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Assessment of Land Use Impacts on Surface Runoff and Its Implication for Long-term Planning, Using SWAT Model at Baro River Basin, Southwestern Ethiopia

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Declaration

I Jemal Mohammed hereby confirm that I have done this research independently by my own without any other sources than the one indicated in the citation. Ideas that have taken directly or indirectly from an external source have been acknowledged and cited properly.

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Certification of approval

This is to certify that this research work was conducted by Mr. Jemal Mohammed Hassen under the supervision of Prof. Dr. Tirusew Asefa. It meets the requirement of Pan African University Institute of Water and Energy Sciences (Including Climate Change) for the award of Master of Science in Water Engineering.

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Abstract

Assessing the effects of land use and land cover change on hydrology is important for long-term planning of water resource management strategies. This study aims to evaluate the impacts of land use and land cover change on surface runoff in upper Baro-river basin (Sore and Geba watershed) covering an area of about 6551 km^2. Landsat images were used to analyze the land use and land cover change trends for the periods of three decades (1987-2015). The land use and land cover maps of 1987, 2001 and 2015 were generated from Landsat-5-TM, Landsat-7-ETM+ and Landsat 8 image, respectively. Maps were produced using the maximum likelihood algorithms supervised classification. The accuracy of the classified map was checked by confusion matrix. The accuracy measures index such as overall accuracy, user's accuracy, producer's accuracy and kappa statistics ($\widehat{K}$) were calculated and gives a satisfactory result. The trends of land use and land cover change showed that cultivated land is increased by 16.55% within the periods of between 1987 and 2015 with annual expansion by 36.15 km^2 at the expense of other land use types such as open forest, dense forest and wood land. To evaluate the impacts of land use and land cover change on surface runoff three SWAT model setup were run using the produced land use maps. The sensitivity analysis, calibration, validation and uncertainty analysis of the SWAT model was assessed by SWAT-CUP computer program. Nine sensitive flow control parameters were identified and used for calibration of the model. The calibration of the model was carried out using the average monthly observed flow from Sore river gage from January 1996 to December 2000 and the validation of the model was carried out from January 2001 to December 2005. The performance of SWAT model was checked by using the values of coefficient of determination (R^2), Nash-Sutcliffe (NS), p-factor and r-factor. There was a good match between the simulated and observed flow during the calibration period with the values of R^2 of 0.8, NS of 0.79, p-factor 0.78 and r-factor of 1.02 and for the validation period with the values of 0.75, 0.54, 0.78 and 1.26, respectively. During the periods between 1987 and 2015, a 16.55% cultivated land expansion was observed which may explain an increase of about 6.65 m^3/s (32 mm) in annual surface runoff. In general, during the study period in Sore and Geba watershed the land use change influences the hydrology of the system (e.g., evapotranspiration, surface runoff and stream flow characteristics).

Keywords: land use change, Sore and Geba watershed, SWAT, surface runoff

Résumé

L'évaluation des effets de l'utilisation de terres et du changement de couverture terrestre sur l'hydrologie est importante pour la planification à long terme des stratégies de gestion des ressources en eau. Cette étude vise à évaluer les impacts de l'utilisation de terres et du changement de couverture du sol sur le ruissellement de surface dans le bassin supérieur de Baro-River (bassin versant de Sore et Geba) couvrant une superficie d'environ 6551 km^2. Les images Landsat ont été utilisées pour analyser la tendance de l'utilisation du sol et du changement de couverture terrestre pour les périodes de trois décennies (1987-2015). Les cartes d'occupation du sol et de couverture terrestre de 1987, 2001 et 2015 ont été générées à partir de Landsat-5-TM, Landsat-7-ETM+ et Landsat 8, respectivement. Les cartes ont été produites en utilisant la classification supervisée des algorithmes de maximum de vraisemblance. La précision de la carte classifiée a été vérifiée par une matrice de confusion. L'indice des mesures de précision, telles que la précision globale, la précision de l'utilisateur, la précision du producteur et le statistique de kappa ($\widehat{K}$) ont été calculés et donnent un résultat satisfaisant. La tendance de l'utilisation de terres et de la modification du sol a révélé que les terres cultivées sont augmentées de 16,55% dans les périodes entre 1987 et 2015, avec une expansion annuelle de 36,15 km^2 au détriment d'autres types d'utilisation des terres, comme la forêt ouverte, la forêt dense et les terres boisées. Pour évaluer les impacts de l'utilisation de terres et du changement de couverture du sol sur le ruissellement de surface, trois modèles SWAT ont été exécutés à l'aide des cartes d'utilisation de terres produites. L'analyse de sensibilité, l'étalonnage, la validation et l'analyse de l'incertitude du modèle SWAT ont été évalués par le programme informatique SWAT-CUP. Neuf paramètres de contrôle de flux sensibles ont été identifiés et utilisés pour l'étalonnage du modèle. L'étalonnage du modèle a été effectué en utilisant le flux mensuel moyen observé à partir du calibre de Sore river de janvier 1996 à décembre 2000 et la validation du modèle a été effectuée de janvier 2001 à décembre 2005. La performance du modèle SWAT a été vérifiée en utilisant les valeurs du coefficient de détermination (R^2), Nash-Sutcliffe (NS), facteur-p et facteur-r. Il y avait une bonne correspondance entre le flux simulé et observé pendant la période d'étalonnage avec les valeurs de R^2 de 0,8, NS de 0,79, facteur-p 0.78 et facteur-r de 1,02 et pour la période de validation avec des valeurs de 0,75, 0,54, 0,78 et 1,26, respectivement. Au cours des périodes entre 1987 et 2015, on a observé une expansion des terres cultivées de 16,55%, ce qui pourrait expliquer une augmentation d'environ 6,65 m^3/s (32 mm) dans le ruissellement annuel. En général, pendant la période d'étude dans le bassin versant de Sore et Geba, le changement d'utilisation de terres influence l'hydrologie du système (par exemple, évapotranspiration, écoulement de surface et caractéristiques du flux).

Mots-clés : changement d'affectation de terres, bassin versant Sore et Geba, SWAT, écoulement de surface

Table of Contents

List of Figures

List of Tables

List of Abbreviation

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
ET	Actual Evapotranspiration
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GLUE	Generalized Likelihood Uncertainty Estimation
GWQ	Ground Water Flow
HBV	Hydrologisika Bayraans Vattenbalans-avediling
HRU	Hydrological Response Unit
HSG	Hydrological Soil Group
k	Soil Erodibility Factor
KM^2	Square Kilometer
LATQ	Lateral Flow
LCCS	Land Cover Classification System
LU	Land Use
LULC	Land Use and Land Cover
M	Meter
M.a.s.l	Meter Above Sea Level
M^3/S	Cubic Meter Per Second
MCMC	Markov Chain Monte Carlo

MIKE-SHE	Systeme Hydrologique European
MM	Millimeter
NASA	National Aeronautics and Space Administration
NSE	Nash-Sutcliffe Efficiency
ParaSol	Parasol Solution
PBIAS	Percent Bias
PET	Potential Evapotranspiration
PSO	Particle Swarm Optimization
R^2	Coefficient of Determination
RGB	Red Green Blue
RSR	Root Mean Square Error
SCS-CN	Soil Conservation Service Curve Number
SUFI-2	Sequential Uncertainty Fitting, version 2
SURFQ	Surface Runoff
SWAT	Soil and Water Assessment Tool
t/ha	Tone per Hectare
TM	Thematic Mapper
U. S	United States
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
USGS	United States Geological Survey

USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
VIC	Variable Infiltration Capacity
WEAP	Water Evaluation and Planning System
^{0}C	Degree Celsius
95 PPU	95 Percent Prediction Uncertainty

Chapter 1. INTRODUCTION

1.1. Background

Water is an essential natural resource for humans, animals, plants and the environment. The quality and the available amount of water in relation to human needs and population growth are still limited. Land and water resource management is a key issue to maintain the sustainability of natural resources and satisfy the current demands of population. Sustainable land use planning has a close link with water resources as the changes of land use has an effect on water resources through the relevant process of the hydrological cycle (Guo *et al*., 2008). The availability of water in an area depends very much on how the Precipitation of the area is separated to various components of the hydrologic cycle such as groundwater recharge, interflow, evaporation, surface runoff. Proportions of these components in the area is mainly affected by the land use and land cover of the catchment. Hence, a change in land use and land cover of the area can modify the proportions of the above-mentioned components, which in turn, results in change in ecological system of the area. Different research outputs suggest that there has been a substantial change in land use and land cover in the past few decades over many parts of the globe. In Ethiopia, a decline in natural vegetation covers such as forest and shrubs together with an increase in cultivated and bare lands have resulted in an increased surface runoff and soil losses from the catchment (Gessesse *et al*., 2014). This report also suggests that the removal of top soils from the catchment because of land use and land cover change resulted in reduction of soil fertility, sedimentation in the downstream and scarcity of soil water availability. In the highland parts of Ethiopia the expansion of cultivated lands at the expense of natural forests and vegetation covers has intensified the problem of land degradation, specifically through soil erosion by water (Bewket and Abebe, 2013).

The natural resources of Baro river basin in southwestern Ethiopia is under continued change because of land use land cover change starting from since 1986 due to resettlement, population growth, over utilization of resources and expansion of commercial farming (Tilahun, 2015). The downstream human settlement and agricultural (both grazing and crop) lands are seriously affected by unusual occurrences of floods overflowing riverbanks beyond the normal flooded zones caused by changes in rainfall patterns and also by human interference within the catchment due to the absence of land use planning (Woube, 1999).

The change in land use from a forest, shrub and grass lands to agricultural lands has an impact on the streamflow of the river and evapotranspiration from the catchment. That the cultivated land increases stream flow and decreases evapotranspiration during the main rainy season while there is inconsistency during a small rainy season and dry periods (Getahun and Haj, 2015). Estimation and assessment of surface runoff is an important issue of hydrological and geographical research. Surface runoff is a significant factor affecting the development and progress of floods, soil erosion and other hydrological hazards. The runoff characteristics of a drainage basin is influenced in a large extent by a land use and land cover change, which in turn affects the availability of surface and groundwater of the area, and hence leads to further change in land use and land cover (Sajikumar and Remya, 2015). The impact of land use on the hydrological regime influences both groundwater and surface water resources. Impacts of land use practices on the surface water can be divided into impacts on overall water availability or the mean annual runoff and impacts on the seasonal distribution of water availability. Therefore, the effects of land use practices on surface runoff, should be assessed to predict its impacts on the environment and the community.

Depending on the input data need and its availability, surface runoff and peak flow of the given watershed can be estimated using different empirical formulas and hydrological models such as SWAT, VIC, HBV, WEAP. In this study, together with a GIS application, the Soil and Water Assessment Tool (SWAT) software was used. SWAT is widely used and is the most applicable software for the study area.

1.2. Problem Statement

Southwestern Ethiopia is the origin of coffee Arabica and the area is suitable for coffee production. As a result, it attracts private investors to produce commercial crops like tea and coffee. There is also an illegal deforestation by the local farmers to use the lands for cultivation of coffee and other cereal crops. All these activities are one of the causes of land use and cover change. In this region, all the activities appear to be done without sustainable land use planning and consideration for the change impacts on the hydrological process. The local residents in southwestern Ethiopia claim that the deposition of sediments, gravel, and sands in the riverbed are a new phenomenon that occurred after deforestation (Kassa *et al*., 2016). Baro-Akobo river basin, which is found in Southwestern parts of Ethiopia, is one of the areas, which is rich in diversified natural resource and a habitat for different peoples with different working culture and farming practices. The forested area is one of the most animal and plant species-rich ecosystems parts of the country and some of them are recognized by the Ethiopian government and UNESCO as a priority area for biodiversity conservation sites. When we compare this area with the central and other highland parts of the country related with the hydrology, there has been a very few studies. This indicates that less attention is given by scholars. In Baro-Akobo river basin little is known about details of the water resources and little is done to understand the possible threats that may happen to the hydrologic system as a result of anthropogenic and climate variabilities (Alemayehu, 2016). The increasing population coupled with the expansion of cereal cropping practices, resettlement and commercial farming like Palm oil, tea, and coffee plantation is one of the threats to deteriorate the original natural forest cover, the traditional farming practices, and livelihood of the community living in that region. Following conversion of forest areas to open farmland has an impact on the water balance of the catchment by changing the pattern and magnitude of surface runoff, which results in riverbank degradation and increasing the extent of water and land management problem. Consequently, the communities living in the lower parts of Baro river basin are affected by recurrent flood and sedimentation on their irrigation channel (Alemayehu, 2016). In Baro basin there is also a research gap to represent the hydrological behavior and understanding of the flow of the basin. Quantifying and understanding the effects of land use and land cover change on the hydrological components will help us to identify the causes of flood and its implication on the watershed. For applying a corrective source based measures for the problem and to develop a new plan in the catchment, assessing the effects of land use practice on hydrology is an important first step in making a better decision about the land use planning by the government and the decision makers. Therefore, there is a need to assess and quantify the effects of land use change on surface runoff. Estimating the surface runoff from the catchment can provide information for long-term planning that can be used for sustainable land use planning and water resources management.

1.3. Objectives

The general objective of this study was to assess the land use change impacts on surface runoff using Soil and Water Assessment Tool (SWAT) model.

The specific objectives were to:

- identifying land cover change trends and compare the different land use practices on runoff response.
- determine the components of water balance of the catchment
- understand implications and recommend a land use management best practices

1.4. Significance of the Study

Agriculture is a major contributor for the economic development of Ethiopia. The Ethiopian Government encourages local and foreign investors to engage in the agricultural sectors. This agricultural activity influences the land use and cover changes. These changes have a significant impact on hydrology, the natural resource, socioeconomic and environmental systems. However, assessing and estimating the impacts of land use change on surface runoff is important to understand the land use and land cover change patterns and the hydrological process of the catchment. To develop a sustainable land and water resource management strategies for the country and particularly for the study area, it is important to understand the types, trends and impacts of land use change on surface runoff.

1.5. Outline of the Thesis

The thesis is organized into six chapters. The first chapter contains the general introduction, statement of the problem, the general objective, specific objectives, significance of the study and expected results. The second chapter describes about definitions and concepts of land use and land cover change, land use and land cover change in Ethiopia, runoff and factors affecting runoff, implication of land use and land cover change on surface runoff, hydrological models, introduction to SWAT model and SWAT model application worldwide and in Ethiopia. Chapter three contains the general descriptions of the study area such as the location, climate, land use and soil types. The fourth chapter describes materials and methods used such as data acquisition, image processing, land use and land cover mapping, accuracy assessment, SWAT model input analysis, model setup and model performance evaluation. Chapter five describes results and discussions which contains land use and land cover analysis, sensitivity analysis, calibration and validation, hydrology of the study watershed, effects of land use and land cover change on surface runoff, and environmental implication of the observed surface runoff. Chapter six contains the conclusion and recommendations of the study.

Chapter 2. LITERATURE REVIEW

2.1. Definitions and Concepts of Land Use and Land Cover Change

According to the food and agriculture organization (FAO) and united nations environment program (UNEP) during the development of land cover classification system (LCCS) adopted the definition of land use and land cover as “land cover is the observed or bio-physical cover on the earth’s surface” whereas “land use is characterized by the arrangements, activities, and inputs people undertake in a certain land cover type to produce, change or maintain it” (Di Gregorio and Jansen, 2005). Land use shows the way how people use the land whether for agriculture, settlement, conservation of natural resources or for other development purposes.

