly with human activities in a short period (Duncan *et al.*, 2014). In this study, alternative land use management practices to be compared with the baseline conditions will be evaluated with the calibrated and validated SWAT model in terms of their efficiencies in the reduction of the amount runoff and sediment yield. Land use management scenarios here are identified based on the capacity of SWAT model to offer options for management operations, and Keeping in mind that the socioeconomic aspects and geography of the study area. The land use management scenarios with their detailed parameter adjustment is presented in Table 1 and discussed below.

1) Baseline Scenario; This scenario will represent the actual conditions based on the land use distribution, soil characteristics, meteorological data and farmers' current management practices in the study area. The watershed is mainly managed by implementing parallel terraces since 1986 (Damene *et al*., 2012; Tilahun *et al*., 2021). To feed this management practice in to the model, the assumption of reduction in slope angle and length was considered through careful observation. After calibration was completed for flow and sediment, this simulation was re-run for the 17 year period. This simulation represented the current conditions including the existing typical management techniques, including conservation practices (Terrace). Hence, all the cropping areas in the catchment were assumed terraced.

2) Landuse Change Scenario; Soil erosion has been reported as a severe problem in sloping areas due to deforestation for crop production and intensive cultivation of soils with very low inputs in the study area (Yeshaneh, 2015). Converting all cultivated fields to forest land is impractical and impossible for many reasons. Instead, foresting cultivated lands with the slope of above 15% is hypothesized to be more feasible in minimizing aggravation of erosion on sloppy areas through cultivation. This scenario assumes that adequate food production will be enough in the remaining slope classes through efficient use of agricultural inputs. In addition to the reforestation of cultivated land on the hilly side, the reforestation of bare lands in the study area was also considered in combination with this scenario. The consideration of the reforestation scenario in this study was designed to control soil erosion by avoiding steep slope cultivation (>15% slope) and improving the coverage of bare land (Gashaw *et al*., 2020; Berhanu *et al*., 2013).

Reforestation was implemented in some parts of the Ethiopian highlands since recently to restore degraded croplands in the form of area closure, and thus, evaluating its effectiveness on sediment yield reduction is essential. Therefore, the reforestation scenario was applied by modifying the land use associated SWAT model parameters in the database.

3) Conservation Tillage Scenario; In this scenario, the disturbance of the soil by tillage was assumed to be reduced. The conventional tillage practice mostly with the traditional country plough is used by the farmers of the maybar watershed. The practice of applying conservation tillage is inattentive in the watershed area due to farmer's poor knowledge on worse side of frequent soil disturbance. Farmers in the study area conventionally till their field more frequently before planting to improve soil structure and the control of weeds and belief of gaining better yields. Decline in the use of fallow, limited recycling of dung and crop residues to the soil are among the causes of soil degradation in the study area (Yeshaneh, 2015). Therefore, simulation of this management practice was postulated to increase the amount of residue on the surface after harvest of the crop and then by at least 30% of the soil surface will be covered with crop residue. Hence, the conservation tillage has been tested and compared with the conventional tillage that represents the actual farmers' practices in the business as usual scenario. The tillage treatments along with their respective mixing efficiencies and tillage depths (mm) were selected based on the suggestion of Neitsch *et al*. (2011).

4) Vegetative Contour Strips Scenario; This scenario presents the practice of alternate growing of field crops with narrow grass strips which are about 1 m-wide and spaced at 1-m vertical intervals following the natural contours of the land to prevent water erosion of the soil. Implementing a grass-strip in a field will result in reduction of surface runoff by retaining water in small depressions, a reduction of peak flow rate by increasing surface roughness, slowing surface runoff and reduction of sheet and rill erosion by preventing channel development. These are established along the contour on croplands to evaluate their capability of replacing physical structures on the basis of filtering the runoff and trap the sediment (Hurni *et al*., 2016). Previous studies proved that grass contour strips could reduce the mean annual SY by 50–76% (Lema *et al*., 2019; Asres and Awulachew, 2010). The effect of grass strips on sediment yield was usually simulated by taking into account the installation of 1m wide grass strips (FLTERW), reducing the slope length (SLSUBBSN) by 50% and the slope steepness (HRU_SLP) by 25%, and adjusting the USLE_P value as 0.34 (Lema *et al*., 2019; Asres and Awulachew, 2010).

5) Contour Farming Scenario; Contour farming consists of performing field operations (e.g., plowing, planting, cultivating, and harvesting) along the contour. Contour practices intercept runoff and reduce the development of the rills by redirecting or modifying the flow pattern. The practice of tillage and planting on the contour, in general, has been effective in reducing erosion in appropriate slope ranges (Wischmeier and Smith, 1978). Thus, in this scenario, contouring will be assumed to be the most effective on slopes that range in 3 to 8% percent.

6) No-Terrace Scenario*;* In this scenario the farmers in the watershed are assumed not to practice terracing at all. Previous studies in the region by Mekuriaw *et al*. (2018) and Belachew *et al*. (2020) reported that farmers complain on constructed physical soil and water conservation practices that reduce the size of their farmlands and create difficulties in plowing the farmlands.

An other assessment result also showed that farmers unknowingly prefer removing the constructed conservation structures rather than maintaining them (Asfaw and Neka, 2017;

Amsalu and De Graaff, 2007). Personal communications with the farmers in the study area also revealed that they have a concern of land wastage and yield loss by rodents regarding terrace construction. Therefore, this scenario will provide a way to show how much soil is lost or conserved and also the effect of the terracing on discharge; then based on the information generated extension agenets can create awareness to farmers. The scenario was developed by ignoring the slope angle and slope length reduction made in the base scenario. To simulate these all the above land use management effects, curve number (CN2) and the USLE_cover and support practice factors were being adjusted accordingly in SWAT.

Table 1. Description of management and climate change scenarios with parameter changes in the Soil and Water Assessment Tool database

Scenario	Description	Adjusted parameter values		
		Parameter	Calibrated	Modified
Baseline with terrace	The existing condition in the catchment	*	*	*
Baseline without terrace	Parallel terraces on the crop field were assumed not practiced	TERR_CN TERR_P TERR_SL	Terrace operation added	Terrace operation ignored
Contouring	Contour farming along the contour	CONT_CN	79	60
		CONT_P	0.65	0.12
Vegetative contour strips	1m wide grass strips established on cultivated land along the contour	FILTERW	0m	1m
		HRU_SLP	a	0.75a
		SLSUBBSN	a	0.5a
		USLE_P	0.65	0.34
Landuse changes	Conversion of hilly side crop fields and bare land to forest	Land use change	*	Land use induced changes
Conservation	Conservation tillage was	EFTMIX	0.85	0.25

tillage	introduced in agricultural lands	DEPTIL	100 mm	40 mm
Baseline climate	Climate data set during simulation periods	weather database	*	*
Future RCP4.5	Climate data set (2022-2070) under RCP4.5	Weather database	*	Re-defining weather database
Future RCP8.5	Climate dataset (2022-2070) under RCP8.5	Weather database	*	Re-defining weather database

Note: * is the value or condition during calibration period

3.5.2. Performance Evaluation of Management Scenarios

Comparison and analysis of the degree of soil erosion under the combination of scenarios was calculated, to evaluate the influence of soil and water conservation measures on soil erosion reduction and to provide scientific basis for soil erosion control in the future. Percent reduction gives an indication about the impact of applied alternative management operations compared with the baseline figures before application of these management practices. A statistical comparison has also been performed on the simulated time series of sediment and discharge values at the outlet of the watershed before and after the application of alternative management practices to see the percent change.

$$\textbf{Reduction, \%} = \frac{\mathbf{100\,(preMP - postMP)}}{\mathbf{preMP}} \quad \text{...........} \quad 17$$

Where pre-MP and post-MP are SWAT outputs before and after implementation of the designed management alternatives, respectively.

3.5.3. Climate Projection and Scenario Setting

Observed climate data of daily rainfall, maximum and minimum temperature of the catchment (1986−2020) was obtained from Soil Conservation Research Project and utilized as a baseline climate scenario to validate future climate scenario data. The statistically downscaled Regional Climate Model (RCM) from Coordinated Regional Climate Downscaling Experiment (CORDEX) under RCP 4.5 and RCP 8.5, was used to predict the past and the future climatic conditions of the study area (Negewo and Sarma, 2021; Liersch *et al.*, 2018). The precipitation and max, min temperature dataset at the daily time scale was downloaded from the above model group of different institutes of climate explorer (Table 1) and provided as an input data for hydrological modeling of this study after necessary bias correction procedures. This dataset contributes bias-corrected daily precipitation, min/max air temperature of ten CORDEX RCM runs covering the country of Ethiopia (Fig. 4) for historical (1960–2001) and for future (2010-2100) (Liersch *et al.*, 2018).

The bias corrected CORDEX-under Ethiopia climate data included in this study were those simulated by four GCMs (CNRM-CERFACS-CNRM-CM5, ICHEC-EC-EARTH, MPI-M-MPI-ESM-LR, and CCCMa-CanESM2) and dynamically downscaled by three RCMs, which are Rossby Center Regional Atmospheric Model (RCA4), Canadian Regional Climate Model (CanRCM4), and KNMI Regional Atmospheric Climate Model, version 22 (RACMO22 T). More information is presented in Table 2. These driving models and RCMs are selected for evaluation due to most of their outputs were assessed and showed rational performance over East Africa and specifically Ethiopia (Bokke *et al.*, 2017; Negewo and Sarma, 2021; Nikulin *et al.*, 2012; Endris *et al.*, 2013; Worku *et al.*, 2019). Two climate scenarios (Table **1**), namely RCP 4.5 that describes the medium stabilization scenario without an overshoot pathway and RCP 8.5 that describes rising radioactive forcing pathways leading to a very high emissions scenario were tested (Van Vurren *et al*., 2011; Thomson *et al*., 2011; Rogelj *et al*., 2012).

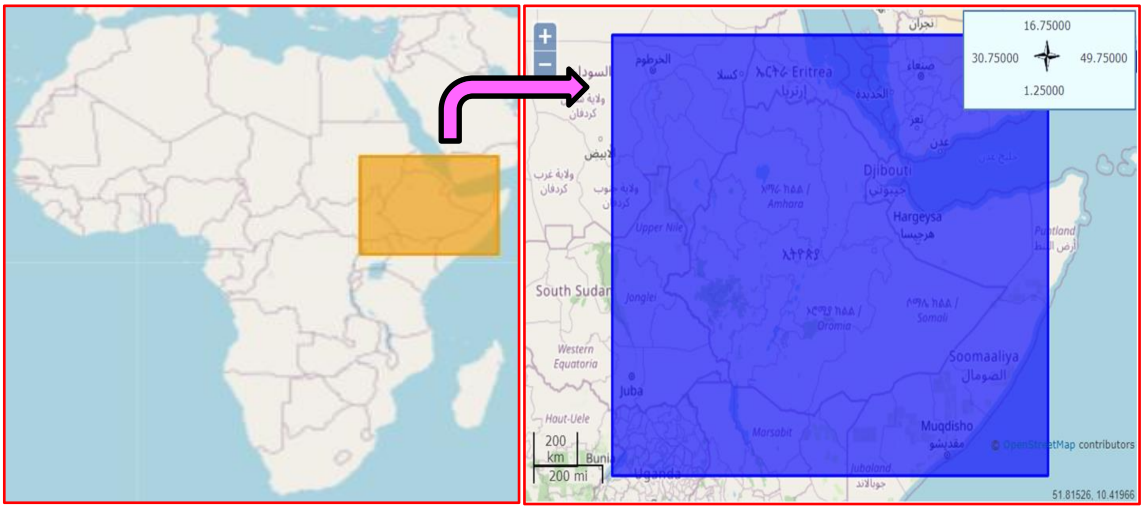


Figure 4. The area coverage of bias-corrected CORDEX precipitation, min/mean/max temperature for Ethiopia, RCP 4.5 and RCP 8.5 (Reproduced from the Source: https://doi.org/10.5880/PIK.2018.009)

Table 2. Description of CORDEX RCMs with their institute and driving GCMs

RCM	Institute	Driving GCM	Country	Reference
RCA4	Sveriges Meteorologiska och Hydrologiska Institute (SMHI)	CNRM-CERFACS-CNRM-CM5	France	Worku *et al*., 2018
RACMO22	Koninklijk Nezerlands Meteorological Institute (KNMI)	ICHEC-EC-EARTH	Europe	Samuelsson *et al*., 2015
RCA4	Sveriges Meteorologiska och Hydrologiska Institute (SMHI)	MPI-M-MPI-ESM-LR	Germany	Worku *et al*., 2018
CanRCM4	Canadian Centre	CCCMa-	Canada	Musie *et al*., 2020

	for Climate Modelling and Analysis (CCCMa)	CanESM2

3.5.3.1. Statistical Bias Correction Techniques

It is obvious that RCM model outputs have biases, making it difficult to use them directly for climate and hydrological impact studies. Several researchers suggested applying bias correction and the use of ensemble mean are important to reduce errors of RCM outputs (Christensen *et al*., 2008; Teutschbein and Seibert 2010; Kim *et al*., 2014; Nikulin *et al*., 2012). Statistical downscaling method (SDSM) is the most known methods used in climate change studies now adays (Gebrechorkos *et al*., 2019). Statistical downscaling is computationally inexpensive, has standard and accepted statistical procedures and is able to directly incorporate the observational record of the region.

A number of studies indicate that the SDSM yields reliable estimates of extreme temperatures, seasonal precipitation, and inter-site precipitation behavior (Wilby and Dawson, 2013; Tesfaye *et al.*, 2014; Wilby *et al*., 2002). It is adopted in this study due to the reason that it could give climate scenarios based on a statistical relationship between climate variables at one or more GCM grid points at a particular site of interest (Nilawar and Waikar, 2019; Dlamini *et al*., 2017). Consequently, the statistical downscaling and bias correction process has been used for the simulation of precipitation and temperature before using CORDEX-RCM outputs for the climate impact modeling.

The study used CMhyd software (Climate Model Data for hydrologic modeling) to extract CORDEX-NetCDF data and Delta-Change bias correction method to the variables listed above for predicting climate change-induced hydrosediment responses of Maybar watershed. CMhyd is a tool that can be used to extract and bias-correct data obtained from global and regional climate models (Rathjens *et al*., 2016). It was designed to provide simulated climate data that can be considered representative for the location of the gauges used in a watershed model setup. The principal idea is to identify biases between observed and simulated historical climate variables to parametrize a bias correction algorithm (Fig. 5) that is used to correct simulated climate data (Rathjens *et al*.,2016). Therefore, climate model outputs have been tested for the ability of overlapped historical data to reproduce observed climate data (Teutschbein and Seibert, 2012).

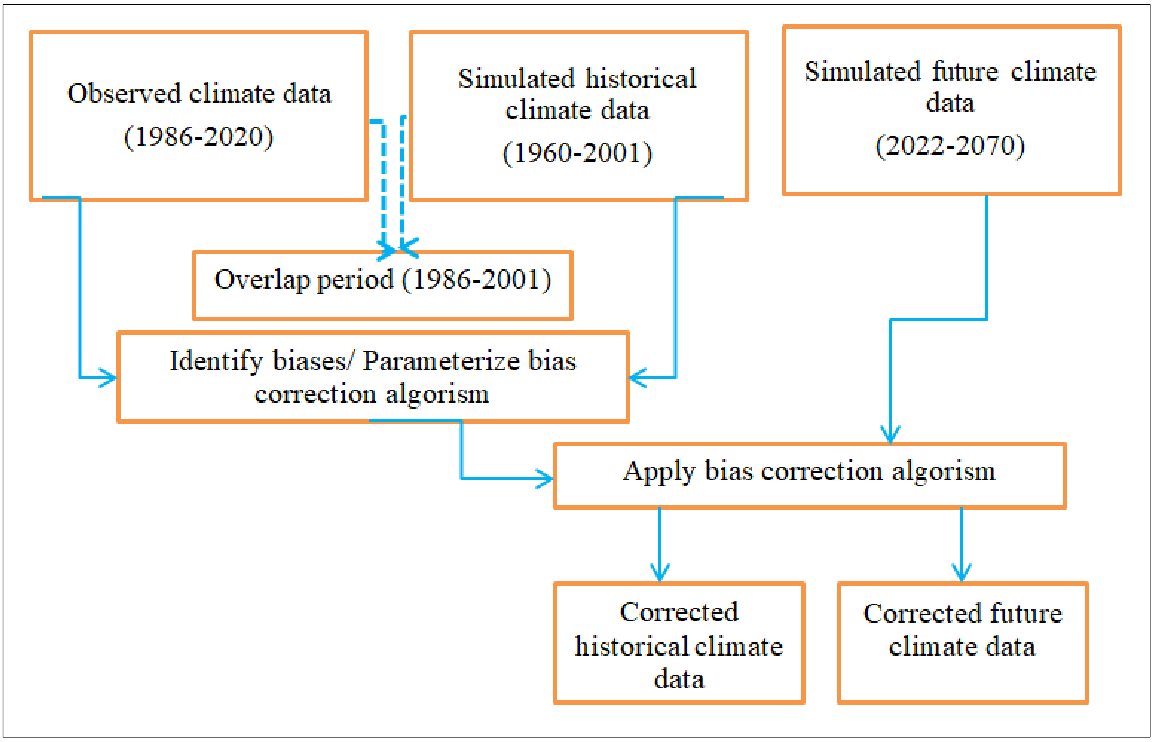


Figure 5. Bias Correction Framework

4. RESULTS AND DISCUSSION

4.1. Spatial Maps of the Model Parameters

4.1.1. Topographic Map

The digital elevation model (DEM) has been used to describe the topography and the geometry of the basin and subbasins. The spatial distribution of erosion is highly dependent on topographic characteristics of an area (Moore and Burch, 1986). Steeper slope causes higher runoff velocities, more splashes downhill and faster flow and therefore contributes greater soil erosion (Morgan, 2009; Zingg, 1940). The topographical elevation of the watershed ranges from 2530 to 2857 masl. The minimum, mean, and maximum slopes are 0.04, 39.40, and, 134.15%, respectively. Just about 65.81% of the watershed is represented by steep (30-50%) and extremely steep (>50%) slopes and the remaining 34.19% represents flat to moderately sloping slope class (Fig. 6 and Table 3).

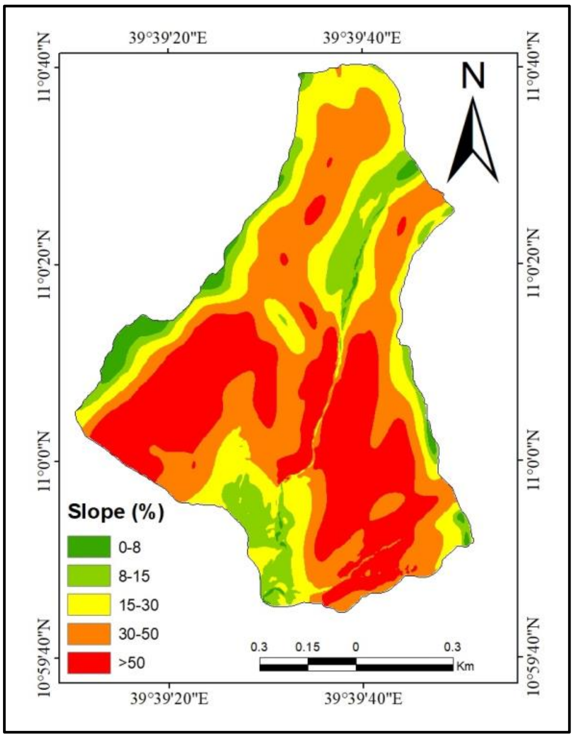


Figure 6. Slope map of Maybar watershed (the study area)

Table 3. Slope classification of Maybar watershed

Slope class	Description	Area coverage	
		(ha)	(%)
0-8	Flat	2.99	2.63
8-15	Gently sloping	11.82	10.42
15-30	Sloping	23.97	21.14
30-50	Steep	39.58	34.90
>50	Very steep	35.06	30.91
Total		113.41	100.00

4.1.2. Soil Map

Soil types of Maybar watershed with their area coverage is illustrated in Fig. 7 and Table 4. The distribution of soil types in the study watershed was digitized from a soil map of Maybar watershed developed by weigel (1986). This digitization process of the soil map was resulted seven soil types. These soils, according to the FAO classification system mainly, are Mollic Gleysols, Haplic Phaeozems, Eutric Fluvisols and Eutric Regosols. More than half of the catchment area which is about 64.1% is covered by shallow Phaeozems (soil depth 0-50 cm, with an average of around 15 cm). The remaining three (Gleysols, Eutric Fluvisols and Eutric Regosols) covers small proportion which is 8.19% of the total area of the watershed.

Table 4. Soil types of Maybar watershed and their descriptions

Soil mapping code in SWAT	Soil type description	Texture	Area coverage	
			(ha)	(%)
Gm	Mollic Gleysols, within shallow water table	Clay	3.14	2.77
Hh1	Haplic Phaeozems, very shallow (10–25 cm deep)	Sand clay loams	48.21	42.51
Hh2	Haplic Phaeozems, shallow (25–50 cm deep)	Clay loams	24.48	21.59

Hh3	Haplic Phaeozems, moderatley deep (50–100 cm)	Sand clay loams	16.68	14.71
Hh4	Haplic Phaeozems, deep to very deep (>100 cm)	Sand clay loams	14.75	13.01
Je	Eutric Fluvisols, >100 cm deep	Clay loams	4.07	3.59
Re	Eutric Regosols, 10–100 cm deep	Clay	2.08	1.83
Total			113.41	100.00

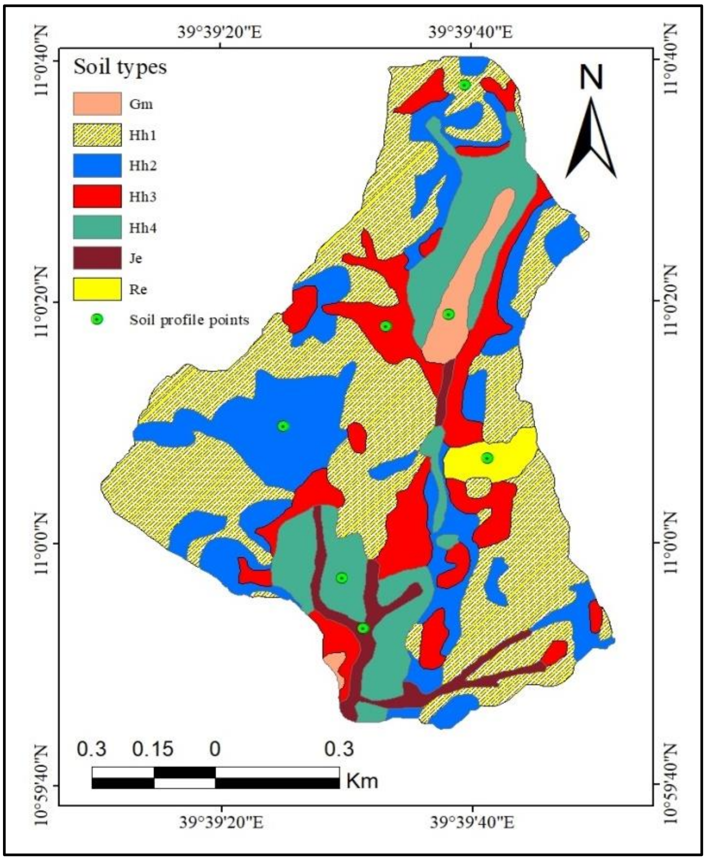


Figure 7. Soil map of Maybar watershed (the study area)

4.1.3. Land Use/Land Cover Maps

Land use land cover map of the watershed was prepared by digitizing the featres on the google earth and actual field visits. Six major land use and land cover types were identified in the watershed; these includes agricultural land, barren land, mixed forest, settlement, range grass and scattered trees & brush. The agricultural land and mixed forest land use types were constituted the largest proportion, which is 32.66% and 32.93% of the study watershed respectively. Range grass and scattered trees & brushes covered 10.17% and 11.72%, respectively. Bare land and settlement land use types were found minor land use types in the watershed representing only 6.24% and 6.28%, respectively. the area coverage for each land uses is illustrated in (Fig. 8 and Table 5).

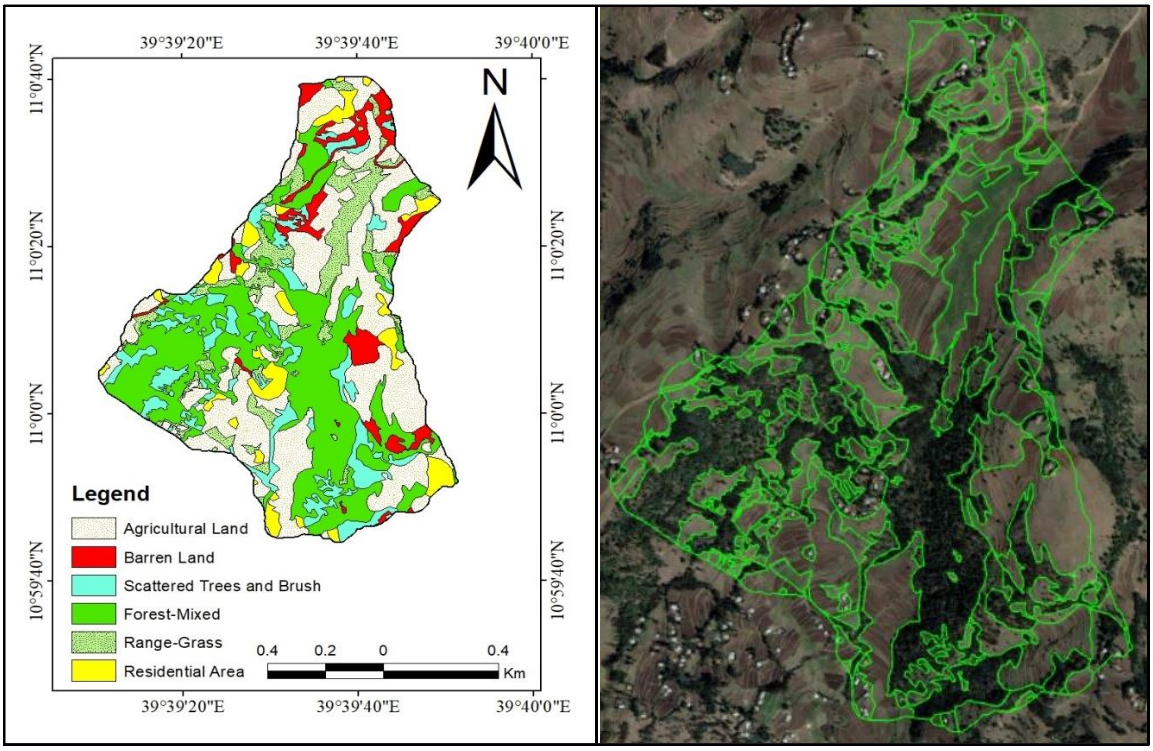


Figure 8. Land use land cover map of Maybar watershed (the study area)

Table 5. Land use/land cover classification of Maybar watershed

SWAT four letter code	Definition	Area coverage	
		(ha)	(%)
AGRL	Agricultural land	37.04	32.66
BARR	Barren land	7.08	6.24
FRST	Forest mixed	37.34	32.93
URBN	Residential area	7.13	6.28
RNGE	Range grass	11.53	10.17
RNGB	Scattered trees and brush	13.29	11.72
Total		113.41	100.00

4.1.4. Hydrologic Response Units (HRUs)

In this study we defined eight subbasins of 1.5, 14.2, and 24.3 ha minimum, mean and maximum areas, respectively in the watershed. Then the combination of soil/landuse/slope maps were overlaid to create a unique combination of HRUs by sub-basin. Finally, 532 HRUs (with an average area of 0.21 ha were created for the watershed (Fig. 9). The stream network, subbasins, outlet, and weather station feature classes are shown in (Fig. 1).

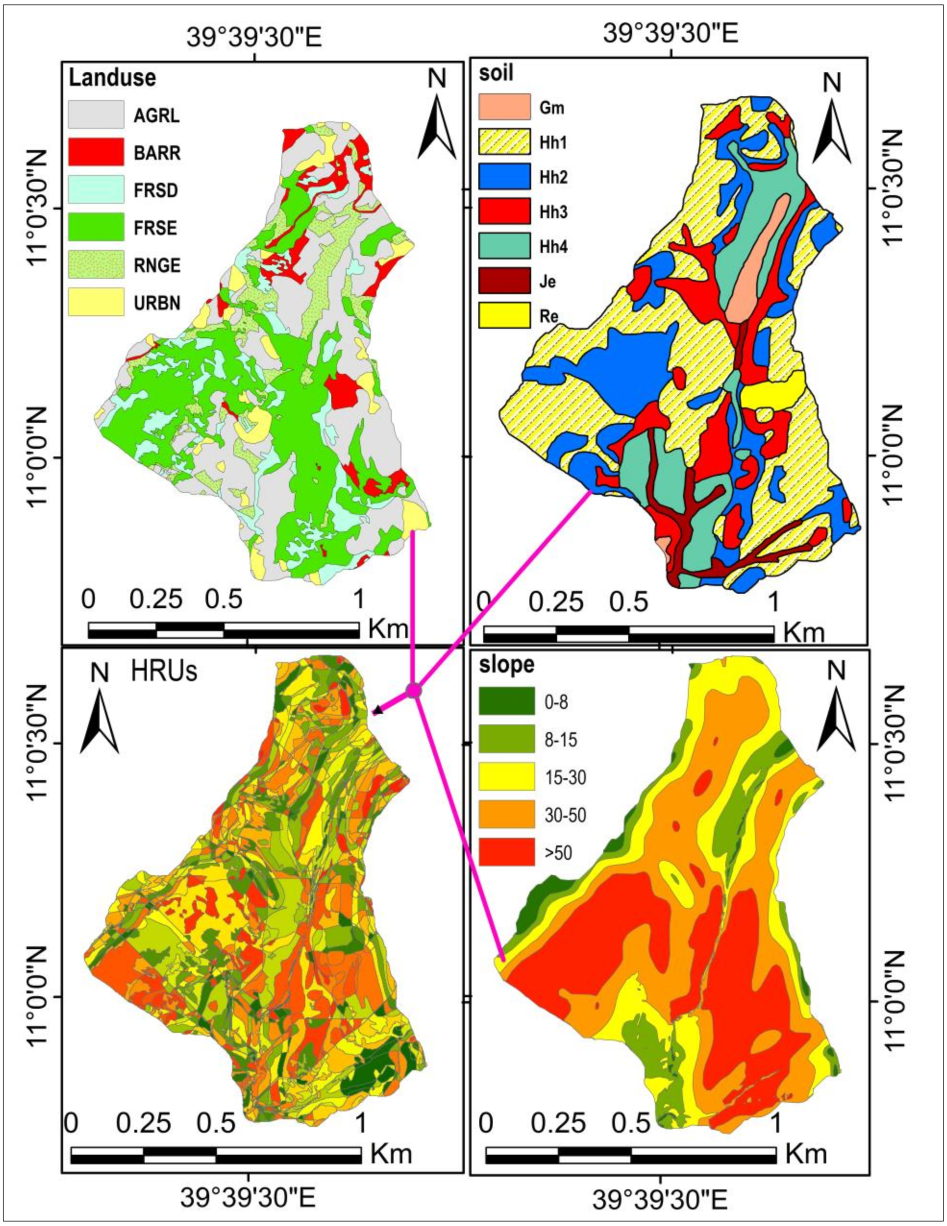


Figure 9. Slope, soil and land use combinations and created HRUs

4.2. Sensitive Flow and Sediment Parameters

Sensitivity analysis were performed considering 14 streamflow parameters and 7 sediment parameters (Table 6) using expert judgment and previous studies in the study region (yesuf *et al*., 2015; Lemma *et al*., 2019; Gashaw *et al*., 2018). SUFI-2 (Abbaspour *et al*., 2007) calibration and uncertainty algorithm, which is linked to SWAT-CUP-2012 version 5.1.5.4, was used to perform sensitivity analysis of parameters. A t-test was used to identify a measure of sensitivity of each parameter (larger in absolute values are more sensitive) and p-values were used to determine the significance of the sensitivity (a value close to zero has more significance) (Khalid, 2016).