Land use and land cover change is the conversion or modification of the existing land use or cover type driving by the forces like economic activity, technological, demographic, scenic and other factors (Meyer, 1994). Even though the natural process may induce for land use land cover change, the most driving factors are human activities (Allen and Barnes, 1985). The fundamental causes of land use change is driven by the combination of resource scarcity leading to an increase in pressure of production on resources, changing opportunities created by markets, outside policy intervention, loss of adaptive capacity and increased vulnerability, and changes in social organization in resource access and in attitudes (Lambin, 2003).

The land use type of the area has a strong influence on soil erosion through its effects on vegetation cover and management practices or conservation measures. Land cover is highly influential factors on erosion process than any other single factors that can also intervene by a human being. The land cover can be a canopy, mulches, plant residues and densely growing plants in direct contact with the soil surface (Asress, 2008).

Not only are hydrological processes such as infiltration, evapotranspiration, surface runoff and groundwater flow altered substantially by land use changes (Fohrer and Kiel, 2001; Sahin and Hall, 1996), but also soil erosion and the transport of sediment to water bodies (Bieger, 2013; Yang *et al*., 2009). Vegetation cover helps to reduce the soil erosion by intercepting and dissipating the erosive energy of raindrops, runoff, and wind. It has also a role in reducing the volume of runoff through increasing the infiltration by following the root system and increases soil organic content which increases the aggregate stability of the soil. The role of plant root system is also by increasing the binding of soil particles thus increasing the mechanical resistance of soil against erosion. Assessing the impacts of land use change on the quality and quality of water is fundamental to the sustainable development of water resources and land use alternatives (Bieger, 2013).

2.2. Land Use and Land Cover Change in Ethiopia

The most contributing factors for deforestation (land use change) in Ethiopia are the prevalence of various types of agricultural activities, cutting trees to fulfill the demand of construction materials, firewood and charcoal production, population growth, expansion of settlements and absence of applicable forest policy (Melese, 2016). According to Kibret *et al*. (2016) the study conducted in south-central Ethiopia during the past four decades from 1972 to 2013 there had been a land use and land cover change through conversion of grassland to agricultural land, expansion of agricultural activities into marginal lands, shifts of land tenure systems and by contrasting interest or change of political regime. Accordingly, the study showed that agriculture nowadays has reached a maximum extension on suitable lands and further expands alarmingly to marginal lands and threating biodiversity in the natural forests. Population growth in the densely populated Ethiopian highlands is one of the most critical drivers of the observed land cover dynamics. Since the livelihood of almost the entire rural population is dependent on agriculture which further leads to deforestation (land use change). Besides anthropogenic activities, the change is aggravated by climatic extremes.

2.3. Runoff

According to united states geological survey (USGS) runoff is defined as the part of precipitation, snow melt or irrigation water that appears in uncontrolled (‘not controlled by a dam, reservoir or other storage structure upstream’) surface streams, rivers, drains or sewers. According to the speed of appearance after rainfall or melting snow runoff can be classified as direct runoff or base flow and according to source as surface runoff, storm interflow, or groundwater runoff. Surface runoff refers to the portion of precipitation that is not lost by infiltration, interception, and evapotranspiration. It occurs whenever the rate of precipitation exceeds the rate of infiltration. Runoff is simply water that, when it reaches the land surface, does not infiltrate into the soil but instead flows over the land surface.

2.4. Factors Affecting Runoff

Factors affecting runoff grouped as: Meteorological factors such as type of precipitation, rainfall intensity, rainfall amount, rainfall duration, distribution of rainfall over the watersheds, direction of storm movement, antecedent moisture content of the soil and other climatic conditions that affect evapotranspiration such as temperature, wind, relative humidity and season. Physical characteristics such as land use, soil type, vegetation, drainage area, basin shape, elevation, slope, topography, drainage network patterns, lakes, ponds, reservoirs and sinks in the basin which prevent runoff continuing downstream (USGS, https://water.usgs.gov/edu/runoff.html)**.**

2.5. Implication of Land Use and Land Cover Change on Surface Runoff

The land under little vegetation cover has assumed to generate high surface runoff, erosion and reduce infiltration of water into the groundwater. The temporal and spatial changes in land cover and land use significantly affect the potential of surface runoff from a watershed (Deshmukh *et al*., 2013). The spatial and temporal changes in surface runoff will have an influence in the management and development of water resources. Change of land use and land cover is expected as an initial stage of the initiation of surface runoff, erosion and land degradation (Melese, 2016) which has a significant contribution to further flooding and development of sedimentation in the downstream water storage structures.

The research conducted in tropical west African catchment (Dano, Burkina Faso) by Yira *et al*. (2016) about the impacts of land use change on water resources reveal that a clear increase in total discharge by (15%) and decrease in evapotranspiration by (-5%) was observed following conversion of savannah to cropland and urban areas. This implies that the surface runoff and yield of discharge generated from agricultural land is higher than savannah. Thus, this clearly indicates that the variation of total discharge from the different land use types is related to the response of the watershed to surface runoff.

The land use and cover change from the 1980s to 2000s in the Ethiopian highlands showed continued decline of shrub lands and forest cover, but there are some improvements in vegetation cover in some areas due to some soil and water conservation intervention. The expansion of cultivated land continued to very steep slopes and marginal lands. The land use and land cover change in the Ethiopian highlands has affected the basic natural resources by causing surface runoff, decreased water retention capacity, decreased stream flow, loss of wetland and drying of lakes.

The research conducted by Tilahun (2015) at Baro river basin indicated that there has been a change of land use and land cover due to resettlement, population growth, overutilization of resources and commercial farming. Accordingly, by using simple empirical runoff coefficient formula, the study also revealed that there has been an increment of surface runoff from 37 to 49% between the period of 1984 and 2001 in Geba sub-watershed. This showed that the change of land use and land cover change has an implication on increasing or decreasing the amount of surface runoff generated from the watershed.

2.6. Hydrological Models

Hydrological models are an expression to show the components of hydrological cycle which can be describe in the form of analog, physical or mathematical model. A number of hydrological models with different application have been developed to estimate the surface runoff from small catchment to global scale (Devi *et al*., 2015). Most models are process based or physically distributed and have been integrated with geographical information systems (GIS). Hydrological models have been developed for hydrologic prediction and for better understanding of the hydrological process of the watershed and how the changes take place in the watershed. It also helps for studying potential impacts of land use land cover change.

According to the review conducted by Devi *et al*. (2015) variable infiltration capacity model (VIC) performs well in moist areas and efficiently used in the water management for agricultural purpose, MIKE SHE model (Systeme Hydrologique European) requires large data and physical parameters and it makes it limited to use in small watersheds, and Soil and Water Assessment Tool (SWAT) models requires only little direct calibration to obtain a good hydrologic predictions.

2.6.1. Introduction to SWAT model

Soil and water assessment tool (SWAT) is a freely available model jointly developed by Texas A&M AgriLife Research and USDA Agricultural Research Service (USDA-ARS). SWAT is a small watershed to river basin scale model developed to predict the impact of land management practices, land use and climate change on water, sediment and agricultural chemical yields on complex watershed with varying soils, land use and management conditions over long periods of time (Neitsch *et al*., 2011). It is a physically based, spatially distributed, continuous time scale hydrological model which requires specific information about soil properties, topography, weather, vegetation and land management practices occurring in the watershed (Neitsch *et al*., 2011). Thus, using these input data, the physical process associated with sediment movement, water movement, crop growth, nutrient cycling, pesticides, agricultural management, channel routing, and pond or reservoir routing are simulated directly by SWAT model.

The major eight components simulated by SWAT model are hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, land management, stream routing and pond/reservoir routing (Arnold *et al*., 1998). From the major hydrologic process, such as evapotranspiration, surface runoff, infiltration, percolation, shallow and deep aquifer flows, and channel routing can be simulated by SWAT model (Arnold *et al*., 1998). The simulation of hydrology of the watershed are separated in to two major divisions such as the land phase of the hydrologic cycle which controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin and the water or routing phase of the hydrological cycle which can be defined as the movement of water, sediment etc. through the channel network of the watershed to the outlet (Neitsch *et al*., 2011).

2.6.2. SWAT model application worldwide and in Ethiopia

Soil and water assessment tool (SWAT) are widely used in the United States of America, Europe (especially intensively used in Germany), Africa (majority in east Africa such as Ethiopia, Kenya, Tanzania and Uganda), Latin America, Asia (intensive use in China, Iran, India and south Korea) (Gassman *et al*., 2010). Most of them are widely used for climate change, water quality, water supply, and land use change assessment. In an east African watershed Kenya, Baker and Miller (2013) successfully used SWAT for the assessment of land use impacts on water resources.

In some parts of Ethiopia the SWAT model application was calibrated and validated and frequently used in Blue Nile basin to model runoff and sediment yield within Gumera watershed (Asres *et al*., 2010), in Lake Tana basin (Setegn, 2008). The performance and feasibility of SWAT model has been tested by Setegn (2008) in Lake Tana basin and Anjeni watershed to examine the influence of land use, topography, soil and climatic condition on stream flow, erosion and sediment yield. From calibration and validation of the model the study showed that there was a good agreement between the measured and simulated flow and sediment yield with a higher value of a coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE). The study suggested that SWAT model is able to model the impacts of land use and land cover change on sediment yield and streamflow from a large complex watershed. Awulachew and Tenaw (2006) simulates runoff and sediment through modeling of Gumera watershed using SWAT model. They showed that reasonable accuracy and indicates long term data can be generated for ungauged basins. The study conducted in Baro Akobo river basin southwestern Ethiopia by Mengistu and Sorteberg (2012) to evaluate the performance of SWAT model in the study basin using model performance measures such as coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) lies within the range limits stated by Moriasi *et al*., (2007) .

Chapter 3. DESCRIPTION OF THE STUDY AREA

3.1. Location of Sore and Geba Region

Baro river is one of the major river in Baro-Akobo basin which lies in southwestern part of Ethiopia located between $33^0$23’39’’ to $36^0$18’21’’E and $9^0$25’’2’’ to $7^0$27’8’’N, which defines part of Ethiopia border with South Sudan. From its source in the southwestern Ethiopian highlands it flows west for 306 kilometers to join the Pibor River that flows to White Nile after forming Sobat River system. Regionally it lies in the Ethiopian administrative regions of Gambela, Oromia and Southern nation nationality peoples regional state. The drainage area of the basin including its tributaries are about 41,400 km^2 and is bordered by the Sudan in the Northwest, Abbay Basin in the east and Akobo basin in the Southwest. The elevation of the catchment ranges from 3244 m in the Southwestern highlands of Ethiopia and 390 m at the point where the border of South Sudan. For this specific study, Sore and Geba watershed about 6551.07 km^2 which is sub watershed of Baro river basin (one of the main tributaries) was selected (Figure 3.1). The elevation of Sore and Geba watershed ranges from 937 to 3001 m.a.s.l.

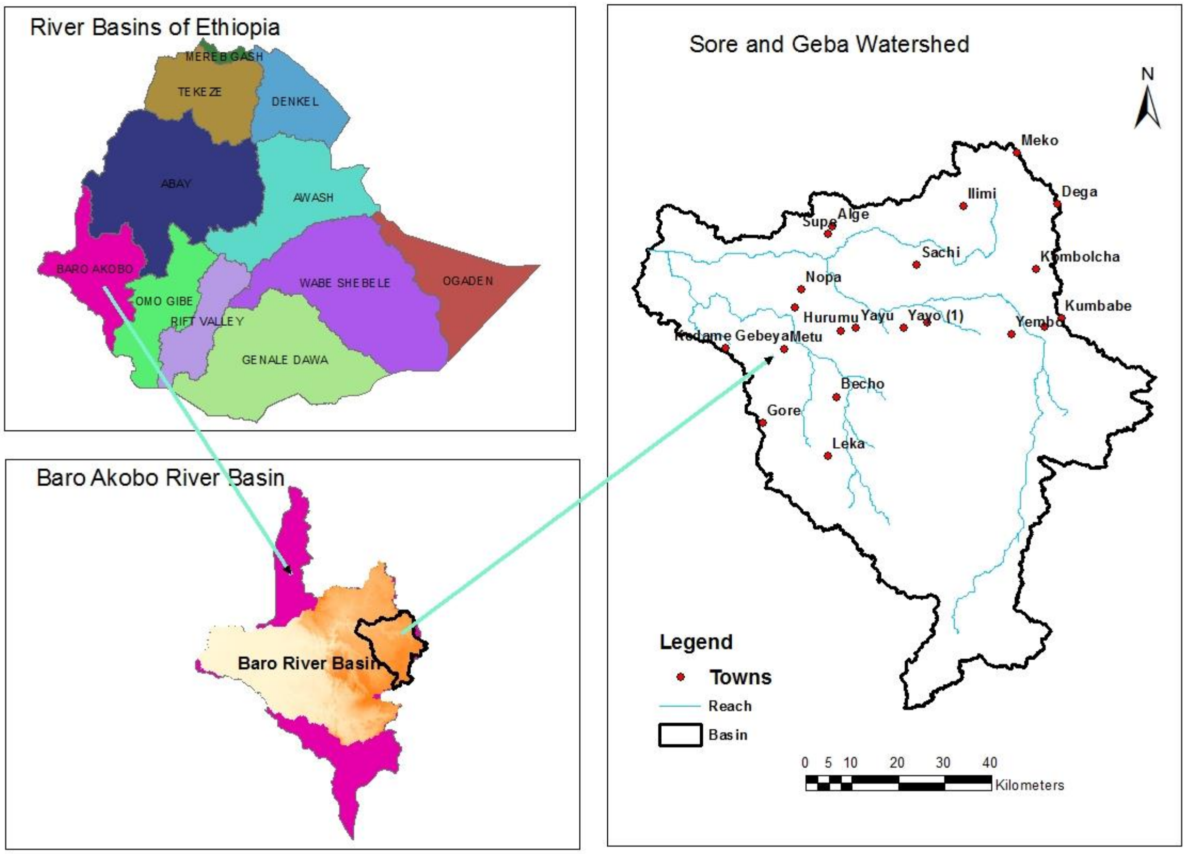

Figure 3. 1. Location map of the study area

3.2. Climate

Depending on the altitude and temperature of the area, Ethiopian climate is defined in to five climatic zones (https://www.nationalparks-worldwide.com/eaf/ethiopia/ethiopia-weather.html). When the elevation below 500m, average annual rainfall less than 400 mm and average annual temperature ranges between 28°C and 34°C or higher are categorized under the hot, arid zones covers the desert lowlands. Areas with an altitude of 500m to 1500m, average annual rainfall around 600 mm but in western lowlands of Gambela as high as 1600 mm and annual average temperature ranges between 20°C and 28°C are categorized under the warm to hot, semi-arid zones. The altitude between 1500m and 2500m, average annual rainfall around 1200 mm, reaching 2400 mm in south-west and average annual temperatures vary between 16°C and 20°C are categorized under the warm to cool, semi humid zones covers the temperate highlands. An altitude ranges between 2500m and 3200m, annual average rainfall 1000 mm up to 2000 mm in higher areas and the temperature ranges between 10^{o}C and 16^{o}C are categorized under the cool to cold humid zones includes the temperate highlands. The elevation between 3200m and 3500m, average annual rainfall less than 800 mm and average temperature below 10^{o}C are categorized to the cold, moist temperate zone covers the Afro-alpine areas on the highest plateaus. According to this category the study area (Sore and Geba watershed) lays in the warm to cool, semi humid zones. The rainfall distribution pattern of the study area is experiencing a unimodal rainfall pattern with continuous highest rain from March to October (Figure 3.2). The average annual rainfall of Sore and Geba watershed varies from 1533 mm (Metu) up to 2046 mm (Alge) (Figure 3.3).