Table 6. Sensitive streamflow and sediment parameters, their rank, and fitted values used for flow and sediment simulation

Variables	Parameter Name	Fitted Values	t-Stat	P-Value	Rank
Flow	r__CN2.mgt	-0.081	-2.83	0.00	1
	v__GWQMN.gw	2675.0	4.16	0.00	2
	r__SOL_BD().sol	-0.135	-5.32	0.01	3
	v__GW_DELAY.gw	127.50	1.94	0.06	4
	v__GW_REVAP.gw	0.17	-1.33	0.19	5
	v__ALPHA_BF.gw	0.06	-0.97	0.33	6
	r__OV_N.hru	0.01	-0.97	0.33	7
	v__RCHRG_DP.gw	0.26	0.90	0.37	8
	r__SOL_K().sol	0.128	-0.81	0.42	9
	v__SURLAG.bsn	17.65	-0.74	0.46	10
	r__SLSUBBSN.hru	0.09	-0.61	0.54	11
	v__REVAPMN.gw	42.50	0.30	0.77	12
	v__CH_K2.rte	17.49	0.23	0.82	13
	v__CH_N2.rte	0.126	0.15	0.88	14
Sediment	r__HRU_SLP.hru	0.17	1.63	0.00	1
	v__USLE_P.mgt	0.65	1.00	0.00	2
	r__USLE_C.plant.dat	0.15	-1.47	0.12	3
	v__USLE_K(..).sol	0.33	-0.07	0.14	4
	v__SPEXP.bsn	1.08	-1.30	0.19	5
	v__LAT_SED.hru	56.01	1.17	0.24	6
	v__SPCON.bsn	0.01	-1.57	0.94	7

The result showed that among the fourteen streamflow parameters considered for sensitivity analysis (Table 6), eight of them were found most sensitive. The five top-sensitive flow parameters from high to low sensitivity were CN2, GWQMN, SOL_BD, GW_DELAY, and GW_REVAP. The remaining three from high to low sensitivity were ALPHA_BF, OV_N and RCHRG_DP. On the other hand, among sediment parameters on which sensitivity analysis was employed, seven of them were sensitive to sediment output. Of these, the five highest-sensitive sediment parameters in the order of their sensitivity were HRU_SLP, USLE_P, USLE_C, USLE_K and SPEXP. The remaining two sensitive-sediment parameters were LAT_SED and SPCON.

4.3. Calibration and Validation Results

Auto-calibration and validation of streamflow and sediment (2001–2014) using SUFI-2 procedure were performed by comparing the measured and simulated streamflow and sediment yield in the hydrometric stations considered (Fig. 10 and Fig. 12). Autocalibration method was employed as suggested by Van Liew *et al*. (2005) that autocalibration option in SWAT provides a powerful, time saving tool that can be used to substantially reduce the frustration and subjectivity that often characterize manual calibrations. The graphical comparisons of observed and simulated streamflow showed that the model has captured observed low and high flows very well in the calibration and validation periods (Fig. 10).

Scatter plots that illustrate the consistency of observed and simulated flows during the calibration and validation periods (Fig. 11) also demonstrate good simulation of the model in the watershed. In terms of model performance statistics (Table 7), NSE of 0.72 and 0.69, PBAIS -13.0% and -10.0% were achieved during the calibration and validation periods, respectively.

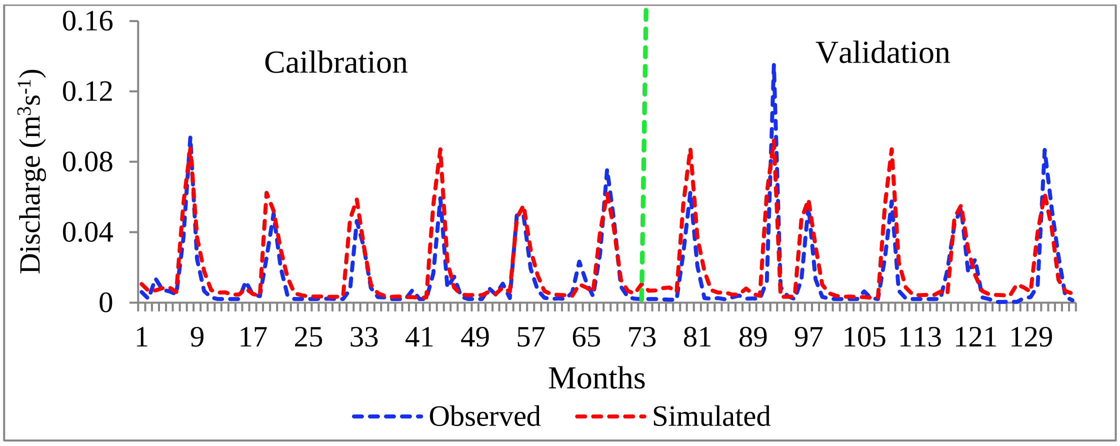


Figure 10. The monthly flow hydrograph in the calibration and validation periods

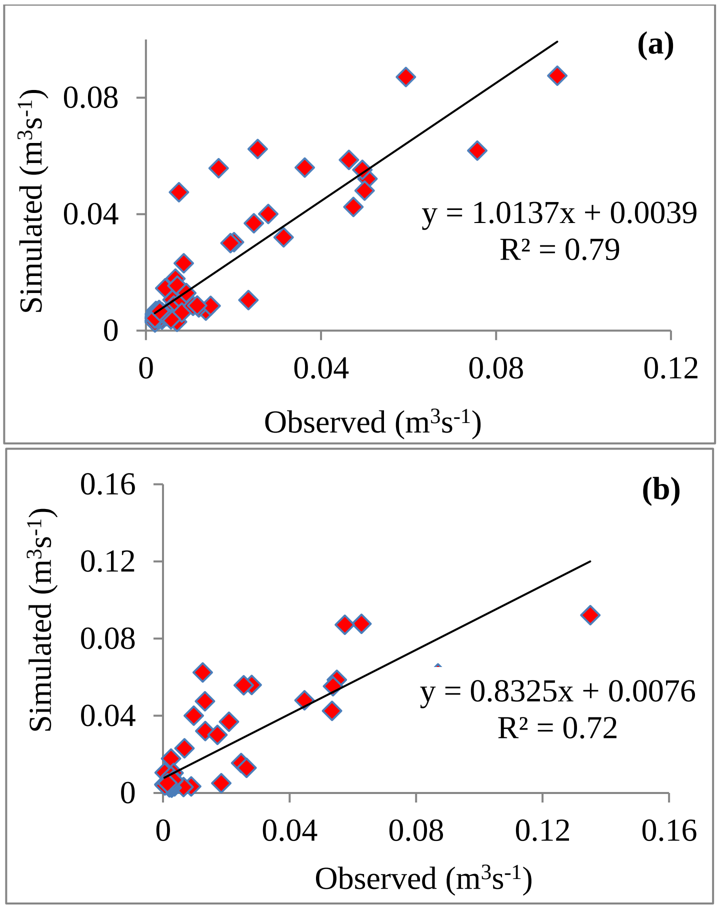


Figure 11. Scatter plot of the observed and simulated monthly flow in the calibration (a) and validation (b) periods

The R^2 values during the two simulation periods were also higher than 0.70 (Table 7). The model performance can be evaluated as 'satisfactory' if $R^2 > 0.5$, NSE > 0.5 and PBIAS in the range of ±25 (Santhi *et al*., 2001; Van Liew *et al*., 2003; Moriasi *et al*., 2007) for the evaluation of the stream flow monthly time steps.

In relation to sediment, both the hydrograph (Fig. 12) and the scatter plot (Fig. 13) of observed and simulated sediment yield illustrate the acceptable simulation of the SWAT model during the two simulation periods. In terms of performance measures, NSE of 0.67 and 0.64, PBAIS of -18.0% and -21.0% and R^2 of 0.69 and 0.66 were achieved during the calibration and validation periods, respectively (Table 7). Model performance can be evaluated as 'satisfactory' if R^2 and NSE > 0.50 (Santhi *et al*., 2001; Van Liew *et al*., 2003) and ±30 ≤ PBIAS < ±55 (Moriasi *et al*., 2007) for the evaluation of the monthly time step sediment yield.

Table 7. Model performance statistics of streamflow and sediment during calibration (2001-2006) and validation (2009-2014) periods

Simulated variables	Simulation period	Objective function values		
		R^2	PBIAS (%)	NSE
Discharge	Calibration	0.79	-13	0.72
	Validation	0.72	-10	0.69
Sediment	Calibration	0.69	-18	0.67
	Validation	0.66	-21	0.64

Comparing the average monthly values of measured and predicted stream fow and sediment load, the model over predicted by 10 % and 21% respectively for validation periods. The sediment yield calibration result in this study indicated better statistical performance than the study conducted by Yesuf *et al*. (2015). The performance variation might attributed to hydrologic simulation period's and data quality because the former researcher reported it.

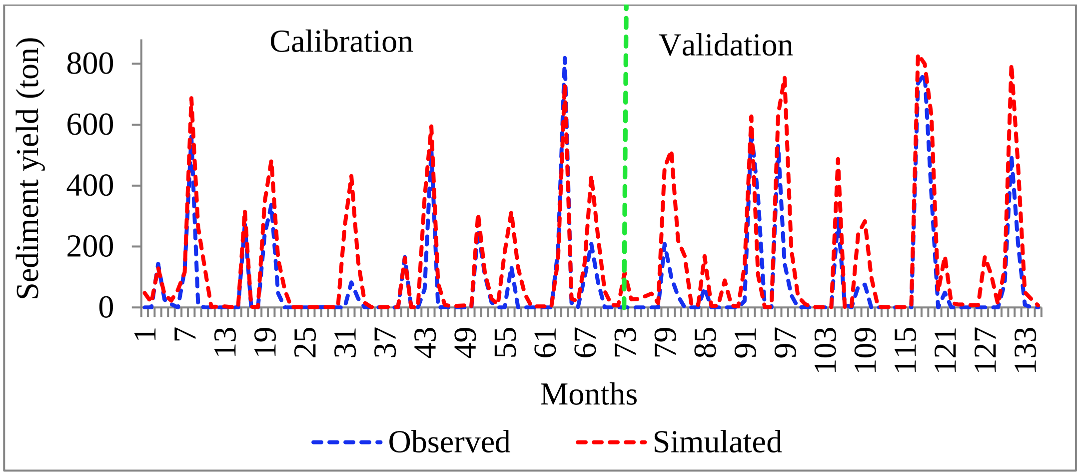


Figure 12. Monthly sediment yield hydrography of the Maybar watershed during the calibration and validation periods

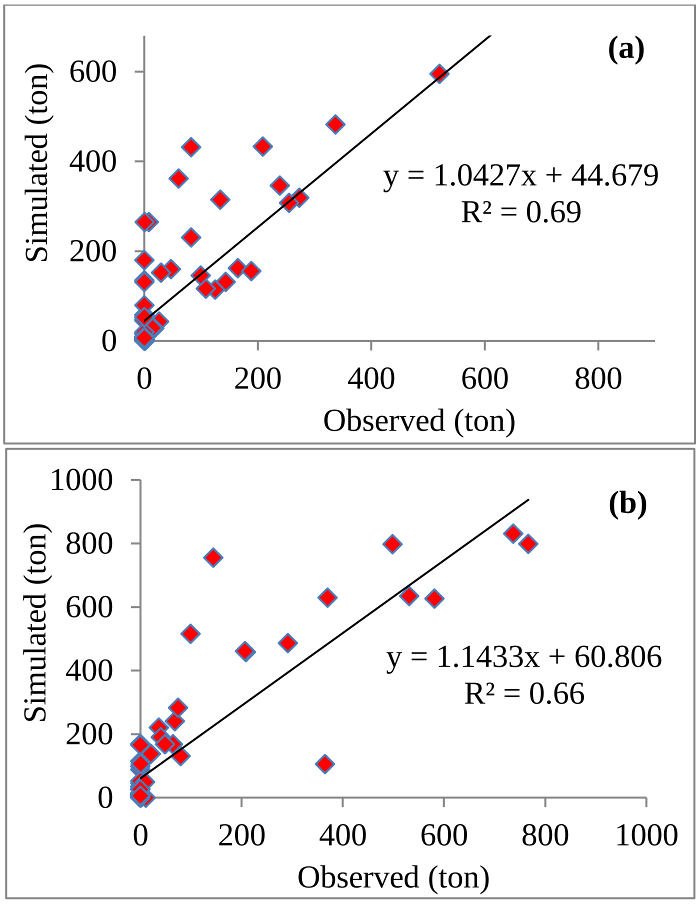


Figure 13. Scatter plot showing the monthly observed and simulated sediment yield during the calibration (a) and validation (b) periods

4.4. Impact of Climate Change in the Watershed

4.4.1. RCM Performances and Projected Climate Variables

Performances of RCM outputs for mean monthly basis against the observed climate data has been employed. In addition statistical bias-correction of the model output was also been conducted for precipitation, maximum/minimum temperature prior to use future scenario data for this study purpose. The results of the model before and after bias correction were correlated with the observed data of maximum and minimum temperature using simple statistical measures. All bias correction has improved the simulation of precipitation and temperature before using CORDEX-RCM outputs for climate impact modeling.

4.4.2. Performances of RCM Outputs for Precipitation

The performance of the model for reproducing observed data in monthly basis has been tested by constructing the scatter plots. Raw RCM outputs were substantially biased from observed data. After doing statistical bias correction, results showed that the simulated RCM rainfall data captured the distributions of the mean monthly observed rainfall for the study area (Fig. 15), although there was a very slight underestimation in April and August with that of the model results (78.47 mm, 295.09 mm) and observed (91.60 mm, 309.0 mm) for April and August, respectively. The scatter plot (Fig. 14) showed a better goodness of fit between observed and bias-corrected RCM (0.99), and relatively low agreement against the raw RCM (0.93). The monthly average, minimum, maximum, and standard deviation of each situation have also been calculated (Table 8). The average monthly value for observed, simulated and raw RCM were (100.54 mm, 101.13 mm and 96.80 mm) respectively.