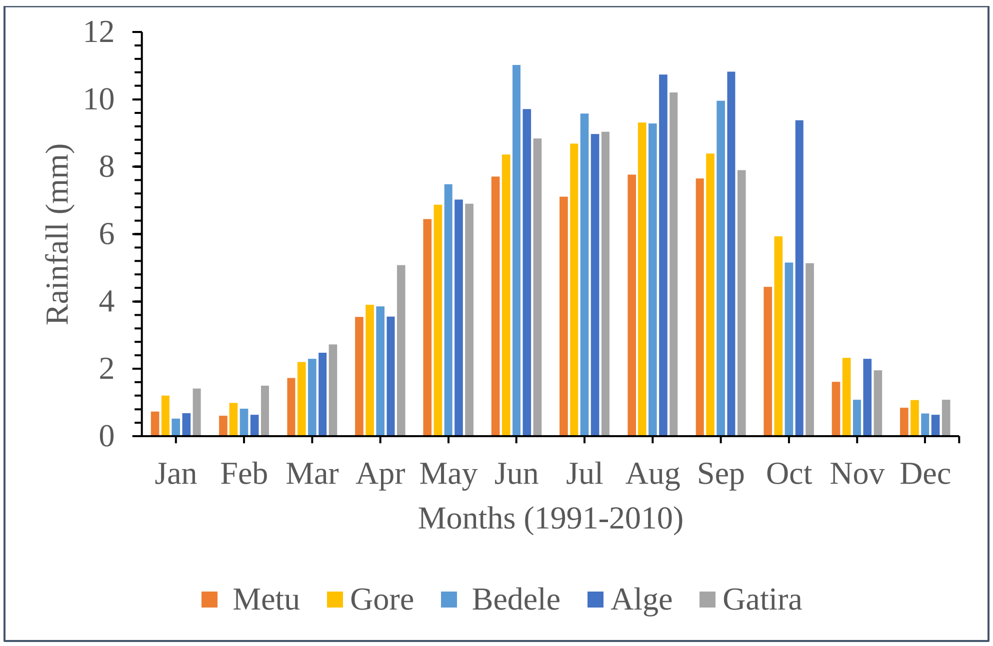

Figure 3. 2. Mean monthly rainfall distribution derived from selected meteorological stations

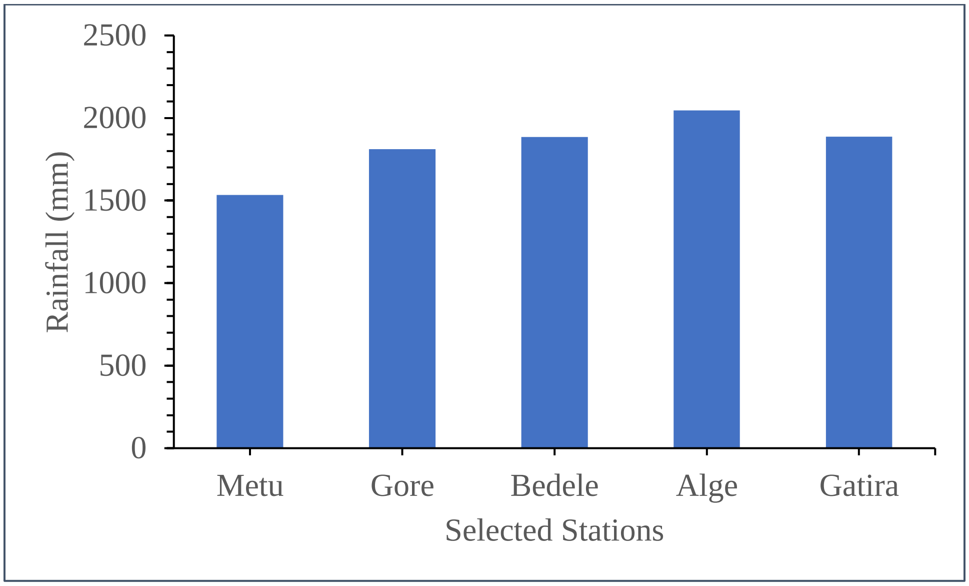

Figure 3. 3. Mean annual rainfall of selected stations from (1991-2010)

The average annual temperature of Sore and Geba watershed from Gore station ranges between 18^{o}C and 20^{o}C. Minimum and maximum temperature and time series plot of average annual mean temperature of Gore station selected for estimating weather generator parameters for this study are described in (Figure 3.4 and 3.5). The trends of the temperature from (1991-2010) also shows that an increasing trend.

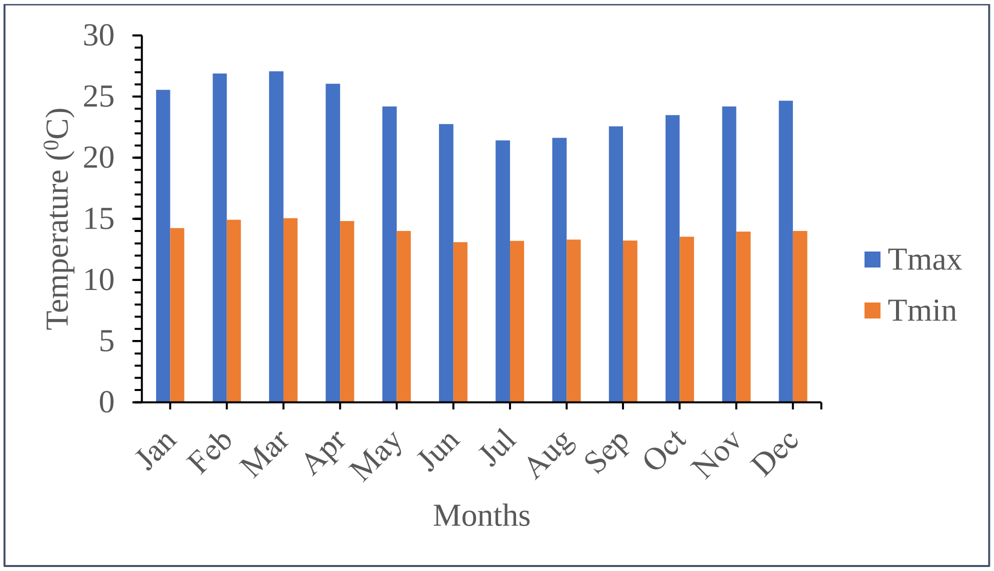

Figure 3. 4. Average monthly maximum and minimum temperature derived from Gore meteorological station (1991-2010)

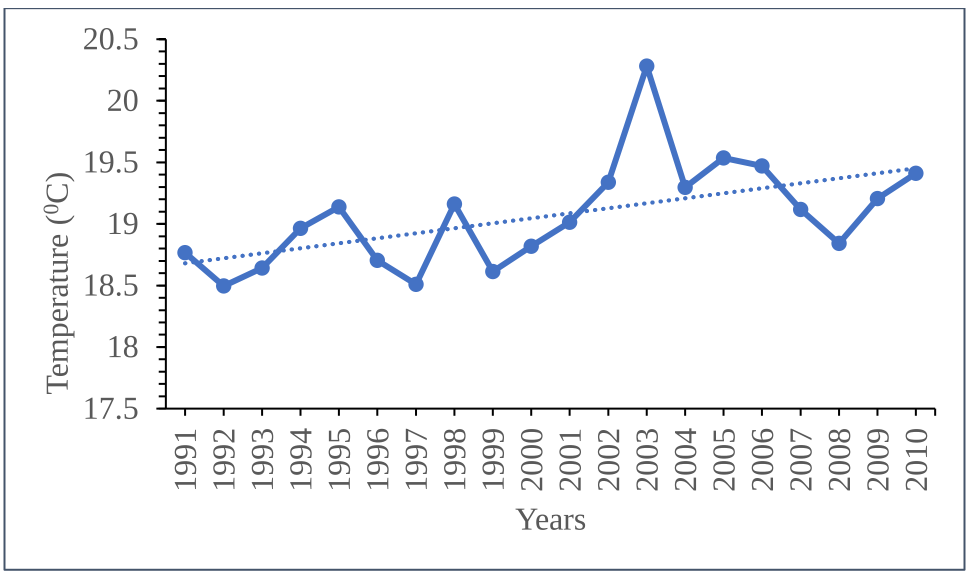

Figure 3. 5. Trends of average annual mean temperature derived from Gore station

3.3. Land Use

The land use types of Sore and Geba watershed is predominantly broad leaf montane forest, wood land, cultivated land and water bodies. The current widespread environmental problems of southwestern parts of Ethiopia when the study site located is forest cover change due to population growth, deforestation, exploitation of natural resources for firewood, construction and for other household uses (Wubie, 2016). The dominant land use types of Sore and Geba watershed is forest lands and agricultural lands.

3.4. Soil

According to FAO soil classification system Sore and Geba watershed soil types are grouped in to four major soil types such as, Eutric Nitosols, Orthic Acrisols, Eutric Cambisols and Humic Cambisols. Based on area coverage the study watershed is dominated by Eutric Nitosols which covers (62%), followed by Humic Cambisols (31%), Eutric Cambisols (5%) and Orthic Acrisols (2%).

Chapter 4. MATERIALS AND METHODS

4.1. Materials and Software's

The materials and software's used for this study were:

- Hydrological data (streamflow).
- Meteorological data (daily rainfall, minimum and maximum temperature, relative humidity, solar radiation and wind speed).
- Excel spreadsheet used for input data (meteorological and hydrological data) preparation and for model output data analysis.
- MATLAB was used for explanatory data analysis and plotting.
- 30 m by 30 m resolution digital elevation model (DEM) data as an input for ArcGIS and ArcSWAT software.
- 30 m by 30 m resolution Landsat images, used for classification of land use and land cover maps.
- ArcGIS 10.2.2 to obtain hydrological and physical parameters and spatial information's, to locate geographical location of the study area, to classify land use and land cover map and used for land use classification accuracy assessment.
- SWAT software to delineate the basin, sub-basin, and hydrological response unit (HRU) of the study area and to estimate the surface runoff.
- SWAT-CUP for sensitivity analysis, Calibration and Validation of SWAT model.

4.2. Methods

The general workflow framework of the study is described in (Figure 4.1).

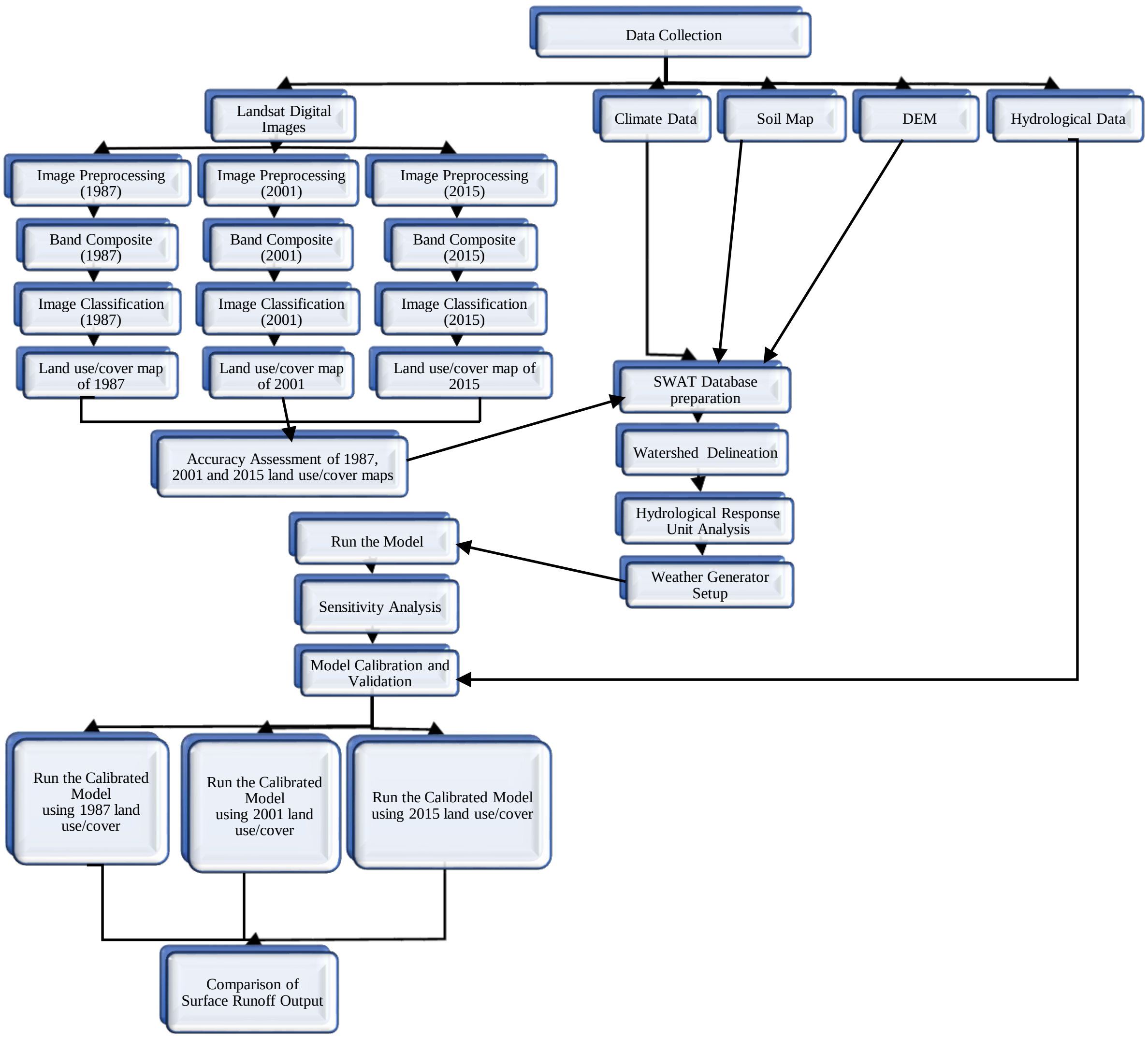

Figure 4. 1. Framework of the study

4.2.1. Hydrological cycle in SWAT

The land phase of the hydrologic cycle is modeled in SWAT based on the following Water balance equation (Neitsch *et al*., 2011):

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

Where, SW_t is the final soil water content (mm), SW_o is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration (ET) on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

4.2.2. Surface runoff

Surface runoff or overland flow, is a flow that occurs by infiltration excess or saturation excess of the soil along the sloping surface. SWAT simulates surface runoff volumes and peak runoff rates for each hydrological response units (HRU) using daily or sub-daily rainfall amounts. SWAT model provides two methods to compute surface runoff volume: using a modified soil conservation service curve number (SCS-CN) method (USDA Soil Conservation Service, 1972) or the Green and Ampt infiltration method (Green and Ampt, 1911). Daily precipitation data is required when SCS method is chosen for simulating runoff. While Sub-daily precipitation data is required when Green and Ampt infiltration method is chosen. For this study to estimate surface runoff volume the soil conservation service (SCS) curve number (1972) was used:

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

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

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

Where, CN is curve number for the day. I_a is commonly approximated as 0.2S and SCS equation becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)}$$

Runoff will only occur when $R_{day} > I_a$

The reason for choosing soil conservation service curve number method is due to the absence of sub-daily precipitation data in the study area to use Green and Ampt infiltration method.