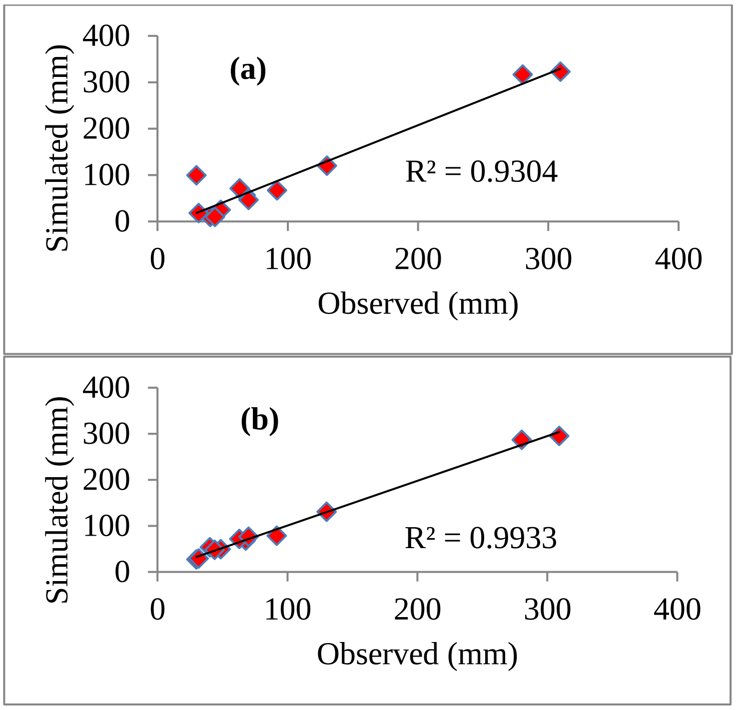


Figure 14. Average monthly precipitation scatter plot before bias correction (a) and after bias correction (b) for the observed and simulated historical periods

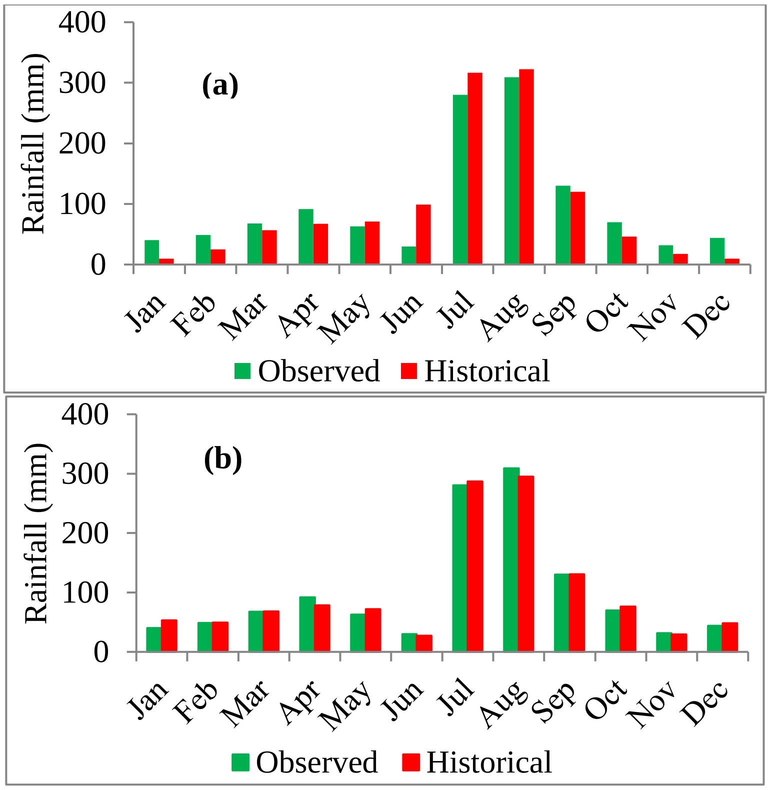


Figure 15. Average monthly precipitation before bias correction (a) and after bias correction (b) for the historical periods observed and simulated

Most research reports advised that to achieve better performance of climate models it is best to take the ensemble mean of the models (Rientjes *et al*., 2018; Alemseged and Tom, 2015). Therefore, using the ensemble average of the RCM might be the reason for achieving this better reproducing performance for this study. The biases in the raw rainfall data in general were substantially reduced after the bias correction was applied (Fig. 15).

Table 8. Statistical measures of the monthly precipitation model output, simulated and observed data sets

	Min	Max	StDev.	Mean	R^2
Observed	29.94	309.18	95.07	100.54	
Simulated	27.04	295.09	92.68	101.13	0.99
Model output	9.50	322.61	109.64	96.80	0.93

Min, (minimum) Max, maximum StDev, standard Deviation

4.4.3. Performances of RCM Outputs for Temperature

Figure 16 compares the raw RCMs outputs of monthly maximum/minimum temperature and bias-corrected RCMs with the corresponding observed data set using the coefficient of determination (R^2). The result showed that the raw outputs of the RCMs had substantial biases or in-agreement compared to the observed data (Fig. 17). For example, a large in-agreement between raw RCM maximum temperatures (R^2, 0.10) was obtained during raw RCM comparison against the observed. Therefore, bias correction was applied and substantially reduced biases for both maximum and minimum temperatures. For example, the R^2 value (0.1) and (0.94) for maximum and minimum temperature, respectively, was improved to a perfectly agreed value of 1. The result is in line with (Mengistu *et al*., 2021) that proved bias-corrected climate data resulted in a better representation of temperature than the rainfall, though indicating greater model performance still exists in model simulated rainfall in this study.

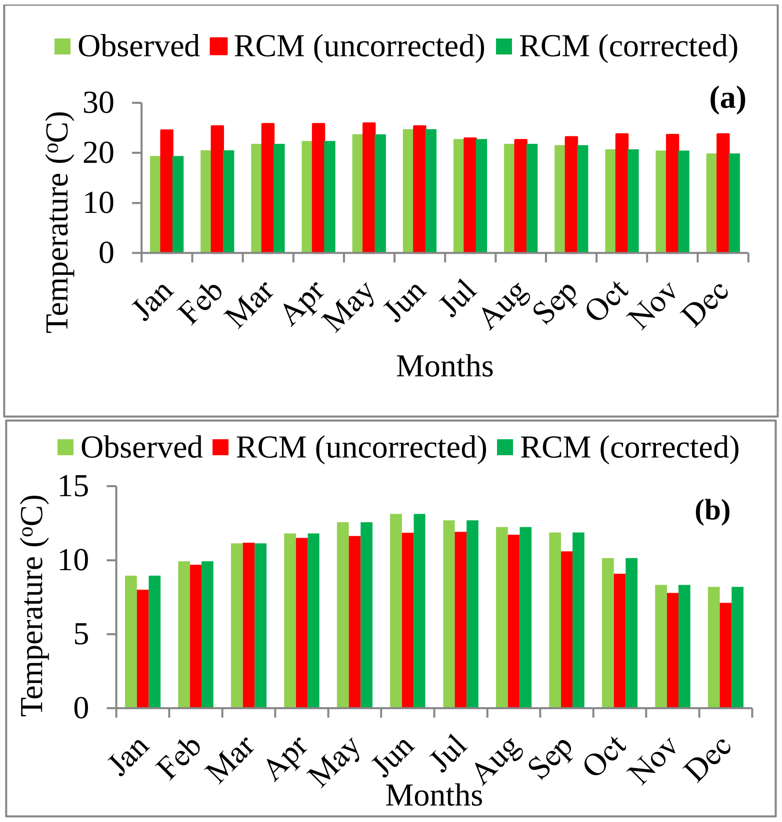


Figure 16. Comparison of bias corrected and uncorrected RCM data of the monthly average maximum temperature (a) and the minimum temperature (b)

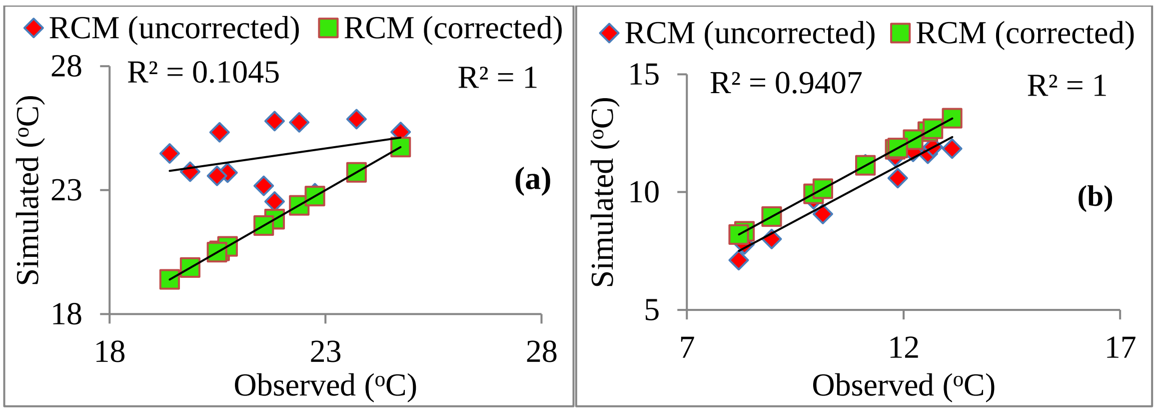


Figure 17. Average monthly maximum temperature (a) and minimum temperature (b) scatter plot for the observed and simulated historical periods

4.4.4. Projected Climate Scenarios for Precipitation

4.4.4.1. Annual Precipitation

The statistical bias correction method was used to simulate precipitation for the future period (2022-2070) under RCP 4.5 and RCP 8.5 scenario. The result showed an increase in long term annual average precipitation in the watershed by 18.71 and 22.33 percent for RCP 4.5 and RCP 8.5 respectively (lustrated in Table 9). This result agrees with the previous studies conducted in other parts of Ethiopia, Future soil loss in highland Ethiopia under changing climate and land use by (Moges *et al*., 2020), downscaling of future Temperature and Precipitation extremes in central Ethiopia under Climate by (Feyisa *et al*., 2018) using baseline and future periods for both emission-scenarios.

4.4.4.2. Seasonal Precipitation

The average precipitation changes for RCP4.5 and RCp8.5 from baseline has also been analyzed on a Seasonal basis (Fig. 18). The highest seasonal precipitation change value is 40.66% under RCP8.5 and 24% under RCP4.5 in the fall season. Similarly, it is also expected to increase in summer season by 17.33% and 38.66% under RCP4.5 and RCP8.5 scenarios respectively. However, specifically for spring, the prediction falls to -4.66% for RCP4.5 and -5.33 for RCP8.5 emission scenarios. The decreasing behavior of precipitation in spring season might be attributed to higher temperatures effect to a general decrease of environmental moisture that contributes atmospheric water vapors and to a decrease in precipitation. Although it is still not too low under RCP8.5, the lowest change is in the winter season, for which a value of 5.33% (RCP4.5) and 17.66% (RCP8.5).

Table 9. Change in the average annual rainfall amount (mm) of the future period relative to the base period under the RCP 4.5 and RCP 8.5 emission scenarios

Scenarios	Baseline	Future period	Relative change in %
RCP 4.5	1213.58	1440.67	18.71
RCP 8.5	1213.58	1484.58	22.33

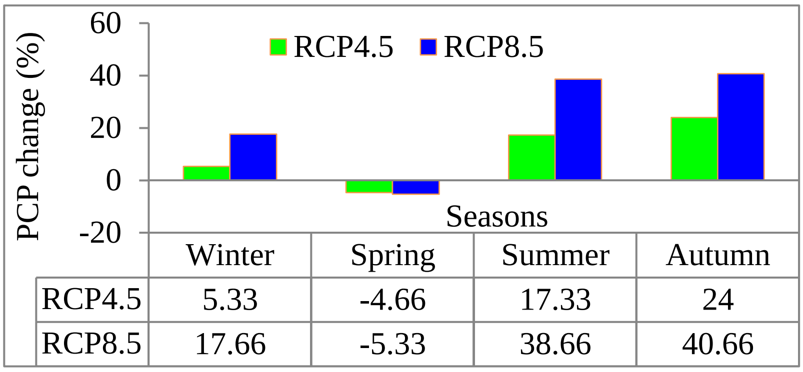


Figure 18. Seasonal change rates of precipitation from the baseline climate dataset for RCP4.5 and RCP8.5 emission scenarios

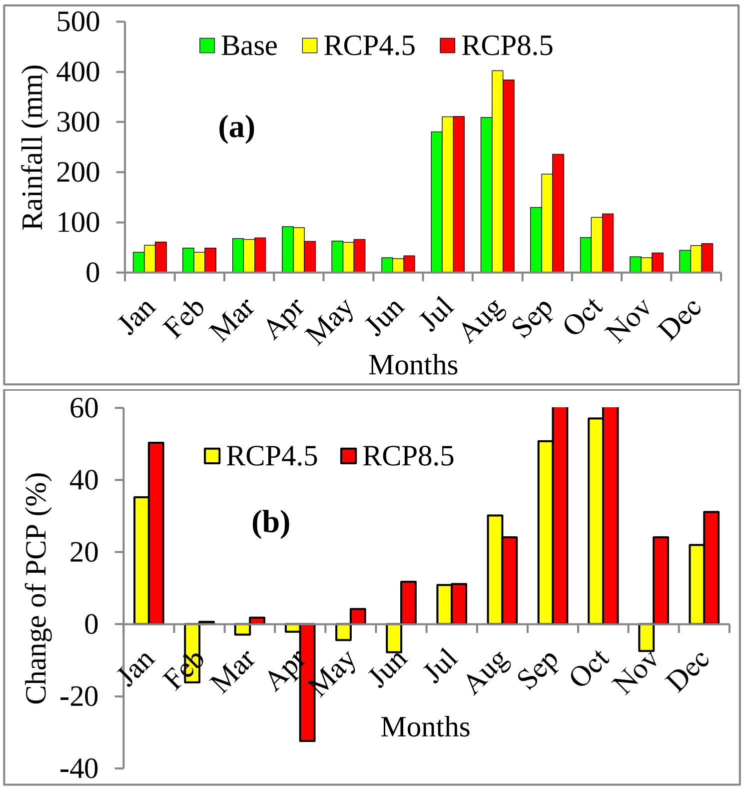


Figure 19. Average observed monthly precipitation for baseline condition, RCP4.5, & RCP8.5 scenarios (a) and Predicted relative changes (percent of baseline levels) in monthly precipitation for RCP4.5 & RCP8.5 (b)

4.4.4.3. Monthly Precipitation

The simulated data of mean monthly precipitation analyzed with the baseline period to find future changes of precipitations also indicated incremental changes in the precipitation amount. Except for the RCP8.5 scenarios in April (-32%) and RCP4.5 in February (-16%) the decreased change, both scenarios predicted precipitation increases (Fig. 19). The projected mean monthly rainfall for this study has a similar pattern to that of the work of climate change impact on sediment yield in the upper Gilgel Abay catchment, Blue Nile Basin, Ethiopia by Adem *et al*. (2016). This work agrees with our study on mean monthly relative rainfall decreases in February, March, and April where as big increamental changes in September and October compared to the baseline period.

4.4.5. Projected Climate Scenarios for Temperature

The monthly temperature of the basin varies from 11 ° C to 22 ° C, with an average of 16.5 ° C. We predicted the long-term average temperature with the historical data for two climate emission scenarios. As shown in (Fig. 21 and Fig. 22), monthly temperatures pointedly increased in all future scenarios compared with the baseline period, and RCP 8.5 led to a most remarkable increase for maximum temperature and RCP4.5 for minimum temperature but they are not significantly different for their long-term mean values. May and June were the warmest months in the baseline period and similarly for future climatic conditions of the catchment (Fig. 21).

The model also predicted that the minimum and maximum temperatures would increase by 3.51 and 2.0 °C (32.18 and 9.25%) under RCP4.5 and by 2.18 and 2.79 °C (19.94 and 12.89%) under RCP8.5 respectively (Fig. 20). This finding is in line with previous studies that projected increasing temperatures in other parts of Ethiopia (Abera *et al*., 2018; Kassie *et al*., 2014; Fentaw *et al*., 2018). The predicted long-term annual average temperatures trend in the mid-term (2022–2070) for RCP8.5 and RCP4.5 scenarios is illustrated in figure 22 and showed a slight increase from their respective long-term mean temperature.

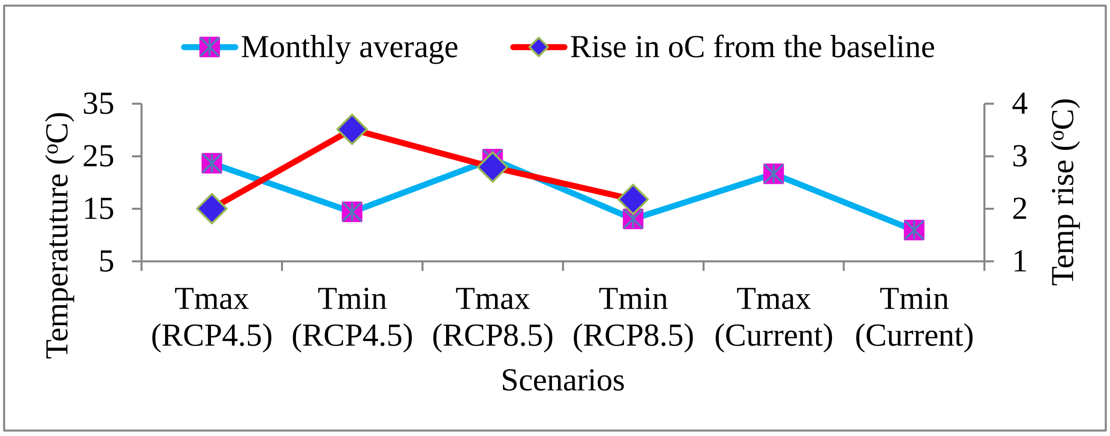


Figure 20. long-term mean of maximum and minimum temperatures for future and current scenarios with the rising magnitude of future scenarios from the baseline period

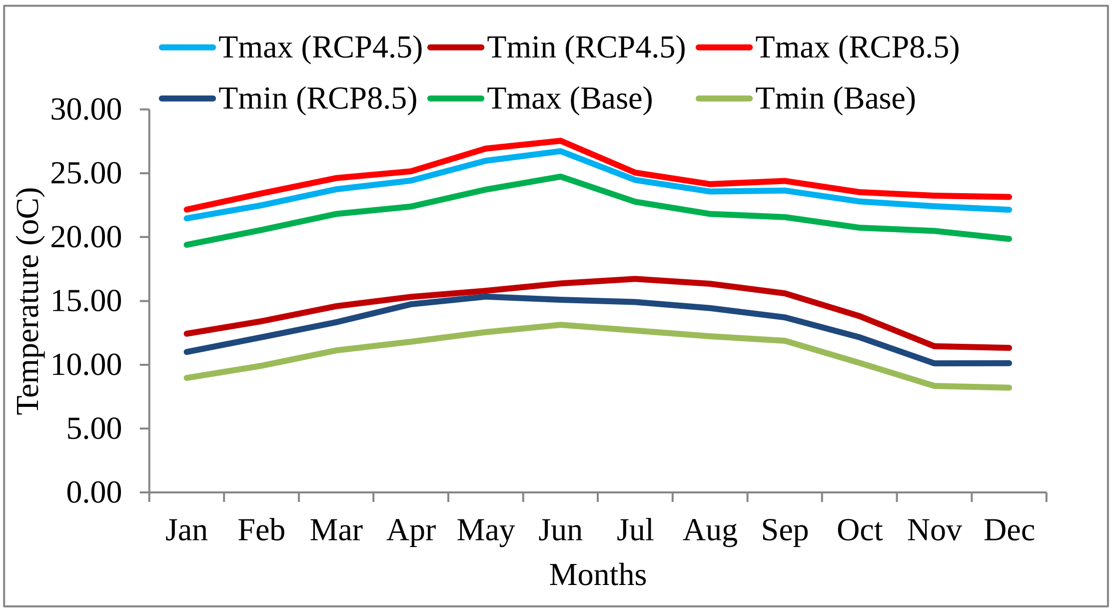


Figure 21. Comparison of mean temperatures for baseline data, RCP4.5, & RCP8.5 scenarios of the bias corrected outputs

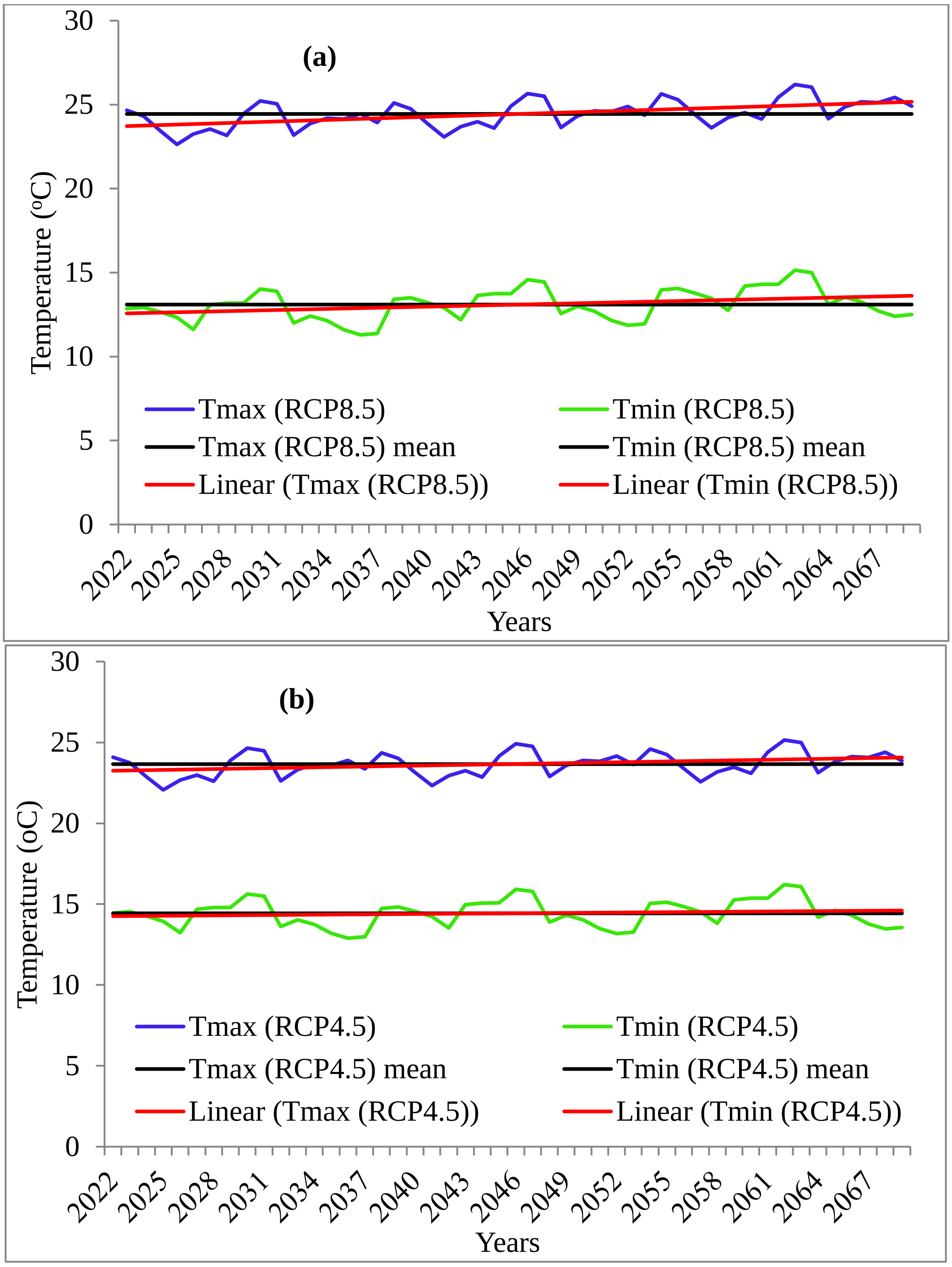


Figure 22. Projected annual average temperature trend in the mid-term (2022–2070) for RCP8.5 (a) and RCP4.5 (b)

4.5. Hydro-sediment Responses to Management Alternatives

The verified model was used to simulate an independent potential impacts of management alternatives on the hydrosediment response of the watershed. In adition, the effects of management alternatives under beseline and future climate change scenarios in response to discharge and sediment yield of the watershed have been evaluated.

4.5.1. Effect of Management Practices on Stream Flow

4.5.1.1. Under Current Climatic Conditions

Terracing operaton supported by filterstrips (Fig. 23a), conservation tillage (Fig. 23b), contouring (Fig. 23c) and landuse change management options (Fig. 23d) were evaluated in comparison with terracing alone and no-terrace (worest-case scenario). The result showed a decrease in the peak flows and increase in low flows among all management alternatives compared to the no-terrace scenario. Low surface runoff is induced by an increase in vegetation/canopy cover as a result of increased mixed forest and by structural conservation measures such as terrace (Gabiri *et al.*, 2019). In contrast, a review study by Guzha *et al*. (2018) on the impact of land use and land cover changes on surface runoff and annual discharge in East Africa reported that loss of forest/vegetation cover led to increased surface runoff and peak discharge. As shown in Figure (23), flow during the peak flow time increased to 0.074 m^3s^{-1} and the low flow decreased below 0.014 m^3s^{-1} when terrace was not implemented in the catchment; in contrast, the terracing practice lowers the runoff-induced peak flow to 0.06 m^3s^{-1} while improving the dry low flow behavior to 0.018 m^3s^{-1}.

In addition to this, the terracing efficiency of reducing runoff induced peak flow behaviors was being improved when supported by other management alternatives although their was a performance variation among them. The management practices listed above were performed well to reduce the peak flow than improving hydrologic flow behavior during the dry seasons. The peak flow was slightly lowered from 0.06 m^3s^{-1} for terracing alone to

0.055 m^3s^{-1} when the terrace was supported by the land use change management option and a very slight reduction in terracing with conservation tillage (0.057 m^3s^{-1}). The low performance of conservation tillage to manage aggressive flows might attributed to the duration of simulation years due to the fact that it takes longer to improve the soil system. In general, the effect of terrace to influence discharge was more visible than other management practices; though practicing these options integrated with terrace structure was found to be advantegious to improve discharge behavior either in wet seasons or dry periods due to an evident effect clearly shown on the observed results.

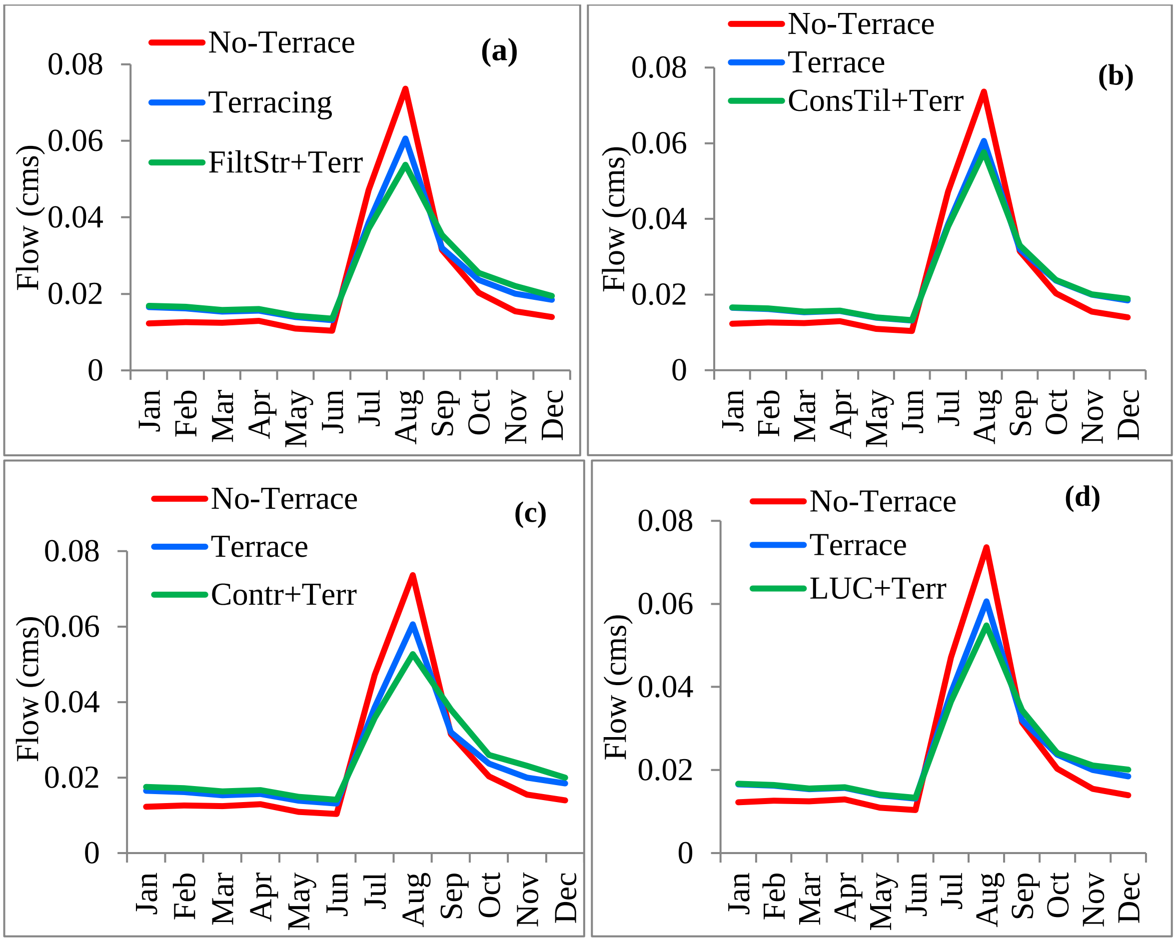


Figure 23. Monthly average discharge (cubic meter per second-cms) of different management scenarios under current climatic conditions compared with the worst case (no-terrace) scenario

4.5.1.2. Under Future Climatic Conditions (Terrace & No-Terrace Scenarios)

The climate change effect on discharge under terrace and no-terrace conditions has been analyzed. After performing the model goodness-of-fit using necessary statistical techniques, future daily rainfall and temperature (minimum and maximum) from CORDEX for Ethiopia under the RCP4.5 and RCP8.5 emission scenarios were used as climate forcing for the SWAT model (to start with the impact of climate on flow and sediment). Thus, the potential impact of climate change scenarios on the hydro-sediment response of the watershed was evaluated by running SWAT over the mid-future time horizon (2022-2070) with parameters calibrated over the baseline period.

The simulated monthly discharge obtained by implementing the outputs of the climate models in the Maybar watershed is shown in Fig. 24. The result showed that the predicted discharge coincides with the projected precipitation. The simulated monthly average discharge values based on RCP4.5, RCP8.5 and the baseline were 0.030 m^3s^{-1}, 0.031 m^3s^{-1} and 0.023 m^3s^{-1} respectively. The simulated values for RCP4.5 and RCP8.5 are a bit close to each other, while their deviation from the baseline is 29.78% for RCP4.5 and 34.49% for RCP8.5. The monthly variation in stream flow under the future climate scenarios was consistent with the predicted precipitation, while the effect of predicted temperature has a slight influence. For example the temperature around May and June is expected to be warmer for both RCP emission scenarios and consequently, it seems that discharge from these RCP's is declined from the base within the same periods.

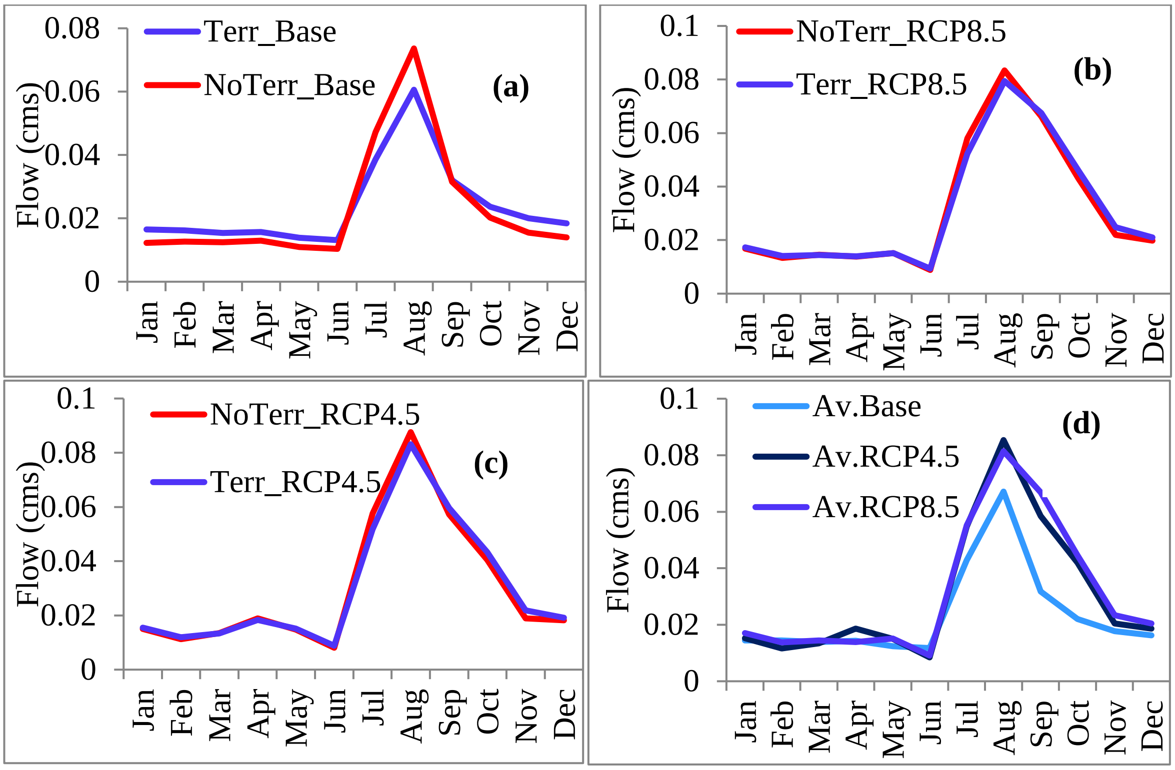


Figure 24. Monthly averages of simulated baseline (a), future RCP4.5 (c), RCP8.5 (b) and average discharge (cubic meter per second-cms) (d) under Terrace/No-terrace conditions