4.2.3. Potential evapotranspiration

There are several methods have been developed to estimate potential evapotranspiration (PET) but SWAT provides three methods to estimate PET such as Penman-Monteith method, Priestly-Taylor method and Hargreaves method. The required input data are varied for each of the potential evapotranspiration method. The Penman-Monteith method requires air temperature, solar radiation, relative humidity and wind speed. The Priestly-Taylor method requires air temperature, solar radiation and relative humidity. Whereas, the Hargreaves method requires air temperature only. For this study, the Penman-Monteith method were applied.

4.3. Data Acquisition

For this study, various climatic and topographic data are required such as Digital Elevation model (DEM), land use and land cover, soil data, daily data of precipitation, maximum and minimum temperature, wind speed, relative humidity and solar radiation. The land cover satellite image and DEM were obtained from United State Geological Survey (USGS) website. The climatic data were obtained from National Meteorological Agency of Ethiopia. Hydrological and Soil data were obtained from Ministry of Water, Irrigation and Electricity of Ethiopia.

4.4. Image Processing

The study was conducted using satellite imageries of different bands for each year to identify the land use and land cover change distribution in Sore and Geba watershed over 30 years' period from 1987 to 2015. Landsat-5-TM, Landsat-7-ETM+ and Landsat 8 were selected for the period of 1987, 2001 and 2015 respectively. The selection of the acquired data date was made as much as possible within the same annual season to avoid a seasonal variation in vegetation pattern and distribution throughout the year. The image data files were downloaded in zipped files from USGS website and extracted in tiff file format. By using ArcGis10.2 software processing tools the images were orthorectified to a Universal Transverse Mercator projection using Geodetic datum Adindan UTM zone 37. All the input satellite images were composite to RGB color composition. To cover the study area by the satellite images, two sets of satellite images were downloaded and mosaic to new raster for each selected study years and clipped out by Sore and Geba watershed then the images were provided complete coverage of the study area. The path/row, acquisition dates, sensor, resolution and the producers of images are described in (Table 4.1).

Table 4. 1. The path/row, acquisition dates, sensor, resolution and the producers of images

Path/row	Acquisition dates	Sensor	Resolution (m)	Producer
170/054 170/055	1987-01-22	Landsat-5-TM	30	USGS
170/054 170/055	2001-02-05	Landsat-7-ETM+	30	USGS
170/054 170/055	2015-02-04	Landsat 8	30	USGS

4.5. Land Use and Land Cover Mapping

4.5.1. The land use and land cover classes of the study area

The land use and cover classes of Sore and Geba watershed has been differentiated and identified depending on the available sources such as, the prior local knowledge of the study area, remote sensing, the google satellite image and the previous research output of the study area. The Landsat images of the study area were classified in to five different types of land use and land cover classes.

Cultivated land: Areas used for annual crops by rainfed agriculture, Cereal Land Cover system which is moderately stocked and scattered rural settlements that are closely associated to cultivated fields. Scattered settlements were difficult to separate from remotely sensed images, due to that it combined to under the categories of cultivated land during classification.

Dense forest: Forest montane, broadleaf, dense (50-80% crown cover) which includes evergreen forest land.

Open forest: Forest montane, broadleaf, open (20-50% crown cover) which includes vegetation's with trees.

Wood land: Areas with bushes, open (20-50% tree cover) mixed with some grasses.

Water bodies: Marsh lands, Rivers and its main tributaries.

4.5.2. Image classification

The image classification was done by using ArcGIS10.2 software image processing tools. There are several image classification techniques exist for remote sensing image classification. They include supervised and unsupervised image classification techniques. The most widely used and accurate method is supervised image classification techniques (Hasmadi, et. al. 2009). For this study, by selecting training sites and generating signature files, supervised image classification techniques was applied to classify the image by maximum likelihood classification algorithms. Majority filter was applied to remove unwanted isolated pixels and to refine the image views.

4.5.3. Accuracy assessment

For this study, the quality analysis was done by the confusion matrix. The various parameters describing the quality of image classifications are derived from the confusion matrix. The confusion matrix is a table with rows which representing the mapped (classified) classes derived from the remote sensing data and the columns which representing the reference (observed) classes (Olofsson *et al*., 2014). The most commonly used index such as overall accuracy, producer's accuracy and user's accuracy has been calculated by this error matrix.

Overall accuracy: indicates the overall percentage of correctly classified pixels. This measure can be calculated as: dividing the total number of correctly classified pixels (diagonals) by the total number of pixels in the confusion matrix. There is no any unique universally acceptable threshold value of overall accuracy for image classification.

Producers accuracy: is calculated by dividing the number of correct pixels in one class divided by the total number of pixels as derived from reference data. It is corresponding to error of omission (exclusion).

Users accuracy: is derived from dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category. It is corresponding to error of commission (inclusion).

The other accuracy assessment statistics used for this study is Kappa coefficient ($\widehat{K}$). It reflects the difference between actual agreement and the agreement expected by chance. It can be calculated by the following equation.

$$\widehat{K} = \frac{(total * sum\ of\ correct) - sum\ of\ all\ the\ (row\ total * column\ total)}{total\ squared - sum\ of\ all\ the\ (row\ total * column\ total)}$$

The value of kappa ranges between 0 and 1, where 0 represents agreement due to chance only. Whereas, 1 represents complete agreement between the two data sets (classified map and reference data).

4.6. SWAT Model Input Analysis

SWAT is one of the most data intensive model that requires a diversity of information about the study watershed. For this study, the required input data were including digital elevation model (DEM) of Sore and Geba watershed, land use and land cover, soil properties, weather data and observed stream flow data for calibration and validation of the model. These data were obtained from different sources and databases. The details of obtained data analysis are described below.

4.6.1. Digital elevation model (DEM)

Digital Elevation Model (DEM) data is required to calculate flow direction, flow accumulation, stream networks, watershed delineation and for calculation of sub-basin parameters using SWAT watershed delineator tools. A product of NASA 30m by 30m resolution ASTER Global Digital Elevation Model was obtained from U.S Geological Survey (USGS) website. This data was projected to Universal Transverse Mercator (UTM) with a Geodetic datum of Adindan-UTM-zone-37 and to fit the model requirement it was in raster format (Figure 4.2).

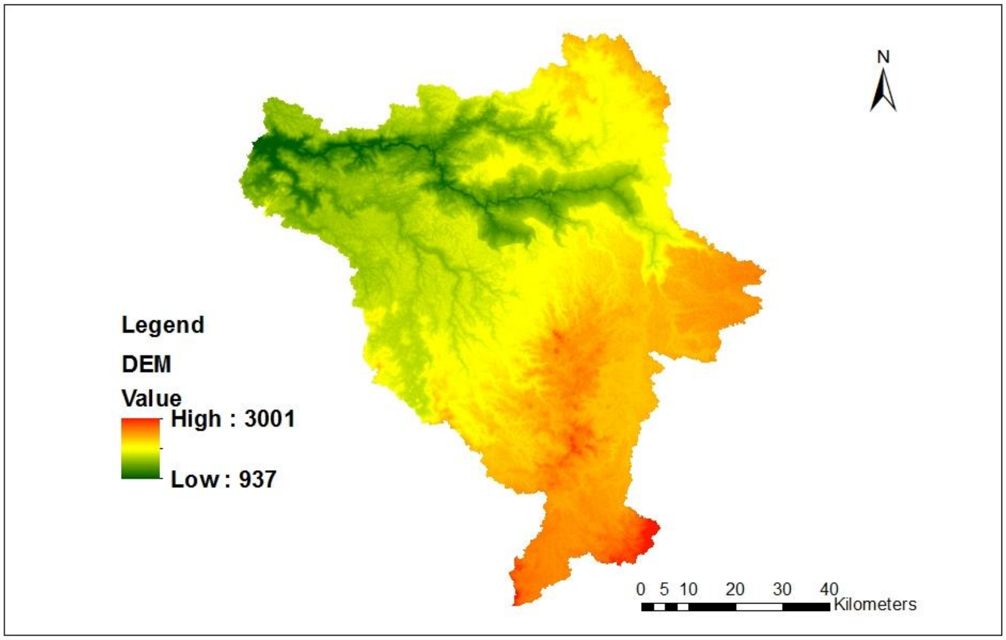

Figure 4. 2. Digital elevation model of Sore and Geba watershed

4.6.2. Weather data

Weather data are one of the main required input data for SWAT model simulation. The required input weather data for SWAT simulation includes daily data of maximum and minimum temperature, precipitation, solar radiation, relative humidity and wind speed. Meteorological station names, locations and variables are described in (Table 4.2). These data were obtained from National Meteorological Agency of Ethiopia. The weather data used for the study were represented from Five stations in and around the Sore and Geba watershed, such as Alge, Bedele, Gatira, Gore and Metu as shown in (Figure 4.3). Only Gore station are first class that has records on all climatic variables, whereas the other ones have only precipitation and temperature records. The climatic data used for this study covers 20 years from 01 January 1991 to 31 December 2010. To understand the trends and homogeneity of daily, monthly and yearly rainfall records from all selected stations, it is described in time series plot in (Figure 4.4 and 4.5).

While, some missing values were identified in some of the climatic variables in all stations. These missing values were selected and assigned with the SWAT no data value code (-99) which could be filled by weather generator embodied in to the SWAT model from monthly weather generator parameter values. For this study, these monthly weather generator parameter values were estimated from Gore Meteorological station by SWAT preprocessing software such as, pcpSTAT for precipitation parameters and dewpoint (dew02) for temperature parameters. Finally, the climatic data were prepared in text format with their respective lookup table as required by the model.

Table 4. 2. Meteorological station names, locations and variables

S. N	Station Name	Latitude	Longitude	Rainfall	Temp Max	Temp Min	Relative Humidity	Wind Speed	Solar Radiation	Duration of records
1	Alge	8.5333	35.6667	√						1991-2010
2	Bedele	8.45	36.3333	√	√	√				1991-2010
3	Gatira	7.9833	36.2	√	√	√				1991-2010
4	Gore	8.1333	35.533333	√	√	√	√	√	√	1991-2010
5	Metu	8.2833	35.5667	√	√	√				1991-2010

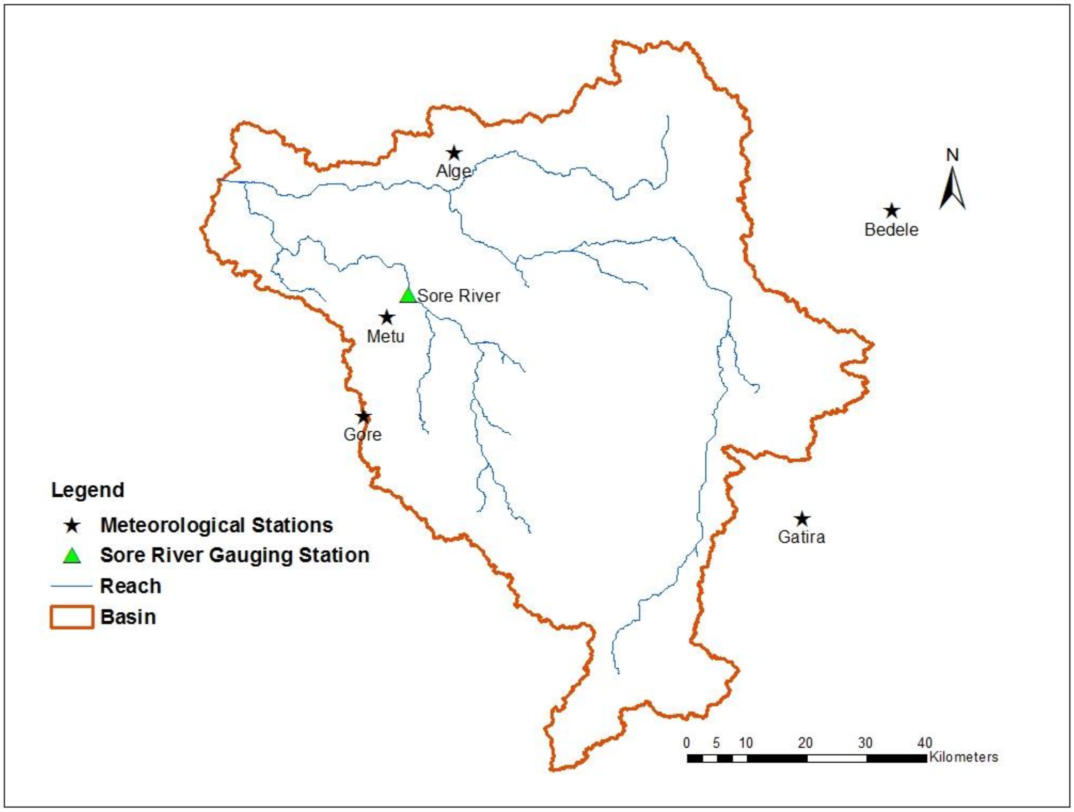

Figure 4. 3. Location map of meteorological stations in and around Sore and Geba watershed

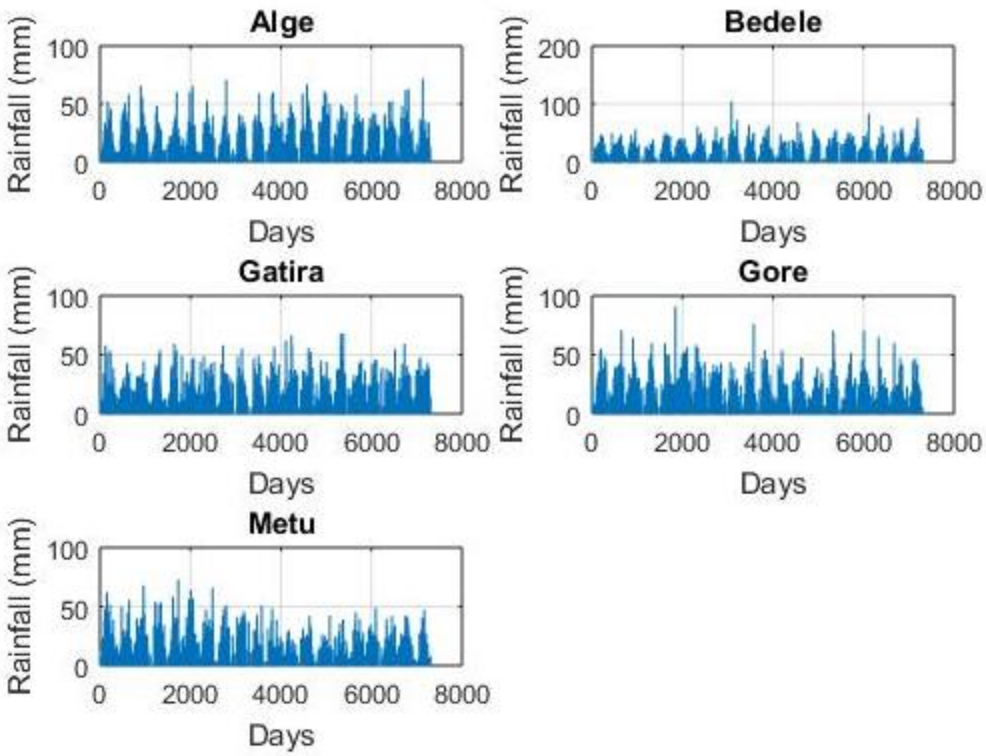

Figure 4. 4. Daily precipitation of selected meteorological stations from 1991-2010