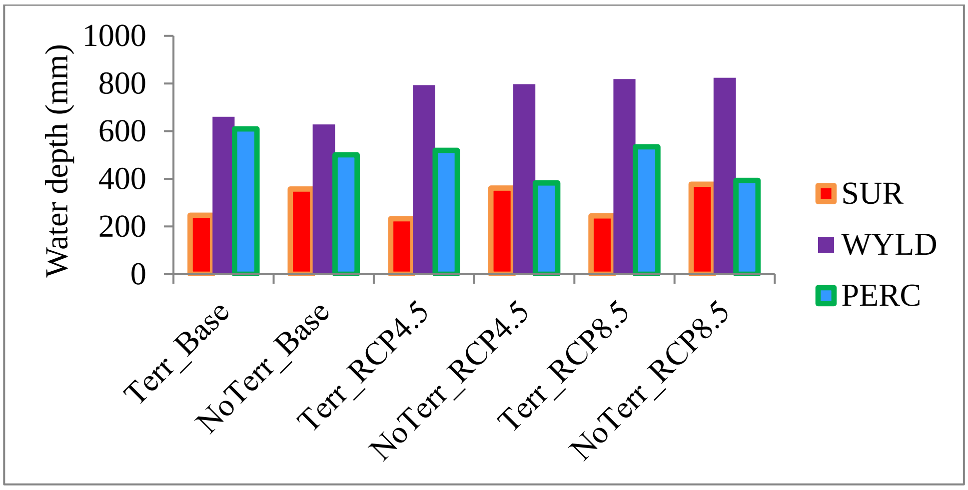


Figure 25. Annual averages of surface (SUR), total water yield (WYLD) and percolation (PERC) depth (mm) for baseline and future climate scenarios considering terrace/no-terrace operation

In general, the finding was found to agree with previous studies by Tekalign *et al*. (2018) Catchment response to climate and land use changes in the Upper Blue line, which supported our discovery that showed the hydrology of the catchment would be dominated by changes in rainfall than by temperature. As is evidently shown from Fig. (24d) the flow under the RCP4.5 and RCP8.5 emission scenarios is expected to have an incredible increase around the end of August to November. Then after the autumn season they tends to sease and continue with a slight overriding hydrologic behavior of the future scenrios over the baseline. The peak flow during August (0.085 m^3s^{-1}) and a rise (0.0186 m^3s^{-1}) in April under RCP4.5 was observed and after September RCP8.5 tends to take over the high flow hydrologic behavior. This was attributed to the consistent variation of rainfall behaviors for both RCP emission scenarios (Fig. 19). Although the influence of temperature appears to be dominated by rainfall, it should not be completely ignored. Temperature would probably be responsible for the behavior of dry period average streamflow for future climatic scenario to respond either decrease or remain unchanged mainly due to temperature-induced higher evapotranspiration.

On the other hand, The effect of terracing through the adjustment of the SWC parameters pertaining to the SWAT terracing operation was evaluated. For the reference model, these parameters (TERR_SL, TERR_P, TERR_CN) were adjusted for the different HRUs according to their soil, land use, and slope considering the appropriate terracing years (Bosshart, 1997; Herweg and Ludi, 1999; Williams *et al.*, 1988). Then present and future climatic scenarios have been evaluated under terracing and no-terrace conditions. Prior to explaining climate change impacts on discharge; the terracing effect under the current climate was established (Fig. 23a). The discharge was substantialy influenced by terracing operation for wet and dry periods in different way. It was observed that discharge increased under terracing conditions during the periods from September to next June and no-terrace situation tends to increase the peak-flow during wet seasons (specifically July and August). The peaks during wet periods from no-terrace condition might attributed to the inability of the system to slowdown runoff. On the other hand the terracing operation was able to reduce runoff during wet periods and improve the system to infiltrate water to shallow aquifers and then able to yield greater water depth in dry periods. To make triangulations on specific hydrological components response to terrace; the depth of annual average surface (SUR), total water yield (WYLD) and percolation to the shallow aquifer (PERC) depth (mm) was investigated for baseline and future climate scenarios (Fig. 25).

The highest simulated annual water yield (660 mm) and percolation to shallow aquifer (609 mm) and reduced amount of surface runoff (247 mm) was obtained by implementing terraces on the crop fields for current climatic conditions. But, under the no-terrace system the obtained annual water yield, percolation to shallow aquifer and surface runoff were 629, 501 and 357 mm respectively. A decrease in summer discharges and increase in winter discharge under terracing operation compared with no-terrace conditions was found by Middelkoop *et al.* (2001); Hurkmans *et al*. (2010). The annual water yield for the future tends to be insignificant for both climatic scenarios while surface runoff was shown similar trend like the baseline climatic conditions. This might attribute to the intensity of future precipitation. The study results reflected that climate change under terracing conditions could increase high flows in the catchment during the dry seasons and could become high during wet periods for no-terracing conditions. So, the seasonal variation as explained above is more meaning-full and should be noted to see its impact and act possible counters than focusing on annual basis.

4.5.2. Effect of Management Practices on Sediment

4.5.2.1. Under Current Climatic Conditions

To fundamentally counteract soil erosion, it is necessary to identify the types of land use that are most prone to high rates of soil erosion (Zhang *et al*., 2010). This information is essential for the selection and implementation of appropriate conservation practices. Sediment yield in response to different management alternatives and their combined effect as erosion reducing strategy under current and future climatic scenarios heve been evaluated and illustrated in figures (26-30) with narations provided below.

The effect of each management scenarios on sediment yield under baseline climate is summarized in Figure 26 with visible data labels. Compared to the baseline, which is the existing condition without terrace, the watershed management alternatives showed a substantial impact on the sediment yields reduction in the catchment. The terracing management option reduced sediment yields by 64.23% compared to baseline, which caused about 34.5 t ha^{-1} yr^{-1} sediment yield on annual average basis. (Fig. 26a). The study by Shao *et al*. (2013) was also reported terracing reduces runoff and soil erosion considerably in the same way. The practice of contour farming with terrace has improved the sediment yield reduction efficiency from 64.26% (sole terracing) to 78.55%. It reflected that treating cultivated lands with terrace and contour farming can tremendously reduce the annual average sediment yield from 34.5 t ha^{-1} yr^{-1} to 7.4 t ha^{-1} yr^{-1}.

Treating the agricultural fields of the catchment with a 1 m wide vegetative contour strips integrated with the terrace reduced the sediment yield by 71.4%. In other way it means that reduced the watershed annual average sediment yield from 34.5 to 9.87 t ha^{-1} yr^{-1}. Land use change management with terrace scenario was also able to impact the catchment sediment yield by 76.76% (Fig. 26b) reduced from baseline. Though its impact is still shown (67.82%), conservation tillage with terrace was relatively lower than other management options. Mean annual sediment yield estimated in this study was found reduced after the application of all management options but the effect of terracing and contour farming takes the leading role of reducing sediment yield.

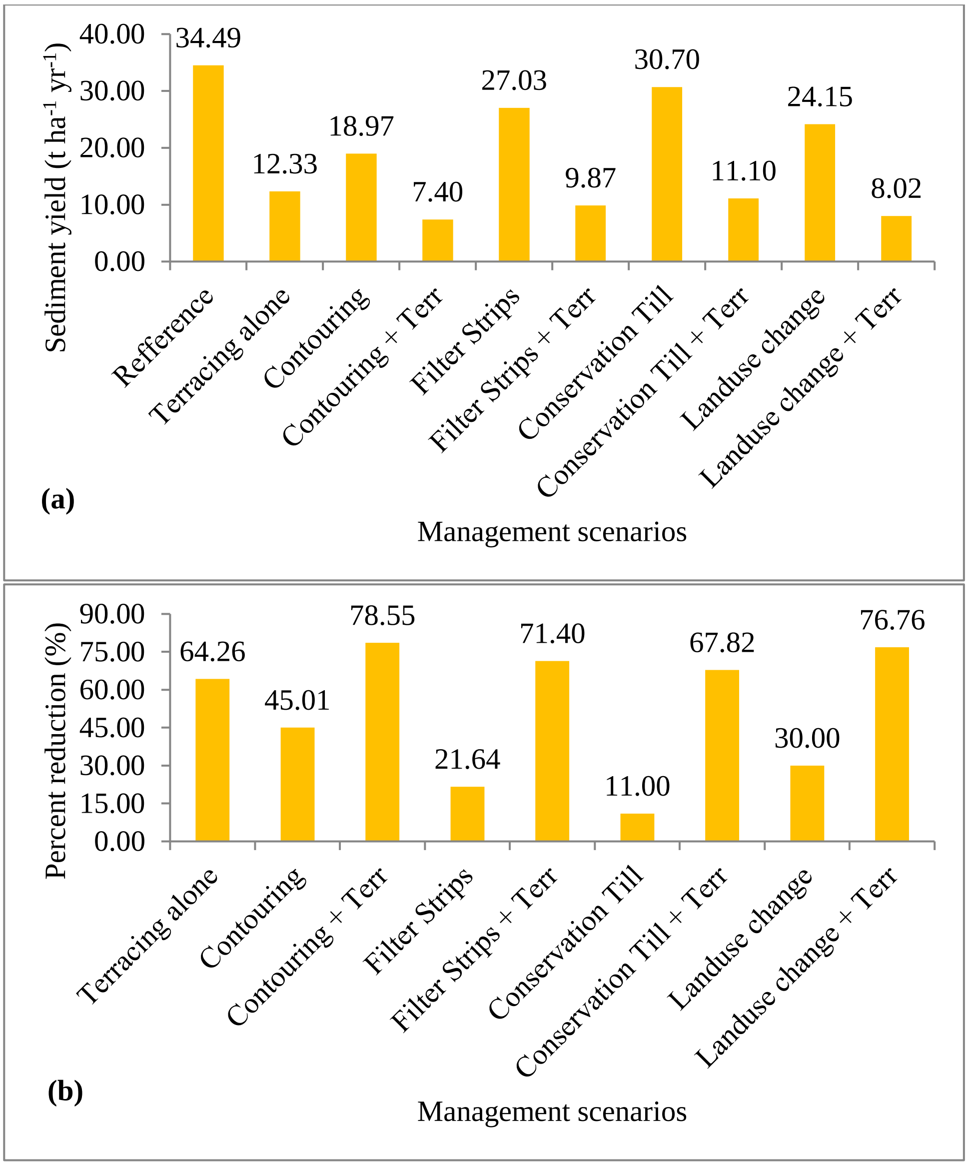
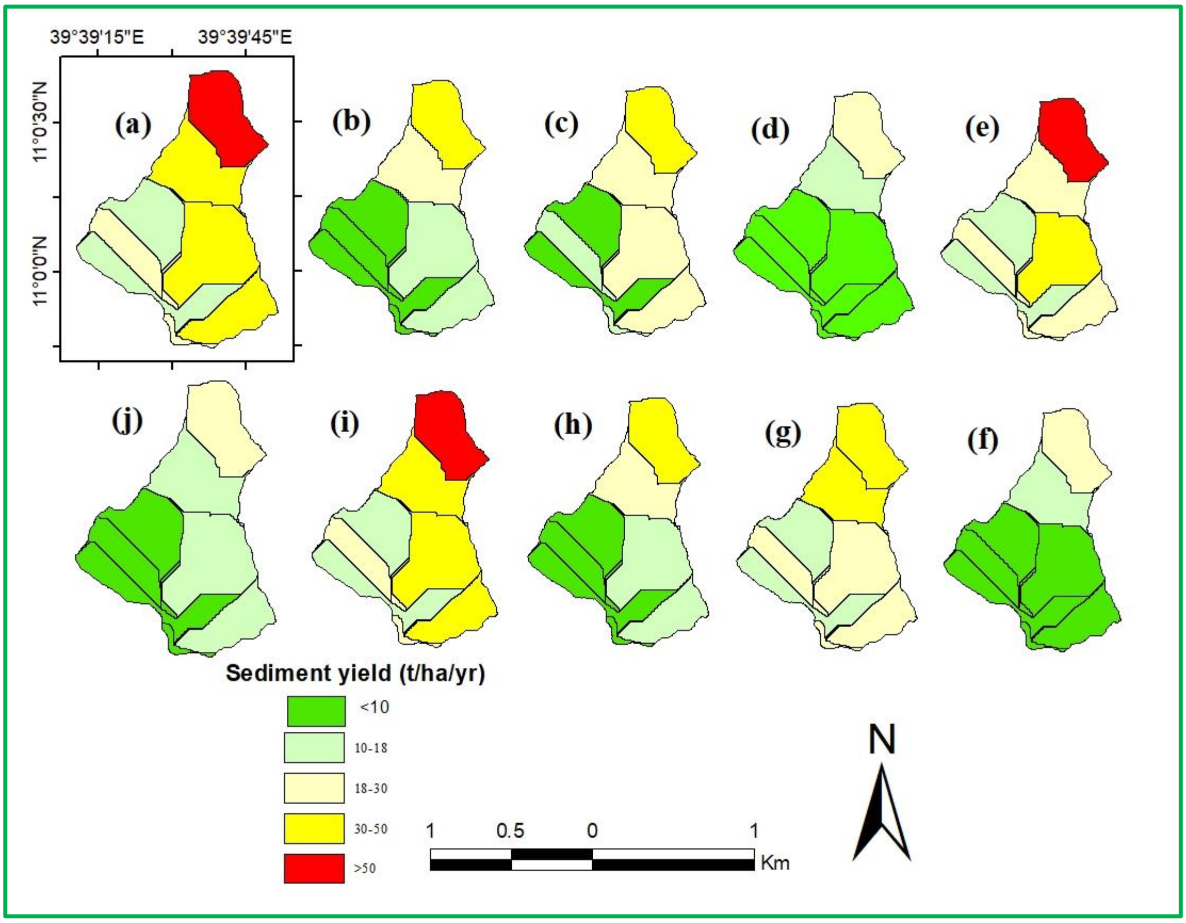


Figure 26. Mean annual sediment yield at different management scenarios (a) and sediment yield reduction percentages (b) compared to the reference scenario under current climatic conditions

Terraces can notably reduce the slope length where they are implemented within a watershed and provide retention space for sediments; as a result, they gradually reduce the original slope and make it more suitable for cultivation by trapping nutrient-rich-eroded sediments (Melaku *et al*., 2018). It is also reported by Descheemaeker *et al.* (2006) that combining terraces and other management alternatives with suitable crops can further reduce the ability of a steep slope to increase soil erosion.



Note (a: reference (baseline without terrace), b: terracing alone, c: contouring, d: contour with terrace, e: filterstrips, f: land use change with terrace, g: land use change, h: conservation tillage with terrace, i: conservation tillage, j: filter strips with terrace)

Figure 27. Mean annual sediment yield of different management scenarios at the sub-basin scale under the baseline climatic conditions

The effect of management options at subbasin scale, which is illustrated in the above figure showed a consistent sediment variability with respect to management alternatives. The variability in the spatial distribution (Fig. 27) of sediment yield can also be attributed to variability in the biophysical components of the watershed, including the topography, land use in addition to management actions .

4.5.2.2. Under Future Climatic Conditions (Terrace & No-Terrace Scenarios)

The output of SWAT model has shown that under no-terrace conditions 75.1 % of the watershed area was above a moderate erosion level (Table 10), while only 32.3% area was affected by high and very high erosion levels when the terrace was practiced under the current climatic conditions. Based on the classes assigned to the annual sediment yield (Gashaw *et al.*, 2019; Lemma *et al*., 2019; Tamene *et al*., 2017), the map was reclassified into five main categories of soil erosion risk region, i.e, low, moderate, high, very high and severe erosion conditions (Appendix Table 2).