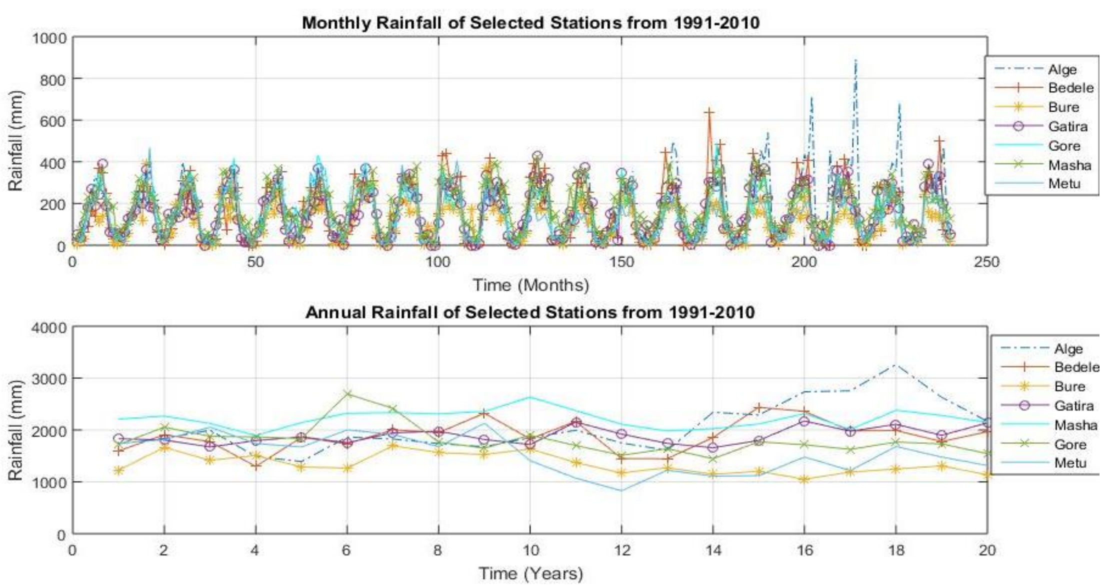

Figure 4. 5. Homogeneity of monthly and annual rainfall of selected stations from 1991-2010

4.6.3. Hydrology data

Stream flow data is needed for calibration and validation of the model. The stream flow data of Sore and Geba watershed were collected from Ministry of Water, Irrigation and Electricity of Ethiopia. Due to the availability of daily stream flow data of continuous records from periods of (1996-2005) was selected and by calculating the average monthly flows it was prepared according to the format SWAT-CUP needed. The data was quite sufficient for calibration and validation of the model. The time series plot of the selected year observed stream flow are described in (Figure 4.6). Most of the highest flows was observed between June and October when the highest rainfall is occurred (Figure 4.7).

Table 4. 3. Hydrological gauging station and available data

Station Name	Longitude	Latitude	Catchment Area (km^2)	Available data
Sore Metu	35.6	8.321	1622	1996-2005

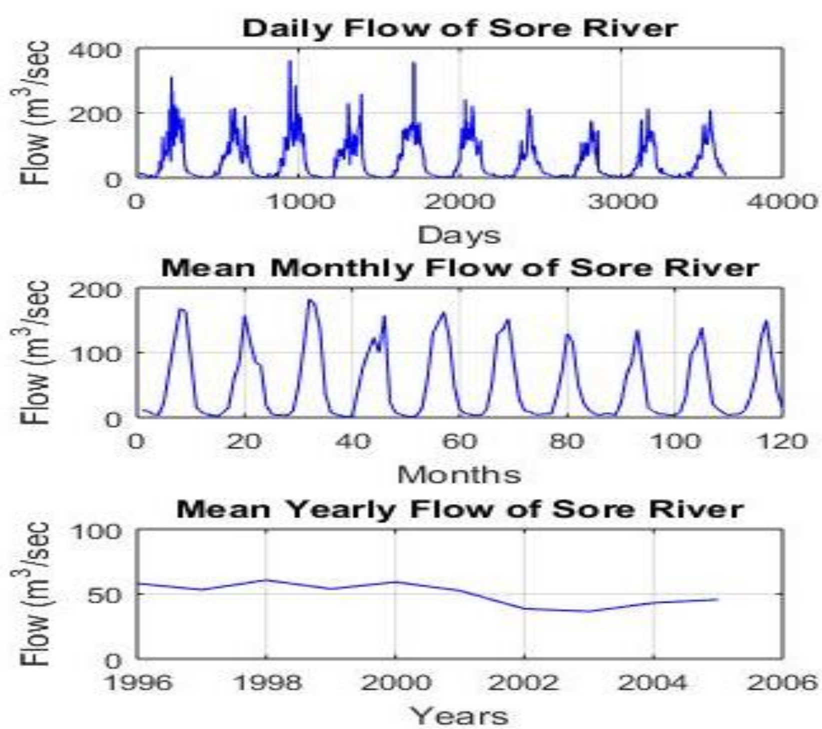

Figure 4. 6. Observed Sore river flow from 1996-2005

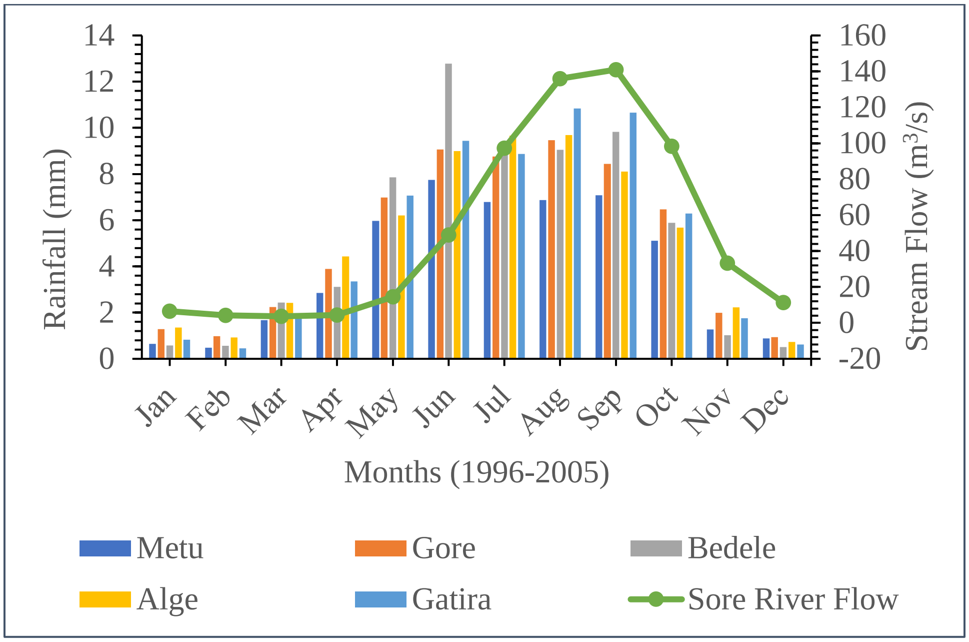

Figure 4. 7. Average observed monthly rainfall and stream flow of selected stations

4.6.4. Land use and land cover data

Land use is one of the main input data for SWAT model to define the hydrological response units (HRU) of the study watershed. The main sources of land use and land cover data was satellite images obtained through downloading from internet. Two sets of cloud free Landsat images were downloaded from USGS database (https://earthexplorer.usgs.gov/) for each respective study years that cover the period from 1987 to 2015 are used to detect the change in land use and land cover. To avoid the seasonal variation of vegetation cover, as much as possible the images were taken within the same season for each study years.

The SWAT model requires a four-letter code for each land use categories to compatible with its databases (Table 4.4). These codes are used to link the land use map of the study area to SWAT land use database. Hence, to compatible with SWAT land use database the lookup table of the study land use map were prepared as required by the model.

Table 4. 4. Land use/cover classification of Sore and Geba watershed as per SWAT model

S. N	Class Name	Land use according to SWAT database	SWAT code
1	Cultivated Land, Rainfed, Cereal Land Cover system, moderately stocked	Agricultural land generic	AGRL
2	Forest Montane, Broadleaf, Dense (50-80% crown cover)	Forest evergreen	FRSE
3	Forest Montane, Broadleaf, Open (20-50% crown cover)	Forest mixed	FRST
4	Woodland, Open (20_50% tree cover)	Forest deciduous	FRSD
5	Water bodies	Water	WATR

4.6.5. Soil data

Soil data is one of the main input data for SWAT model with including physical and chemical properties. The soil map of the study area was obtained from Ministry of Water, Irrigation and Electricity of Ethiopia. According to FAO soil classification four major soil types were identified in Sore and Geba watershed (Figure 4.8).

Soil physical and chemical properties required by SWAT model are soil hydraulic group, maximum rooting depth of the soil profile, depth from soil surface to bottom of layer, moist bulk density, available water capacity of the soil layer, saturated hydraulic conductivity, organic carbon content, clay content, silt content, sand content, rock fragmented content, moist soil albedo and USLE equation soil erodibility (k) factor for different layers of each soil type. These data were obtained from FAO soil database.

A user soil database was prepared which contains soil physical and chemical properties for each soil layers and added to the SWAT user soil database. To integrate the soil map with SWAT model, a soil lookup table were prepared. Area coverage and symbol of the soil types are described in (Table 4.5).

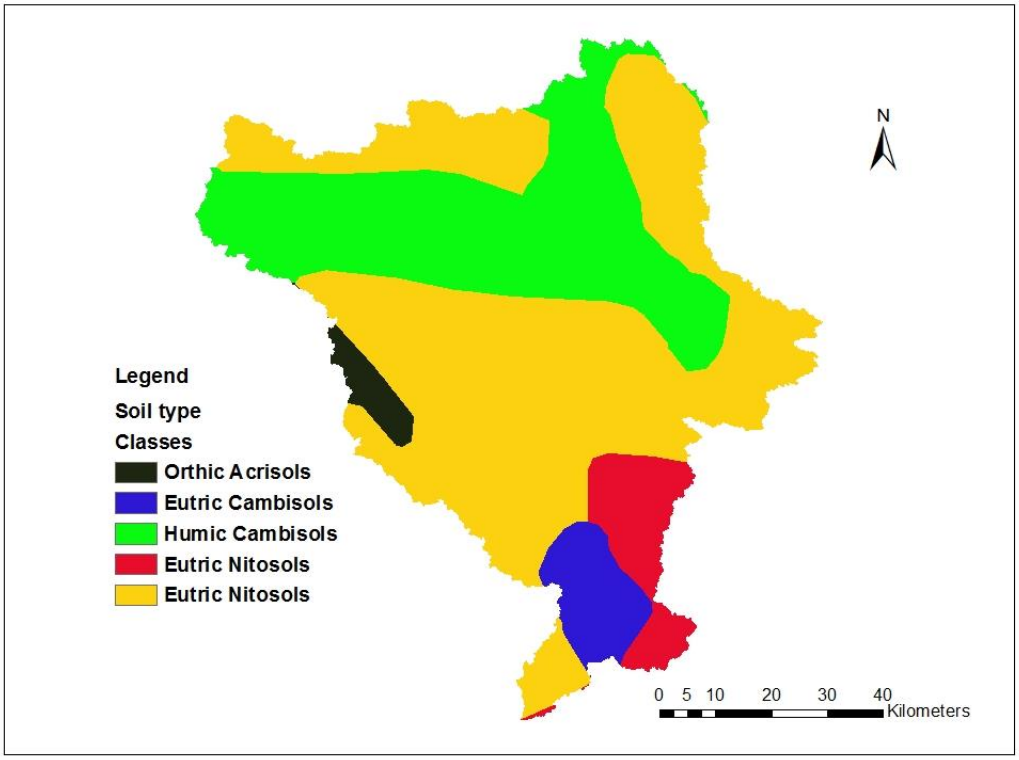

Figure 4. 8. Soil type map of Sore and Geba watershed

Table 4. 5. Soil types with their respective symbol and area coverage of Sore and Geba Watershed

Soil type	Symbol	Area	
		Km^2	%
Orthic Acrisols	Ao63-3b-6	126.63	1.93
Eutric Cambisols	Be49-3c-20	317.71	4.85
Humic Cambisols	Bh12-3c-31	2045.35	31.22
Eutric Nitosols	Ne12-2c-155	401.33	6.13
Eutric Nitosols	Ne13-3b-158	3660.05	55.87

4.8. Model Setup

4.8.1. Watershed delineation

The hydrological modeling of Sore and Geba watershed was carried out using ArcSWAT software interface of SWAT in ArcGIS. It requires basic spatial data such as digital elevation model (DEM), land use and soil type. The simulation of surface runoff in SWAT is carried out using various input data such as land use, topography, soil properties and weather data of the basin. The 30m by 30m resolution Aster Global DEM were downloaded from U.S Geological Survey (USGS) website and georeferenced to the projection system of Adindan_UTM_zone_37 N, which is the Universal Transverse Mercator Projection Parameters for the selected river basin in Ethiopia using GIS interface of the modeling tool. Using the DEM, the drainage and flow pattern is obtained and the stream network is defined. The stream network definition and the size of sub-watershed were determined by selecting the minimum threshold value of drainage area suggested by ArcSWAT interface (15122.7119 hectares). The smaller the specified number of hectares, the more detailed the drainage network will be delineated by the interface. By adding the flow gauge using add by table interface and outlet points were selected and the watershed is delineated. The sore and Geba watershed was delineated in to 29 sub-watersheds having an estimated area of 6551.07 km^2. To define hydrological response unit (HRUs), the model requires data on soil type, land use and slope. For the land use map, 30m by 30m resolution of Landsat imageries was obtained from the USGS website. After supervised classification in ArcGIS, it was loaded onto the delineated area. Land use pattern has long drawn effect on the economy as well as on the ecology and hydrology of any area.

The soil map of the basin was clipped from the soil map of Ethiopia and overlapped with the delineated area. Based on soil characteristics, further classification was done into hydrological soil groups (HSG) for ArcSWAT interface. Subdividing the catchment into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils (Arnold *et al*., 2013).

The slope of the watershed and sub-watershed were also generated from the DEM data. The elevation of sore and Geba watershed ranges from 937 to 3001 meters above mean sea level. The slope classification was performed based on the elevation range of the DEM used during watershed delineation. By selecting multiple slope classes, the study area slope was reclassified in to five classes (Table 4.6).

To overlay land use, soil and slope using the HRU definition the SWAT user's manual suggested for most modeling application a threshold value of 20% land use, 10% soil and 20% of slope combination. However, a research conducted in Ethiopia a threshold value of 10% land use, 20% soil and 10% of slope combination was good for better estimation of stream flow (Setegn, 2008). Thus, for this study the HRU definition with multiple options a threshold of 10% land use, 20% soil and 10% of slope combination was used. Hence, the Sore and Geba watershed was divided in to 345, 344 and 300 HRUs for the land use map of 1987, 2001 and 2015 respectively, each has a unique combination of soil and land use.

The weather data, was obtained from the National Meteorological Agency of Ethiopia and is formatted into the SWAT weather generator files and accordingly input into the database. The model is then setup and run. This weather generator data helps to generate the missing value by interpolation.

Thus, for understanding the effect of land use and land cover change on surface runoff over different time periods, the model was runs by varying the land use map and keeping the other SWAT input parameters constant. The SWAT model associates each land cover type with a cluster of parameter values include those related to lateral flow, evapotranspiration and overland flow.