The prediction of future sediment yield has also been conducted under the influence of climate change with the assumption of terraces practiced on crop fields and no-terrace practices. Simulation of climate-induced sediment yield under RCP4.5 and RCP8.5 emission scenarios showed an increase compared to the baseline scenario (Table 10). The significant increase in change (percentage) of sediment yield than discharge was found in this study; It was in line with previous studies by Moges *et al*. (2020). The more significan sediment could be attributed to the sediment concentration in the catchment that will likely increase in the future periods under the RCP4.5 and RCP8.5 scenarios. As shown in Table 10, there was no area classified under low erosion severity class for no-terrace scenario under current and future climate conditions. Although the effect of climate change on sediment yield was still very serious, practicing terraces under the baseline climate converses 35.1% of an area to be classified under low erosion rates compared to the no-terrace scenario. If terrace would not be maintained and practiced well in the future, 65% of the catchment is expected to suffer losing massive sediment (>100 t ha^{-1} yr^{-1}) (indicated on Notes under the table) for both RCP's. It is estimated to be 49% by far from terrace practices under the baseline climate conditions (16% of the area losses >50 t ha^{-1} yr^{-1}).

Table 10. Percentage of erosion potential areas and severity class under baseline and climate change induced outputs

Class	Sediment yield (t ha^{-1} yr^{-1})	Scenarios (area %)						Severity class
		Without Terrace			With Terrace			
		Base	RCP4.5	RCP8.5	Base	RCP4.5	RCP8.5	
1	<10	0.0	0.0	0.0	35.1	1.3	1.3	Low
2	10-18	24.8	0.0	0.0	32.6	8.9	8.9	Moderate
3	18-30	10.2	1.3	1.3	16.5	24.8	24.8	High
4	30-50	49.1	33.8	33.8	15.8	0.0	0.0	Very high
5	>50	15.8	64.9[a]	64.9[c]	0.0	64.9[b]	64.9[d]	Severe
Tot.		100	100	100	100	100	100	

Note: note that future climate change erosion severity is classified under 'severe' in both (with-out terrace and terrace conditions) while their sediment yield magnitude has a substantial difference as; **[a]** (107.3), **[b]** (69.3), **[c]** (112.1), and **[d]** (73.0) t ha^{-1} yr^{-1})

Future climate scenarios under RCP4.5 nd RCP8.5 were found insignificant to vary during erosion severity classes while a slight increase in magnitude is observed under RCP8.5 emission scenario. Figure 28 showed spatial variability of mean annual sediment yield at the subbasin scale for future climate scenarios under terrace/no-terrace conditions compared with the baseline climate. Although sediment spatial variability is attributed to the catchment bio-physical characteristics; the implementation of terrace under future climatic conditions reduces around 10% of the catchment area from very high and high erosion levels to moderate and low. Terracing seems to not influence areas rated as severe erosion class under future climatic conditions due to the fact that the sediment yield observed was large but around 37% sediment yield reduction was obserced (Table 10).

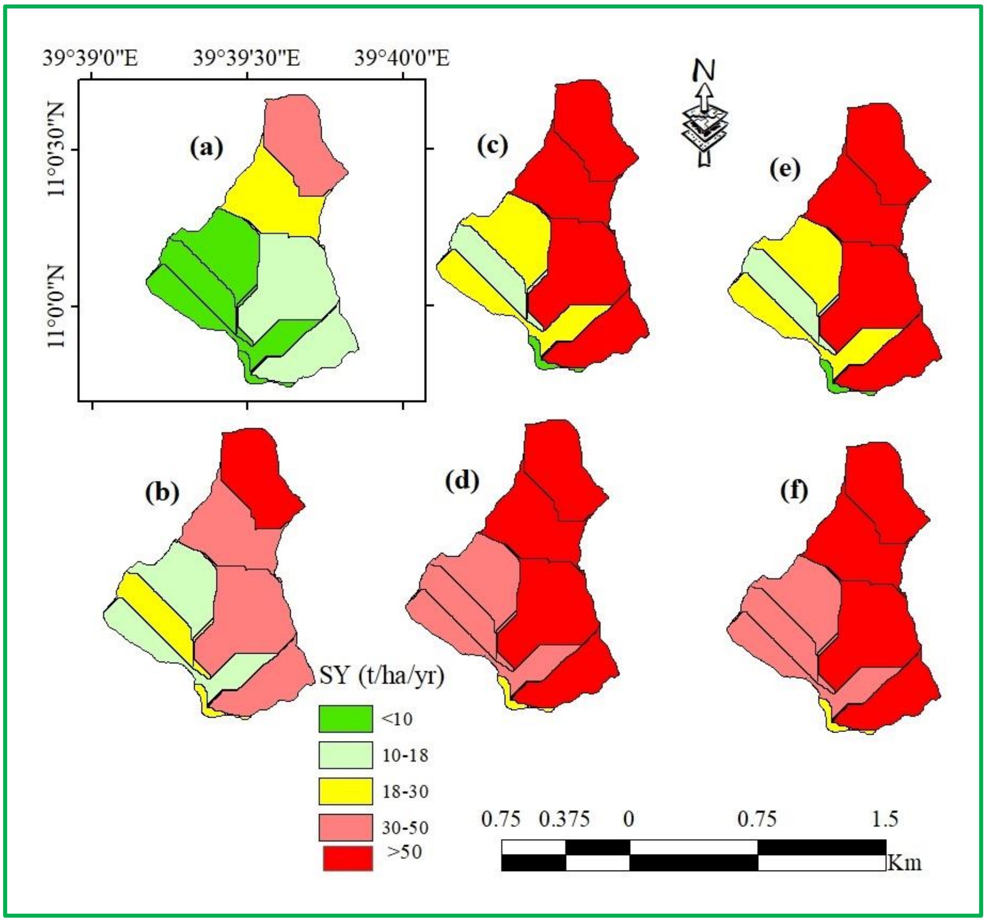


Figure 28. Mean annual sediment yield at the subbasin scale that scenarios with terrace; baseline (a) RCP4.5 (c); RCP8.5 (e) and without terrace baseline (b) RCP4.5 (d); RCP8.5 (f)

A deeper investigation of model outputs revealed that much higher erosion from the upper catchment was due to the much greater proportion of agricultural land and barren land in the watershed (Fig. 8). The magnitude of soil loss in the watershed can be evaluated by comparing the estimated soil losses with threshold values that define the soil loss tolerance level. In all climatic scenarios treated under no-terrace condition, were experiencing more than 70% of the watershed erosion rates to be higher than the maximum tolerable level of soil loss, which is 18 t ha^{-1} yr^{-1} for Ethiopia (Hurni, 1985). Climate change influences soil erosion in different ways.

The most direct and significant influence of climate change is through changes in the erosive power of rainfall (Nearing *et al*., 2004). Higher rainfall amounts and intensities as well as extreme rainfall events, increase soil loss due to their direct impacts on runoff rates and the mechanics of soil erosion (Li and Fang 2016). Pruski and Nearing (2002) predicted that every 1% change in rainfall amount could change runoff by 2% and erosion by 1.7%. Similarly, Zhang *et al.* (2007) showed that a 4 to 18% increase in precipitation can increase runoff by 49 to 112% and soil erosion by 31 to 167%. The finding by Lu *et al.* (2013) also proved that every 1% change in precipitation has led to a 2% change in sediment loads and a 1.3% change in water discharge. Therefore, the predicted 18.71% and 22.33% for RCP4.5 and RCP8.5 emission scenarios increase in rainfall from the baseline in Maybar watershed was likely to cause consistently high increase in runoff and erosion.

4.5.2.3. Under Future Climatic Conditions (Terrace integrated with others)

The management alternatives impact on sediment yield under future climatic scenarios of the study watershed is shown in Fig. 29. The response of sediment yiled for no-terrace circumstances under future climate scenario was already found very serious in the above discussion parts of the paper. So, management options integrated with terrace and the reference (terrace alone) in terms of their adaptive performance on reducing sediment loss under future climate conditions were compared here. The catchment treated with terrace as a reference is expected to experience 43.31 t $ha^{-1}yr^{-1}$ (Fig. 29a) and 45.44 t $ha^{-1}yr^{-1}$ (Fig.

29b) on an annual mean basis under RCP4.5 and RCP8.5 climate change scenarios, respectively.

Though the sediment yield from both scenarios is not significantly varied, the magnitude is estimated to be above three fold of the annual mean sediment yield from baseline climate under the same terracing condition which is 12.33 t $ha^{-1}yr^{-1}$ (Fig. 26a). Our results also showed that the implementation of contour farming integrated with terrace can reduce the expected annual sediment loss of the watershed by 30.5% (average of RCP's) compared with the sediment loss with the reference scenario which is terracing alone.

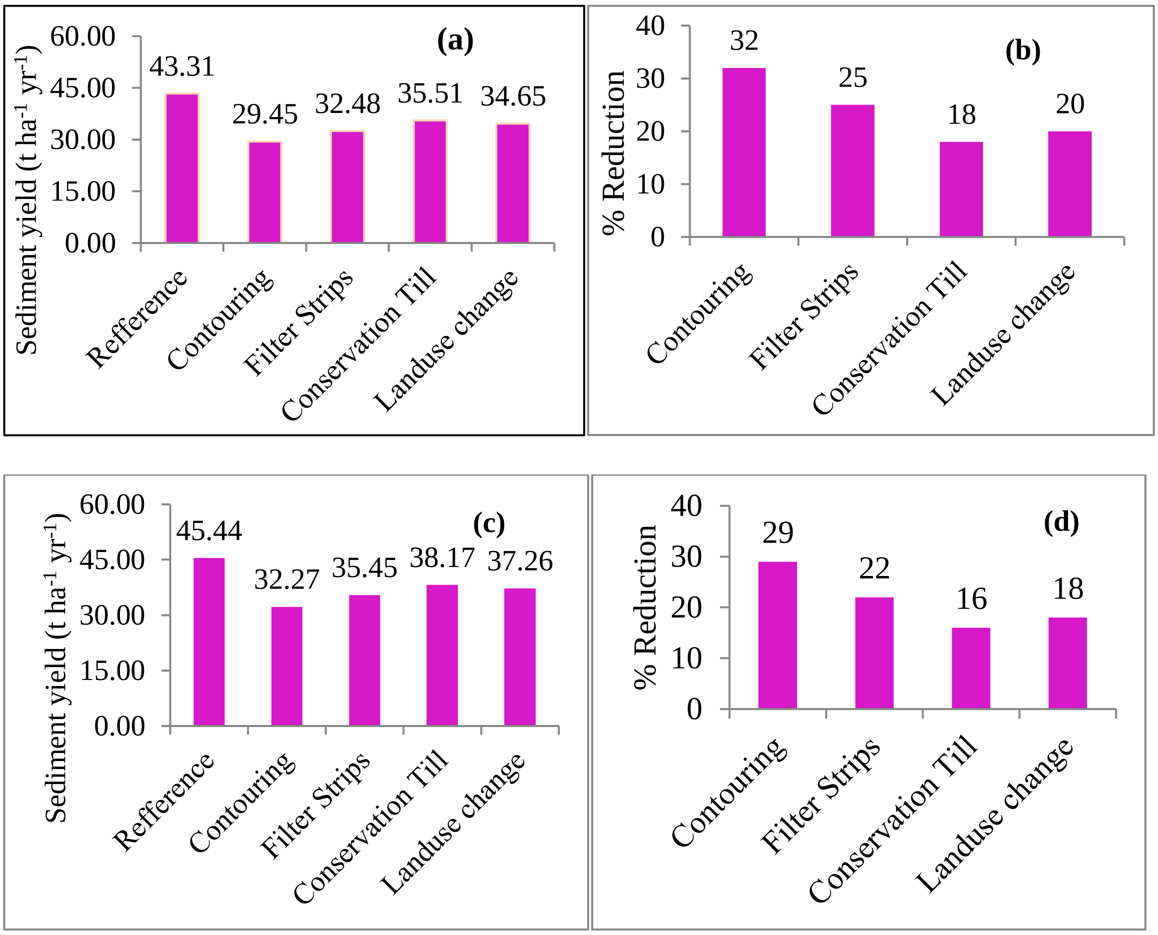
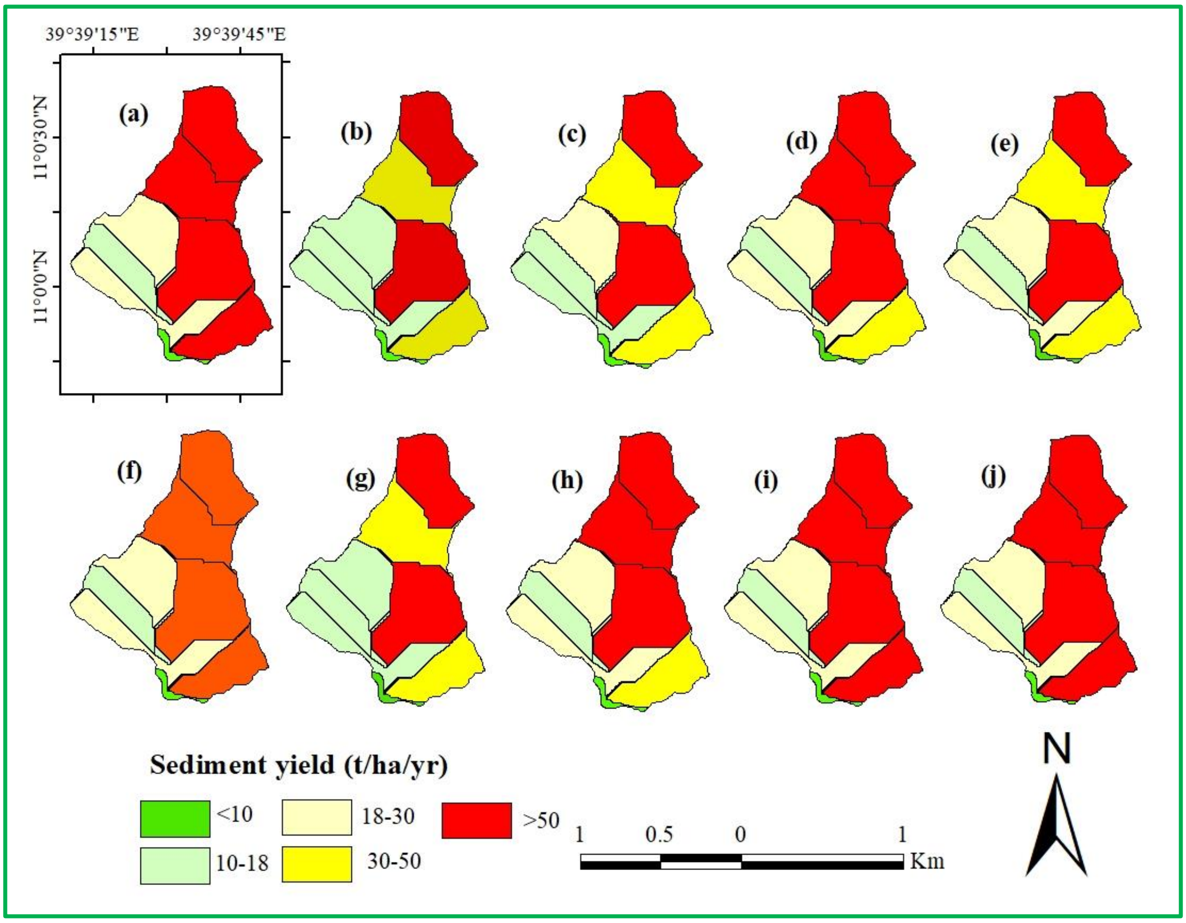


Figure 29. Mean annual sediment yield of management scenarios combined with the RCP4.5 climate scenario (a), RCP8.5 (c), and sediment yield reduction percentages RCP4.5 (b) and RCP8.5 (d)

An integrated implementation of 1-m wide vegetative contour filters with terrace under future climatic conditions (average RCPs; Fig. 29b & 29d) was also reduced sediment yield by 23.5% from the reference scenario. Such physical and biological measures can noticeably intercept runoff, increase infiltration, and trap sediments, but also reduce the slope of the land between adjacent structures, there by slowing runoff and reducing its erosive power (Nyssen *et al*., 2007).



Note: (a: baseline, b: contouring, c: filter strip, d: conservation tillage, e: landuse change under RCP4.5 and f: baseline, g: contouring, h: filter strip, i: conservation tillage, j: landuse change under RCP8.5; note that terracing is considered for all scenarios).

Figure 30. Mean annual sediment yield of different management scenarios at the subbasin scale under future climatic conditions

In adition we found that conversion of bare lands and hilly side crop fields to forest can reduce the mean annual sediment loss rate by around 19% compared with future sediment loss rates under sole implementation of terracing conservation measure in the catchment. Though the area considered for this treatment in our study is not much more; the finding agrees with the researcher who demonstrated that afforestation was capable of reducing runoff and sediment yields by up to 51% in highly degraded areas of northern Ethiopia (Moges *et al.*, 2020; Tesfahunegn *et al*., 2012). Average sediment losses under terrace integrated conservation tillage were 36.84 t ha^{-1} yr^{-1}, which decreased the sediment by 17% from the sole terracing measure. Model simulated sediment yield output reported by another researcher Parajuli *et al*. (2016) from the state of Mississippi showed that annual sediment yield declined in reduced tillage systems as compared to the conventional system.

5. SUMMARY AND CONCLUSION

5.1. Conclusive Remarks

This study was aimed to quantify the impact of management alternatives on discharge and sediment yield under current and future climate change conditionon in Maybar sub-watershed. The SWAT model was first calibrated and validated for monthly stream flow and then for sediment yields observed at the outlet of Maybar. The SWAT model calibration and validation showed reasonable agreements between simulated and measured variables. Statistical downscaling using CMhyd software (Climate Model Data for hydrologic modeling) was proposed to obtain spatially correlated climate data to drive the hydrological model. Our modeling predicted considerable changes in climate which is 18.71 and 22.33% change of precipitation for RCP 4.5 and RCP 8.5, respectively. The model also predicted that the minimum and maximum temperatures would increase by 3.51 and 2.0 °C under RCP4.5; 2.18 and 2.79 °C under RCP8.5 respectively in average basis for the coming periods (2022-2070).

The potential impacts of climate changes on hydro-sediment behavior of the catchment and evaluation of the potential effectiveness of simple conservation measures interms of erosion mitigation was analyzed. The discharge and sediment simulation results under future climate conditions were implying consistencies with predicted rainfall. The predicted peak flow during the summar season was found to be extended for the coming autumn seasons under the future climate compared with the baseline periods. Extremely massive sediment loss of the catchment was predicted under the future climatic conditions for the scenarios that considred the catchment to continue without any conservation measures in the future. Our modeling suggests that conversion of agricultural land and implementation of bio-physical soil conservation measures can greatly reduce soil erosion, but their effects would be greatest when integrated. The implementation of conservation measures was also found to be very effective in improving dry period hydrologic flows and reducing runoff-induced aggressive peak flows during the wet season. Therefore our results can be used to aware farmers to consider better maintenance of existing terraces and introducing additional biological measures to prevent climate change-induced soil erosion expected in the future.

5.2. Recommendations

The result indicated that the implementation of terraces in crop fields was found strong in influencing the response of discharge and sediment yield under current and future climate change conditions. In addition, its performance was also improved when integrated with other biophysical soil conservation measures. So farmers in the catchment and other agro-ecologies should be fully aware of how to improve poorly maintained previously installed physical structures and introduce additional biological measures such as filter strips and afforestation.

Soil erosion was found to be higher in the subbasins with more crop fields and hilly areas; infact it was previously reported that farmers in the Maybar catchment use frequent tillage practices and low soil input. Subsequently, contour farming and conservation tillage practices, which showed reduction of sediment yields in this study might improve the soil health; then we suggested they should be practiced in the study area and other similar farming systems. Converting hilly-side agricultural lands to plantation areas should also be practiced with optional livelihood strategies for the farmers.

It is also important to note that climate-induced soil erosion is substantial in the catchment and is expected in similar agro-ecologies to experience the same future manner. So, decision-makers and planners should take climate change considerations during their plan of future watershed management strategies. The management alternatives considered in this study were evaluated in terms of hydrosediment responses and therefore additional studies on the economic feasibility of conservation measures could help farmers and decision-makers to better prioritize optimal methods.

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7. APPENDICES

Appendix Table 1. Performance ratings of SWAT for a monthly based simulation (Moriasi *et al*., 2007)

Performance rating	NSE	PBIAS	
		Stream flow	Sediment
Very good	0.75 < NSE ≤ 1.00	PBIAS < ±10	PBIAS < ±15
Good	0.65 < NSE ≤ 0.75	±10 ≤ PBIAS < ±15	±15 ≤ PBIAS < ±30
Satisfactory	0.50 < NSE ≤ 0.65	±15 ≤ PBIAS < ±25	±30 ≤ PBIAS < ±55
Unsatisfactory	NSE ≤ 0.50	PBIAS ≥ ±25	PBIAS ≥ ±55

Appendix Table 2. sediment severity classes (Adpted from Gashaw *et al*., 2021; Lemma *et al*., 2019; Tamene *et al*., 2017)

Class	Sediment yield (t ha^{-1} yr^{-1})	Severity class
1	<10	Low
2	10-18	Moderate
3	18-30	High
4	30-50	Very high
5	>50	Severe

Appendix Table 3. Description of SWAT parameters used for streamflow and sediment calibrations

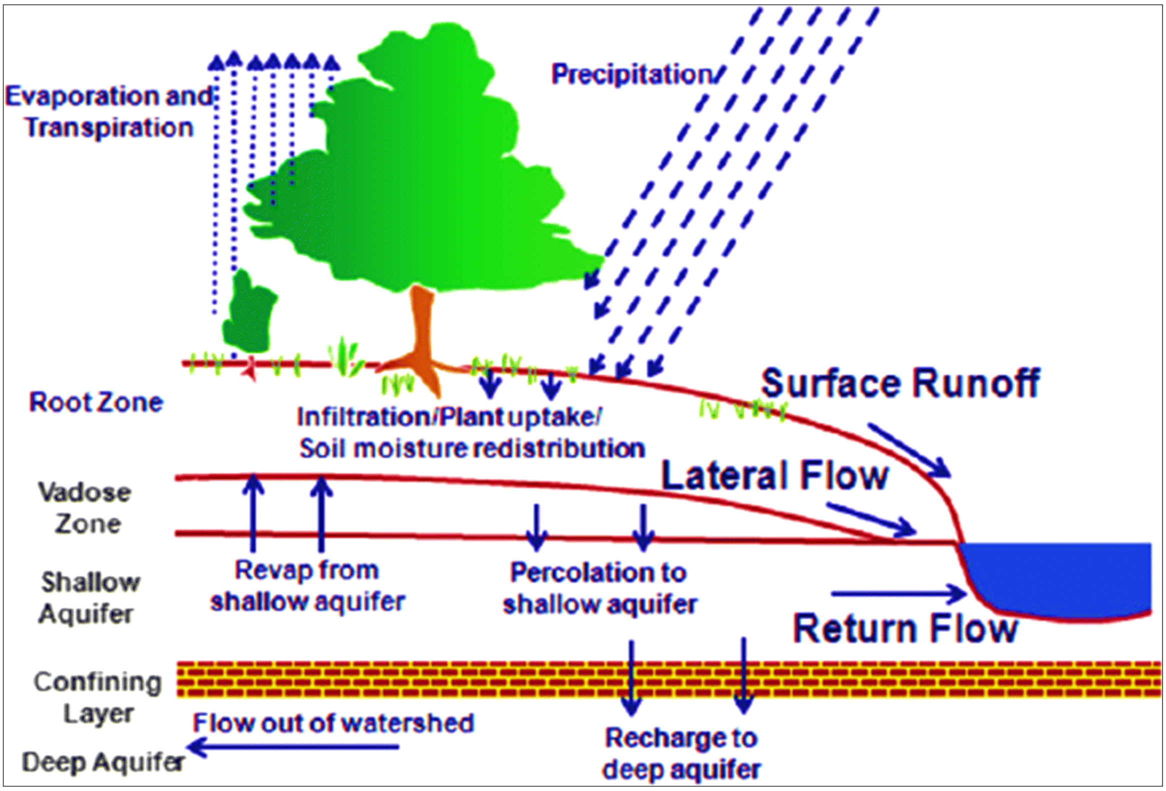
Parameter Name	Description
CN2.mgt	SCS runoff curve number
GWQMN.gw	Return flow treshold depth in the shallow aquifer (mm H_2o)
SOL_BD().sol	Moist bulk density
GW_DELAY.gw	Groundwater delay (days)
GW_REVAP.gw	Groundwater "revap" coefficient
ALPHA_BF.gw	Baseflow alpha factor (days)
OV_N.hru	Manning's "n" value for overland flow
RCHRG_DP.gw	Deep aquifer percolation fraction

SOL_K().sol	Saturated hydraulic conductivity
SURLAG.bsn	Surface runoff lag time
SLSUBBSN.hru	Average slope length
REVAPMN.gw	Threshold depth in the shallow aquifer for "revap" (mm H_2o)
CH_K2.rte	Effective hydraulic conductivity in main channel alluvium
CH_N2.rte	Manning's "n" value for the main channel
HRU_SLP.hru	Average slope steepness
USLE_P.mgt	USLE equation support practice factor
USLE_C.plant.dat	Min value of USLE C factor applicable to the land cover/plant
USLE_K(..).sol	USLE equation soil erodibility (K) factor
SPEXP.bsn	Exponent re-entrainment parameter in sediment routing
LAT_SED.hru	Sediment concentration in lateral flow and groundwater flow
SPCON.bsn	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing

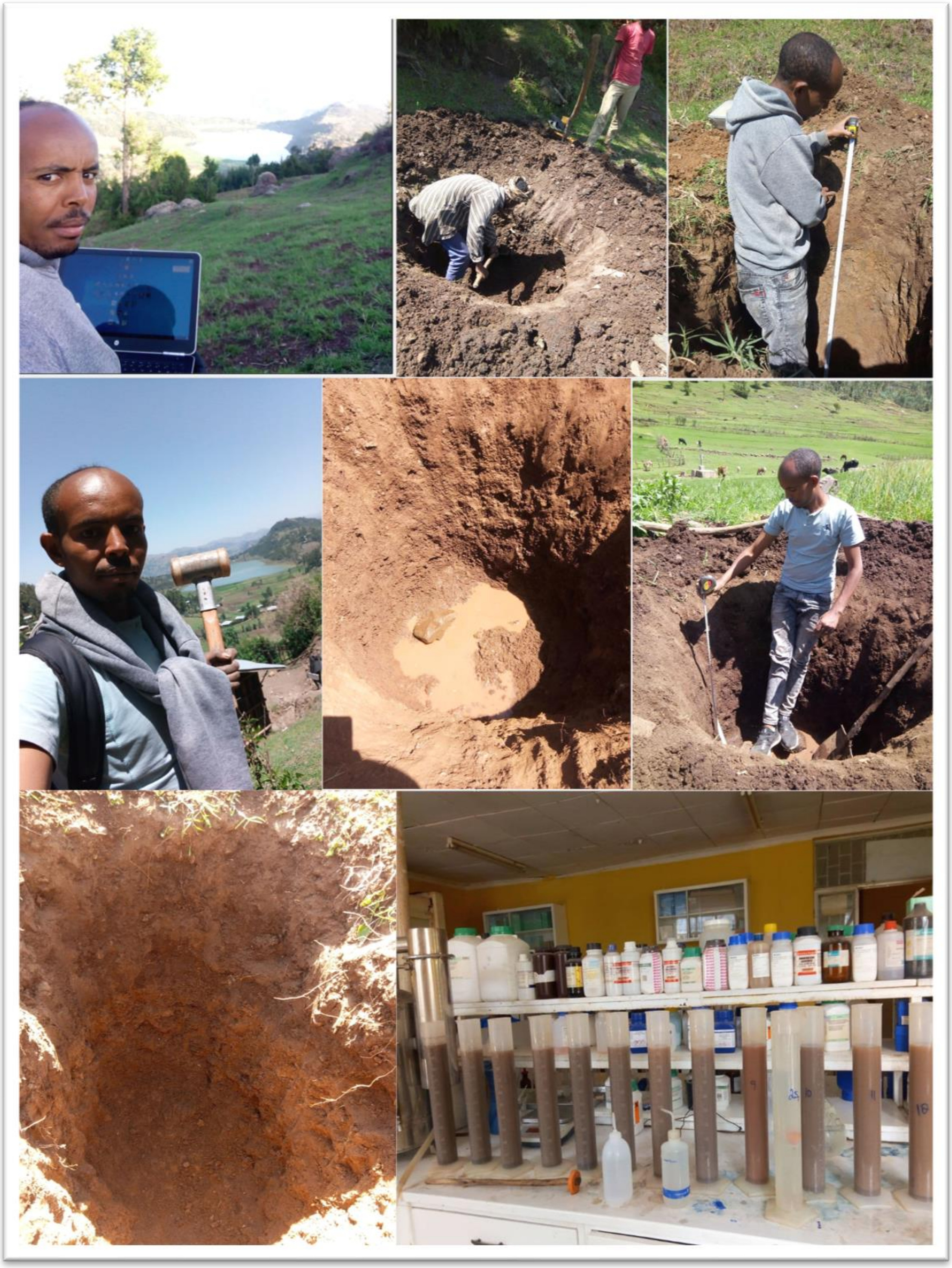
Appendix Table 4. RCMs and deriving GCMs short hand form and their description

RCM/deriving GCMs	Description
CNRM	Centre National de Recherches Météorologiques (Météo-France)/National Meteorological Research Centre
CERFACS	Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique /European Centre for Research and Advanced Training in Scientific Computing
EC-EARTH	EC-Earth Consortium (and its Earth system model)
MPI-ESM-LR	Max Planck Institute Earth System Model, low resolution
CanESM2	CanESM2 Second Generation Canadian Earth System Model
RCA	RCA Rossby Center Regional Atmospheric Model
RACMO	RACMO Regional Atmospheric Climate Model
CanRCM4	CanRCM4 Canadian Regional Climate Model

Appendix Figure 1. Hydro-sediment guage (left) and weather station (right) of Maybar watershed



Appendix Figure 2. Schematic representation of the hydrologic cycle in SWAT model



Appendix Figure 3. Field investigation

Appendix Figure 4. Laboratory analysis work at SARC soil laboratory

Amhara Regional Agricultural Research Institute (ARARI)
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Sirinka Agricultural Research Center (SARC)
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Soil and Water Management Research Directorate (SWMRD)
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Soil Analysis Result Delivery Sheet

Requested by: **Muluken Lebay Egigu** Signature: .... Date: 02/09/13 E.C Sample type: **Soil**

Lab No-	Sample Location		Organic Carbon (%)	Bulk Density (g/cm3)	Soil Texture (%)			Textural Class
	Easting	Northing			Sand	Clay	Silt	
1	571664	1216360	2.00	1.18	29.75	39.25	31.00	Clay Loam
2	571664	1216360	1.14	1.17	32.25	39.25	28.50	Clay Loam
3	572140	1216393	2.00	1.08	31.25	37.75	31.00	Clay Loam
4	572140	1216393	0.81	1.40	33.00	38.50	28.50	Clay Loam
5	572140	1216393	0.50	1.45	29.75	39.25	31.00	Clay Loam
6	571998	1215904	2.00	1.38	47.25	28.25	24.50	Sandy clay loams
7	571998	1215904	1.15	1.56	48.50	23.75	27.75	Sandy clay loams
8	571998	1215904	0.74	1.67	46.75	30.25	23.00	Sandy clay loams
9	571998	1215904	0.54	1.66	45.75	29.75	24.50	Sandy clay loams
10	571907	1215953	1.81	1.28	27.75	43.25	29.00	Clay
11	571907	1215953	0.99	1.48	28.75	40.25	31.00	Clay
12	572253	1216263	1.80	1.41	47.75	29.75	22.50	Sandy clay loams
13	572253	1216263	0.56	1.48	46.25	30.25	23.50	Sandy clay loams
14	572253	1216263	0.56	1.29	45.25	30.50	24.25	Sandy clay loams
15	572006	1216629	1.54	1.11	28.25	40.25	31.50	Clay
16	572186	1217207	1.96	1.38	47.75	27.00	25.25	Sandy clay loams
17	572186	1217207	1.14	1.60	45.75	29.75	24.50	Sandy clay loams

Analyzed by: Adise Degu .... Signature: .... Date: 04/10/13 E.C

Approved by: Sisay Dessale .... Signature: .... Date: 04/10/13 E.C

Soil & Water Research Directorate Coordinator
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Appendix Figure 5. Soil parameters analysis result