Runoff is predicted separately for each Hydrological Response Unit (HRU) and routed to obtain the total runoff for the catchment.

Table 4. 6. The slope classes of Sore and Geba watershed

Classes	Slope ranges (%)	Area	
		Km^2	%
1	0-3	123.67	1.89
2	3-10	1069.75	16.33
3	10-20	2228.08	34.01
4	20-30	1684.10	25.71
5	>30	1445.48	22.06

4.8.2. Calibration and validation

For this study, calibration, validation, sensitivity and uncertainty analysis of stream flow parameters were done by SWAT-CUP (SWAT calibration and uncertainty programs). SWAT-CUP is a public domain computer program for calibration of SWAT models. The program links the Sequential Uncertainty Fitting, version 2 (SUFI-2), Particle Swarm Optimization (PSO), Generalized Likelihood Uncertainty Estimation (GLUE), Parasol Solution (ParaSol) and Markov Chain Monte Carlo (MCMC) procedures to SWAT model output files (Abbaspour, 2015). For this study, the Sequential Uncertainty Fitting program (SUFI-2) algorithm was used for calibration of Sore and Geba watershed (Sore river gauge) for the monthly SWAT runs. The available stream flow data of sore river gauge covered 10 years (1996-2005). The data were split in to two for calibration period (1996-2000) and validation period of (2001-2005). The Sore river gauge was in sub-basin 14 of the delineated Sore and Geba watershed (Figure 4.9).

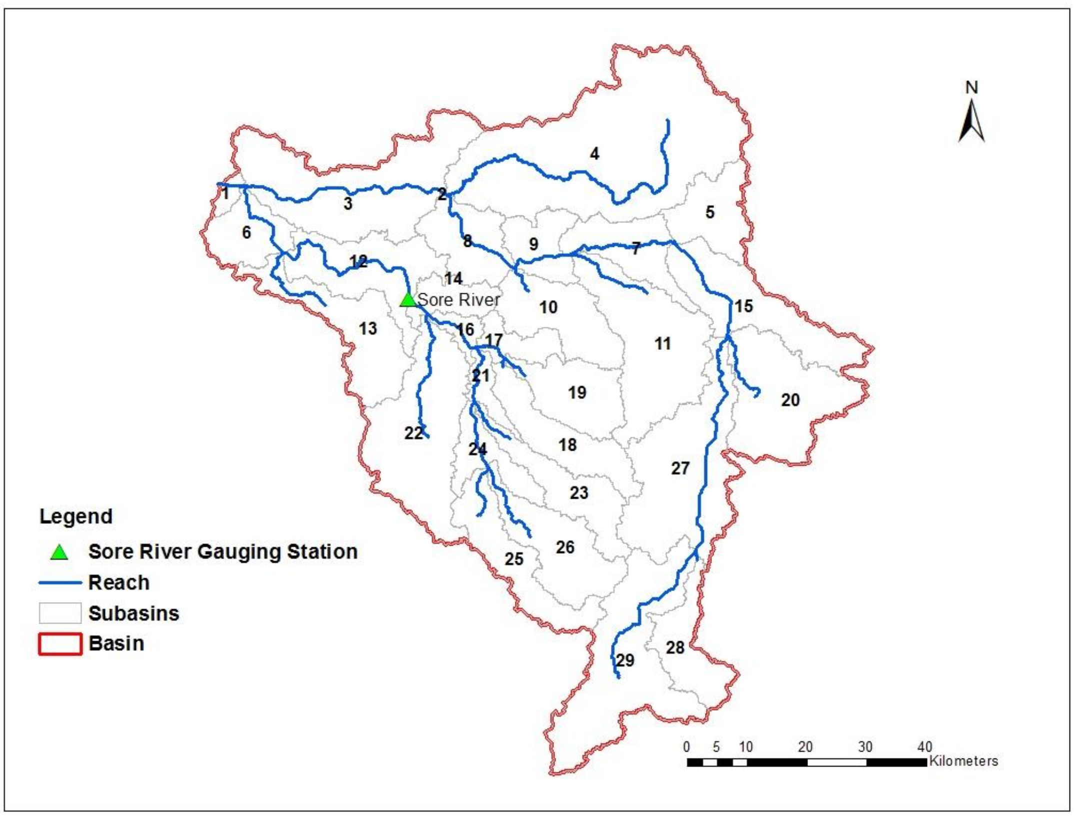

Figure 4. 9. Map of sub-basins within the delineated Sore and Geba watershed

The expressive flow parameters identifiers were chosen from SWAT database, previous study output and its initial ranges of the parameters used in the calibration were assigned from absolute SWAT values that linked in SWAT-CUP programs. The sensitive parameters included in the calibration were chosen based on a Global sensitivity analysis that varies all parameters simultaneously. Then, a t-test was used to identify the relative significance of each parameter.

SUFI-2 was run 2 iterations, 400 simulations in each iteration on the Sore river gauge and the best simulated parameter values were used to edit SWAT model run. The model was calibrated using the simulated flow obtained from the land use map of the year 1987. Then the best simulated parameter values were used for each land use map (1987, 2001 and 2015) model run. All the uncertainties are quantified by the p-factor, which is the percentage of measured data bracketed by the 95 PPU (95% prediction uncertainty). The quality of the calibration was measured by r-factor, which indicates the thickness of the 95% prediction uncertainty (95 PPU).

The validation of the model for stream flow was carried out for the period of (2001-2005) by using the calibrated SWAT-CUP parameters ranges (without any further changes) and by running an iteration one time with the same number of simulation used for calibration (400 simulation).

4.9. Model Performance Evaluation

There are different model performance evaluation techniques such as, Nash-Sutcliffe efficiency (NSE), coefficient of determination (R^2), percent bias (PBIAS) and by the ratio of the root mean square error of the standard deviation of measured data (RSR) etc. To judge the simulation of streamflow as satisfactory NSE > 0.50, RSR $\leq$ 0.70 and PBIAS $\pm$25% (Moriasi *et al*., 2007). For this study, the calibration and validation performance was carried out using the p-factor, r-factor, R^2 and NS model performance techniques. R^2 and NS was calculated by equation (4.1 and 4.2) respectively.

Coefficient of Determination (R^2): describes the proportion of the variance in measured data explained by the model.

$$R^2 = \frac{\left[\sum_i (Q_{m,i} - \bar{Q}_m)(Q_{s,i} - \bar{Q}_s)\right]^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2 \sum_i (Q_{s,i} - \bar{Q}_s)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (4.1)$$

Where,

R^2 = Coefficient of determination

Q = Discharge and the bar stands for average

m = Measured data

s = Simulated data

i = The i^{th} measured or simulated data

Nash-Sutcliffe (NS): Nash-Sutcliffe efficiency is a model performance measures technique which indicates how well the observed versus simulated data plots fits the 1:1 line.

$$NS = 1 - \frac{\sum_i (Q_{m,i} - Q_{s,i})^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

Where,

NS = Nash-Sutcliffe

Q = Discharge and the bar stands for average

m = Measured data

s = Simulated data

i = The i^{th} measured or simulated data

4.11. Evaluation of Land Use and Cover Change on Water Balance Components

To evaluate the changes of the simulated water balance components such as, surface runoff contribution to stream flow, ground water and lateral flow contribution to stream flow, actual and potential evapotranspiration due to land use and land cover change, the study was carried out for three different years (1987, 2001 and 2015). To evaluate the variability of the water balance components due to land use and land cover changes from 1987 to 2001, 2001 to 2015 and 1987 to 2015, three independent simulation runs were performed on monthly bases using the classified land use maps of 1987, 2001 and 2015 by keeping the other parameters unchanged. The following procedures was applied:

1. Delineated the watershed and simulated the model using land use map of 1987
2. Calibrated the model using the simulation result from land use map of 1987
3. Using the calibrated baseline scenario uploaded the new land use map for the period of 2001 and 2015.
4. Uploaded soil and slope map
5. Overlaying land use, soil and slope again and doing HRU analysis
6. Uploaded weather data
7. Creation of input and rewrite of land use data
8. Run the model again and read the output

Following the above procedures, the model was run for 13 years simulation period from 1993-2005 considering the first 3 years as a warmup period. Then the outputs from land use map of 1987, 2001 and 2015 was compared.

Chapter 5. RESULTS AND DISCUSSIONS

5.1. Land Use and Land Cover Analysis

5.1.1. Accuracy assessment

Accuracy assessment is used to evaluate the correctness of the classified image. For this study confusion matrix was used. Using google earth image as a reference and the original mosaic satellite image, there were randomly selected reference points for each land cover types. The randomly selected points were compared with the corresponding classified map. For the validation of classification 82, 85 and 108 points were selected for the year 1987, 2001 and 2015 images respectively. The overall accuracy, producer's accuracy and user's accuracy of Landsat images of 1987, 2001 and 2015 were calculated using the confusion matrix described in Table 5.1, 5.2 and 5.3, respectively.

The confusion matrix result of overall accuracy for the maps of 1987, 2001 and 2015 were 89%, 95.3% and 96.3% respectively. The most accurate map is 2015 which is the latest product of Landsat 8 satellite image. The minimum value suggested by Anderson (1976) for overall accuracy is 85%. Therefore, the classification carried out for this study for all land cover maps produces an overall accuracy that fulfils the minimum value suggested by Anderson (1976).

The producer's accuracy result for land use map of 1987, 2001 and 2015 ranges from 60% to 100%, 72.7% to 100% and 63.6% to 100% respectively. Whereas, the user's accuracy ranges from 75% to 96.7%, 85.7% to 100% and 88.9% to 100% respectively. The lowest values were misclassified due to the spectral similarity of different land uses.

The accuracy assessment results from the Kappa coefficient statistics $(\widehat{K})$ is 0.85, 0.94 and 0.95 for the period of 1987, 2001 and 2015 respectively. A kappa of 0.85 for the period of 1987 means there is 85% better agreement than by chance alone. Kappa of 0.94 for the period of 2001 means 94% better agreement than by chance alone. And for the period of 2015 there is 95% better agreement than by chance alone.

Table 5. 1. Confusion matrix for the classification of 1987 land use map

		Reference Data						
		CL	DF	OF	WL	WB	Total	Users Accuracy
Classified Image	CL	23	0	0	0	3	26	88.5%
	DF	0	8	2	0	0	10	80%
	OF	1	0	29	0	0	30	96.7%
	WL	0	0	0	7	1	8	87.5%
	WB	2	0	0	0	6	8	75%
	Total	26	8	31	7	10	82	
	Producers Accuracy	88.5%	100%	93.5%	100%	60%		Overall Accuracy = 89%

Note: CL=Cultivated Land; DF= Dense Forest; OF=Open Forest; WL=Wood Land; WB=Water Bodies

Table 5. 2. Confusion matrix for the classification of 2001 land use map

		Reference Data						
		CL	DF	OF	WL	WB	Total	Users Accuracy
Classified Image	CL	27	0	0	0	2	29	93.1%
	DF	0	6	1	0	0	7	85.7%
	OF	0	0	29	0	1	30	96.7%
	WL	0	0	0	11	0	11	100%
	WB	0	0	0	0	8	8	100%
	Total	27	6	30	11	11	85	
	Producers Accuracy	100%	100%	96.7%	100%	72.7%		Overall Accuracy = 95.3%

Note: CL=Cultivated Land; DF= Dense Forest; OF=Open Forest; WL=Wood Land; WB=Water Bodies

Table 5. 3. Confusion matrix for the classification of 2015 land use map

		Reference Data						
		CL	DF	OF	WL	WB	Total	Users Accuracy
Classified Image	CL	42	0	0	0	0	42	100%
	DF	0	7	0	0	0	7	100%
	OF	0	4	32	0	0	36	88.9%
	WL	0	0	0	10	0	10	100%
	WB	0	0	0	0	13	13	100%
	Total	42	11	32	10	13	108	
	Producers Accuracy	100%	63.6%	100%	100%	100%		Overall Accuracy=96.3%

Note: CL=Cultivated Land; DF= Dense Forest; OF=Open Forest; WL=Wood Land; WB=Water Bodies

5.1.2. Land use and land cover maps

Using supervised image classification techniques in Sore and Geba watershed five major land use types were identified such as cultivated land, dense forest, open forest, wood land and water bodies. Figure 5.1 showed the land use map of 1987, 2001 and 2015 that have been generated from Landsat-5-TM, Landsat-7-ETM+ and Landsat 8 image classification respectively. Over the last 30 years (1987-2015), in Sore and Geba watershed there is an increase of cultivated land and decrease of dense forest, open forest, wood land and water bodies. The total cultivated land area coverage in 1987 was about 33% and in 2001 about 34% of the total area of the watershed but in 2015 rapidly increased to 50%. This is because of the gain of land from the shrinkage of other types of land use due to population growth and deforestation. For example, the total area coverage of dense forest, open forest, wood land, and water bodies in 1987 land use and land cover maps was about 3%, 49%, 4% and 11% of the total area of the watershed respectively. However, in 2015 land use and land cover map it decreased to around 0%, 44%, 1% and 5% of the total area of Sore and Geba watershed. The individual area coverage and change statistics for the three periods 1987 to 2001, 2001 to 2015 and 1987 to 2015 are summarized in (Table 5.4).

Figure 5.2 clearly showed the physical comparison of classified land use types in 1987, 2001 and 2015 by bar graph using area coverage in percent.

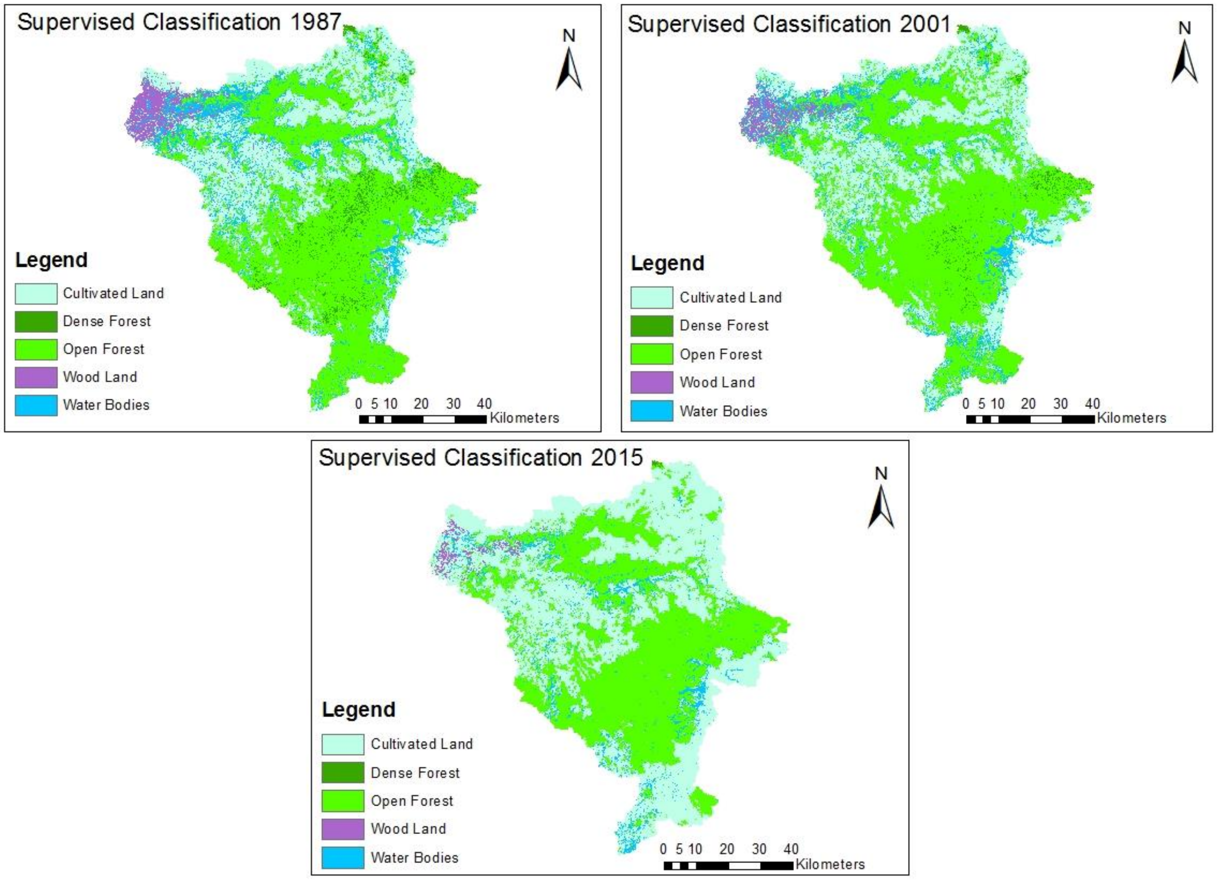

Figure 5. 1. Land cover map of Sore and Geba watershed in 1987, 2001 and 2015

Table 5. 4. Area of land use types and change statistics of Sore and Geba watershed for the period of 1987, 2001 and 2015

Land use types	1987		2001		2015		2001-1987		2015-2001		2015-1987	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Cultivated Land	2161.20	32.99	2240.62	34.20	3245.66	49.54	79.42	1.21	1005.04	15.34	1084.46	16.55
Dense Forest	222.04	3.39	84.52	1.29	4.14	0.06	-137.52	-2.10	-80.38	-1.23	-217.90	-3.33
Open Forest	3231.68	49.33	3447.04	52.62	2887.37	44.08	215.36	3.29	-559.66	-8.54	-344.30	-5.25
Wood Land	235.27	3.59	169.35	2.59	70.96	1.08	-65.92	-1.00	-98.39	-1.50	-164.31	-2.51
Water Bodies	700.88	10.70	609.54	9.30	342.94	5.24	-91.35	-1.40	-266.60	-4.07	-357.94	-5.46

The results of Change statistics are: -

- 1987-2001
  - Gain of cultivated land by 1.21% (79.42 km^2)
  - Loss of dense forest by 2.10% (137.52 km^2)
  - Gain of open forest by 3.29% (215.36 km^2)
  - Loss of wood land by 1.00% (65.92 km^2)
  - Loss of water bodies by 1.40% (91.35 km^2)
- 2001-2015
  - Gain of cultivated land by 15.34% (1005.04 km^2)
  - Loss of dense forest by 1.23% (80.38 km^2)
  - Loss of open forest by 8.54% (559.66 km^2)
  - Loss of wood land by 1.50% (98.39 km^2)
  - Loss of water bodies by 4.07% (266.60 km^2)

- 1987-2015
  - Gain of cultivated land by 16.55% (1084.46 km^2)
  - Loss of dense forest by 3.33% (217.90 km^2)
  - Loss of open forest by 5.25% (344.30 km^2)
  - Loss of wood land by 2.51% (164.31 km^2)
  - Loss of water bodies by 5.46% (357.94 km^2)

The results revealed from this study is consistent with the results of previous study in different parts of Ethiopia. For example, in south western parts of Ethiopia forest cover was diminished from 19.55% in 1986 to 11.8% by 2001 (Wubie, 2016). In Blue Nile basins of Ethiopia within the period of four decades (1957 to 2001) forest cover and shrub grassland decreases by 64% and 6% respectively and consistent increase of cultivated land and rural settlement were identified (Bewket and Abebe, 2013).

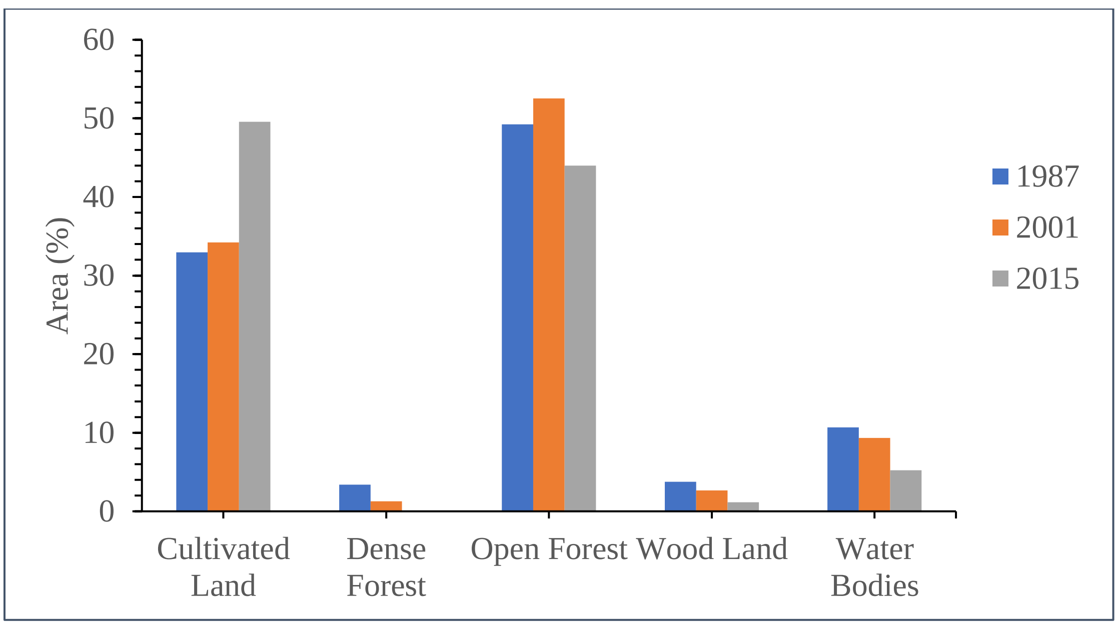

Figure 5. 2. Comparison graph of land use types for the year 1987, 2001 and 2015

5.2. Sensitivity Analysis, Calibration and Validation

5.2.1. Sensitivity analysis

The sensitive parameters were selected based on Global sensitivity embodied in SWAT-CUP. The t-stat and the p-value in SWAT-CUP helps one to identify sensitive parameters. The larger, in absolute value, the value of t-stat and the smaller the p-value, the more sensitive the parameters (Abbaspour, 2015). Nine sensitive flow parameters were obtained for Sore and Geba watershed based on t-stat and p-value from Sore river gauge simulation. These sensitive parameters are SCS runoff curve number for moisture condition II (CN2), groundwater delay time (GW_DELAY), maximum canopy storage (CANMX), available water capacity of the soil layer (SOL_AWC), soil evaporation compensation factor (ESCO), base flow alpha factor (ALPHA_BF), manning's "n" value for the main channel (CH_N2), threshold depth of water in the shallow aquifer for "revaporation" to occur (REVAPMN), threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN). The rank of parameter sensitivity and final fitted values are described in (Table 5.5 and 5.6). The first three most flow sensitive parameters for Sore and Geba watershed were SCS runoff curve number for moisture condition II (CN2) followed by groundwater delay time (GW_DELAY) and maximum canopy storage (CANMX).

Table 5. 5. Sensitive parameter rank and descriptions

Rank	Sensitive Parameter Name	Definition
1	R__CN2.mgt	SCS runoff curve number for moisture condition II
2	V__GW_DELAY.gw	Groundwater delay time (days)
3	V__CANMX.hru	Maximum canopy storage
4	V__SOL_AWC(..).sol	Available water capacity of the soil layer (mm H_2O/mm soil)
5	R__ESCO.bsn	Soil evaporation compensation factor
6	V__ALPHA_BF.gw	Base flow alpha factor (days)
7	V__CH_N2.rte	Manning's "n" value for the main channel
8	V__REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)
9	V__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)

Table 5. 6. Final fitted values of sensitive parameters

Parameter Name	Fitted Value	Minimum Value	Maximum Value
R__CN2.mgt	-0.051024	-0.093816	0.118816
V__GW_DELAY.gw	-106.372864	-179.280151	240.330139
V__CANMX.hru	67.032516	6.423392	68.826607
V__SOL_AWC(..).sol	0.453067	0.180464	0.727036
R__ESCO.bsn	0.712795	0.386736	1.160764
V__ALPHA_BF.gw	0.097154	-0.063264	0.645764
V__CH_N2.rte	0.09431	-0.042398	0.185925
V__REVAPMN.gw	319.604065	177.74379	533.506226
V__GWQMN.gw	0.527521	-0.179022	1.274022

5.2.2. Calibration and validation

The model was calibrated using SWAT-CUP computer program by sequential uncertainty fitting (SUFI-2) algorithm. The model was evaluated using goodness of fit measures of Coefficient of Determination (R^2) and Nash-Sutcliffe efficiency (NS) values. The value of R^2 ranges from 0 which indicates the model performance is poor to 1 which is good and the value of NS ranges from negative infinity to 1. The larger the value of R^2 and *NS* the better the agreement between measured and simulated flows. The other model prediction uncertainty measures selected for this study was p-factor and r-factor. The value of p-factor ranges between 0 and 100% while the value of r-factor ranges between 0 and an infinity. A threshold value suggested by (Abbaspour, 2015) >70% of p-factor and having r-factor of around 1 is recommended for a better result of calibration of a model by SWAT-CUP. The p-factor indicates the percentage of measured data bracketed by the 95% prediction uncertainty (95 PPU) and it provides the models ability to capture uncertainties. The r-factor indicates the thickness of the 95 PPU and it is a measure of the quality of the calibration.

The model was calibrated for Sore and Geba watershed with Sore river gauging station. Figure 5.3 shows the time series plot comparison of measured and simulated monthly stream flows for Sore and Geba watershed at Sore river over five years (1996-2000) calibration and (2001-2005) validation periods. The SWAT model accurately tracked the lowest observed stream flows but some of the highest observed flows in the first year of simulation was over predicted for both calibration and validation period. However, the simulated flows in calibration period is closely followed the observed flows than the validation period. The model performance measures statistics during calibration were stronger than those computed for validation period. According to a threshold values suggested by different scholars the computed statistics for Sore and Geba watershed showed satisfactory result for both calibration and validation periods. For example, for monthly data simulation the p-factor 0.78, r-factor 1.02, coefficient of determination (R^2) 0.8 and Nash-Sutcliffe efficiency (NS) 0.79 during calibration period where as during validation period the p-factor 0.78, r-factor 1.26, coefficient of determination (R^2) 0.75 and Nash-Sutcliffe efficiency (NS) 0.54. In general, the statistics shows that a strong correlation between simulated and measured values.

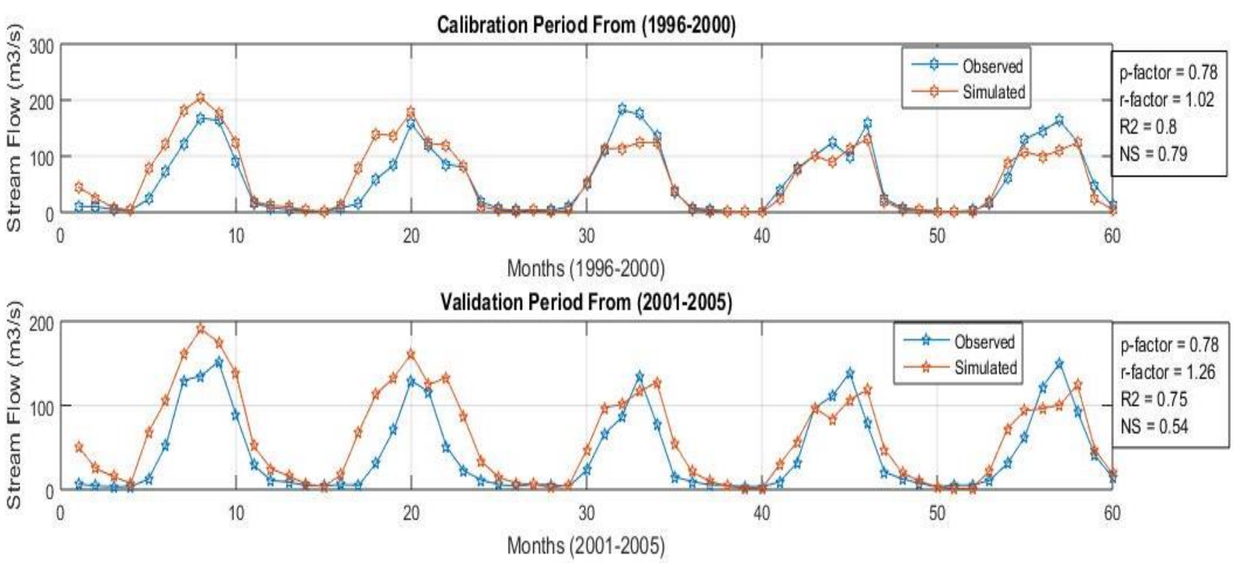

Figure 5. 3. Time series plot of observed and simulated stream flow at sore river gauging station for calibration and validation period

Table 5. 7. Comparison of measured and simulated average monthly stream flow at Sore river gauging station for calibration and validation period

Period	Average Monthly Flow (m^3/s)		p-factor	r-factor	R^2	NS
	Measured	Simulated				
Calibration (1996-2000)	56.75	60.47	0.78	1.02	0.8	0.79
Validation (2001-2005)	43.12	61.34	0.78	1.26	0.75	0.54

As shown in Table 5.7, the simulated average monthly stream flow at Sore river gage for both calibration and validation periods were pretty much close to observed flows with the agreement slightly is better in calibration period. Overall, the model performance was good.

Results of this study are consistent with other studies in different parts of Ethiopia. The study conducted by Mengistu and Sorteberg (2012) in Baro-Akobo river basin for calibration and validation of monthly streamflow simulation at Gambela gauging station gives the Nash-Sutcliffe efficiency (NS) 0.9 and Coefficient of Determination (R^2) 0.92 for calibration period and 0.81 and 0.89 for validation period, respectively.

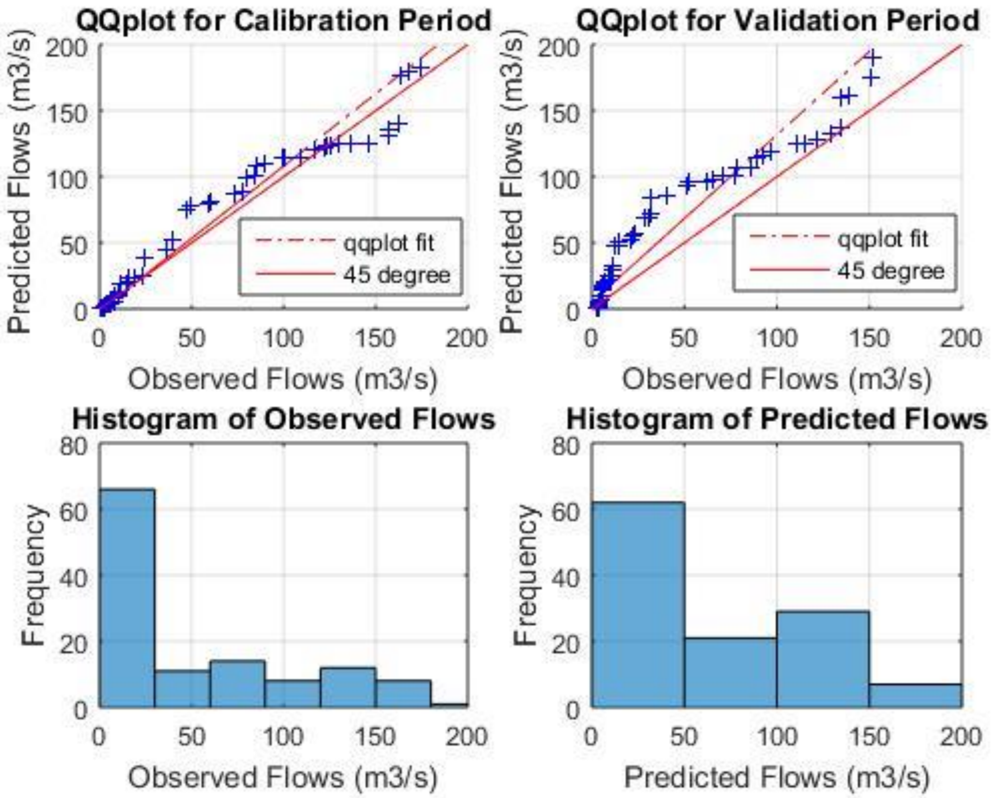

Figure 5. 4. qqplot and histogram of observed and simulated stream flow at Sore river gauging station

The qqplot in Figure 5.4 shows some of the highest flows are under predicted by the model during the calibration period. Whereas, during validation, except for the lowest flows, almost all other flows were over predicted. Also, the histogram in Figure 5.4 shows that the lowest flows are more frequent than the highest flows on both predicted and observed flows.

5.3. Hydrology of the Study Watershed

Major monthly and yearly hydrological components of Sore and Geba watershed such as rainfall, surface runoff (SURFQ), lateral flow (LATQ), water yield, actual evapotranspiration (ET) and potential evapotranspiration (PET) were simulated for the periods of 1987, 2001 and 2015 land use and land cover maps. Average simulated monthly basin values of such hydrological components for the periods of 1987, 2001 and 2015 are described in Tables 5.8, 5.9 and 5.10, respectively. The hydrological cycle of Sore and Geba watershed simulated from 1996 to 2005 using land use and land cover map of 1987, 2001 and 2015 are illustrated in Appendix 1.

Table 5. 8. Simulated average monthly basin values from land use map of 1987

Month	RAIN (mm)	SURFQ (mm)	LATQ (mm)	WATER YIELD (mm)	ET (mm)	PET (mm)
Jan	31.13	2.61	3.05	9.45	43.28	106.68
Feb	18.26	0.38	1.34	3.79	43.08	116.52
Mar	63.46	0.61	1.74	3.71	88.17	136.16
Apr	107.77	1.36	1.81	4.4	105.35	127.6
May	211.65	7.48	9.41	24.92	106.29	116.61
Jun	274.38	23.27	27.73	92.95	95.11	99.37
Jul	268.81	35.78	36.58	151.98	90.49	94.59
Aug	290.71	49.11	42.82	188.91	91.67	97.5
Sep	263.79	36.03	43.66	178.56	86.72	102.11
Oct	179.16	25.81	33.81	136.6	71.6	102.79
Nov	51.87	5.56	11.27	40.61	53.87	96.86
Dec	22.55	1.28	3.62	11.2	43.19	98.85

Table 5. 9. Simulated average monthly basin values from land use map of 2001

Month	RAIN (mm)	SURFQ (mm)	LATQ (mm)	WATER YIELD (mm)	ET (mm)	PET (mm)
Jan	31.14	2.67	3.16	9.66	40.68	104.68
Feb	18.26	0.42	1.38	3.9	40.51	114.67
Mar	63.47	0.76	1.82	3.97	86.11	134.01
Apr	107.78	1.57	1.87	4.74	104.07	125.54
May	211.65	7.66	9.84	25.67	105.32	114.46
Jun	274.39	23.42	28.96	95.01	94.45	97.3
Jul	268.81	35.88	38.01	154.8	89.84	92.54
Aug	290.7	49.72	44.56	193.43	91.03	95.42
Sep	263.79	36.18	45.48	183.12	86.07	100.01
Oct	179.16	26.31	35.24	140.73	69.98	100.71
Nov	51.87	5.63	11.65	41.62	51.74	94.93
Dec	22.55	1.3	3.74	11.43	41	96.89

Table 5. 10. Simulated average monthly basin values from land use map of 2015

Month	RAIN (mm)	SURFQ (mm)	LATQ (mm)	WATER YIELD (mm)	ET (mm)	PET (mm)
Jan	31.13	3.25	3.28	10.58	36.41	101.44
Feb	18.26	0.67	1.44	4.29	35.88	111.66
Mar	63.46	1.39	2.26	5.2	80.98	130.52
Apr	107.77	2.39	2.18	6.08	102.72	122.21
May	211.65	9.22	10.18	27.78	104.45	110.99
Jun	274.38	26.98	30.1	101.04	93.29	93.96
Jul	268.81	41.11	39.59	164.15	88.67	89.24
Aug	290.71	55.83	46.05	203.44	89.36	92.07
Sep	263.79	41.55	47.43	193.11	81.79	96.61
Oct	179.16	30.38	37.01	149.64	63.21	97.34
Nov	51.87	6.76	12.24	44.65	46.36	91.81
Dec	22.55	1.66	3.91	12.37	36.54	93.71

5.4. Effect of Land Use and Land Cover Change on Surface Runoff

The impacts of land use and land cover changes on surface runoff are derived from the model output comparison from land use and cover maps of the year 1987, 2001 and 2015. The simulated average annual basin values of surface runoff contribution to streamflow (SURFQ) from land use maps of the year 1987, 2001 and 2015 are described in (Table 5.11). Figures 5.5 and 5.6 also illustrated the simulated average monthly and annual surface runoff results respectively from land use maps of 1987, 2001 and 2015 using bar graph. By considering the 1987 land use and cover map as a baseline scenario the changes of average monthly and annual surface runoff during the periods of 1987 to 2001, 2001 to 2015 and 1987 to 2015 are calculated using simple change statistics formula (Tables 5.12 and 5.13). The annual simulated amount of surface runoff contribution to stream flow from land use map of 1987, 2001 and 2015 are 39.32 m^3/s (189.28 mm), 39.78 m^3/s (191.52 mm) and 45.95 m^3/s (221.19 mm) respectively. The average annual contribution of surface runoff to stream flow increased from 39.32 m^3/s to 39.78 m^3/s due to the land use and land cover change occurred between the periods of 1987 and 2001 (increased by 1.18%). The land use change occurred between the periods of 2001 and 2015 leads to increase the surface runoff from 39.78 m^3/s to 45.95 m^3/s (which is increased by 15.49%). Whereas, during the period of 1987 and 2015 land use land cover change the surface runoff contribution to stream flow increased from 39.32 m^3/s to 45.95 m^3/s (which is increased by 16.86%).

The average monthly and annual contribution of surface runoff to stream flow during the periods of 1987 and 2001 land use and land cover change doesn't show significant change. However, during the periods of 2001 and 2015 the surface runoff is rapidly increased by 15.49%. This is because of the expansion of cultivated land over dense and open forest between the periods of 2001 and 2015 that resulted in increased surface runoff following rainfall events. The increments of cultivated land in between the periods of 1987 and 2001 is 1.21% while between the periods of 2001 and 2015 the cultivated land increased by 15.34%. The higher increment of surface runoff in between the periods of 2001 and 2015 in Sore and Geba watershed is strongly related to the expansion of cultivated land. Figure 5.7 illustrated the spatial distribution of simulated surface runoff using land use map of 1987, 2001 and 2015. The spatial distribution of changes in surface runoff due to land use changes between 1987 and 2015 are described in (Figure 5.8).

Table 5. 11. Simulated average annual SURFQ basin values from land use map of 1987, 2001 and 2015

Year	1987	2001	2015
SURFQ (mm)	189.28	191.52	221.19
(m^3/s)	39.32	39.78	45.95

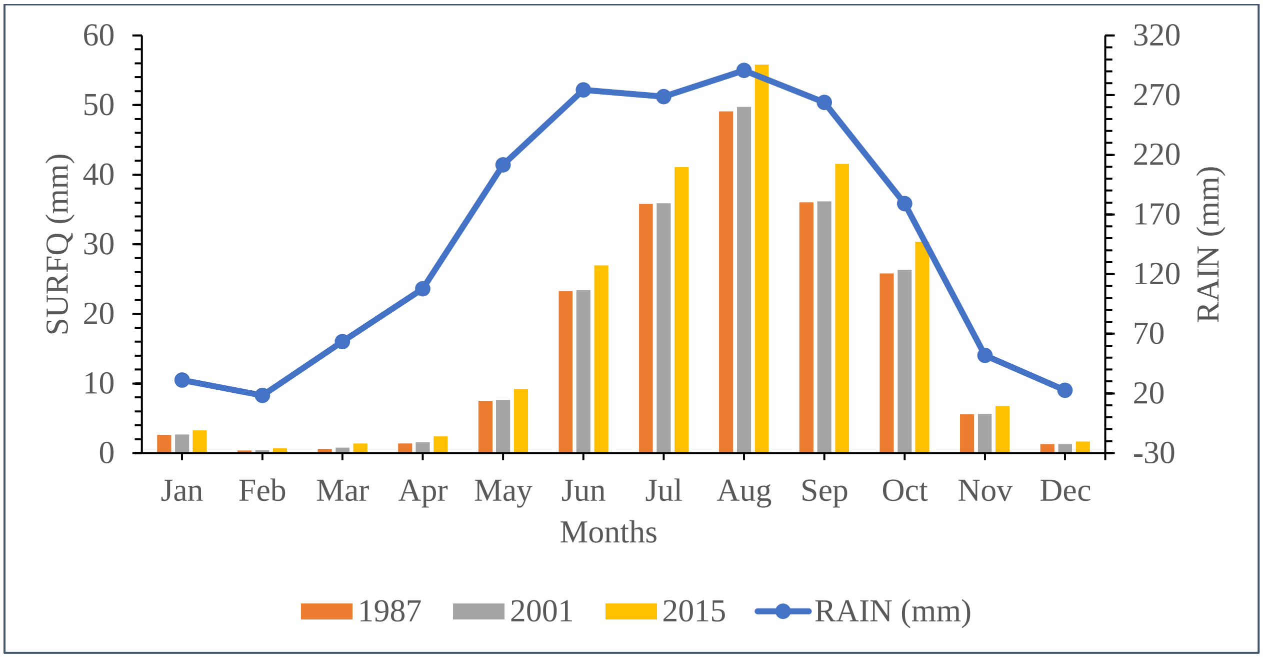

Figure 5. 5. Simulated average monthly SURFQ and RAIN basin values from land use map of 1987, 2001 and 2015

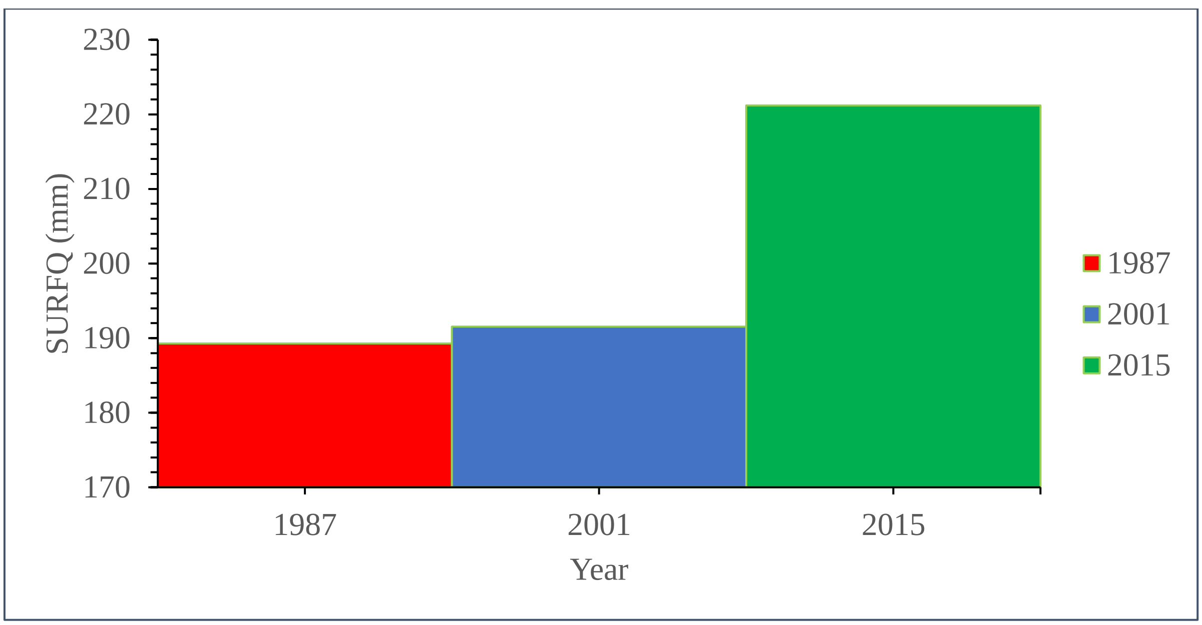

Figure 5. 6. Simulated average annual SURFQ basin values from land use map of 1987, 2001 and 2015

Table 5. 12. Average monthly surface runoff basin values change statistics for the period of 1987, 2001 *and* 2015.

Year	1987	2001	2015	2001 - 1987		2015 - 2001		2015 - 1987	
Month	SURFQ (mm)	SURFQ (mm)	SURFQ (mm)	mm	(%)	mm	(%)	mm	(%)
Jan	2.61	2.67	3.25	0.06	2.30	0.58	21.72	0.64	24.52
Feb	0.38	0.42	0.67	0.04	10.53	0.25	59.52	0.29	76.32
Mar	0.61	0.76	1.39	0.15	24.59	0.63	82.89	0.78	127.87
Apr	1.36	1.57	2.39	0.21	15.44	0.82	52.23	1.03	75.74
May	7.48	7.66	9.22	0.18	2.41	1.56	20.37	1.74	23.26
Jun	23.27	23.42	26.98	0.15	0.64	3.56	15.20	3.71	15.94
Jul	35.78	35.88	41.11	0.10	0.28	5.23	14.58	5.33	14.90
Aug	49.11	49.72	55.83	0.61	1.24	6.11	12.29	6.72	13.68
Sep	36.03	36.18	41.55	0.15	0.42	5.37	14.84	5.52	15.32
Oct	25.81	26.31	30.38	0.50	1.94	4.07	15.47	4.57	17.71
Nov	5.56	5.63	6.76	0.07	1.26	1.13	20.07	1.20	21.58
Dec	1.28	1.3	1.66	0.02	1.56	0.36	27.69	0.38	29.69

Table 5. 13. Average annual surface runoff basin values change statistics for the period of 1987, 2001 *and* 2015

Year	1987	2001	2015	2001 - 1987		2015 - 2001		2015 - 1987	
SURFQ					(%)		(%)		(%)
(mm)	189.28	191.52	221.19	2.24	1.18	29.67	15.49	31.91	16.86
(m^3/s)	39.32	39.78	45.95	0.47		6.16		6.63	

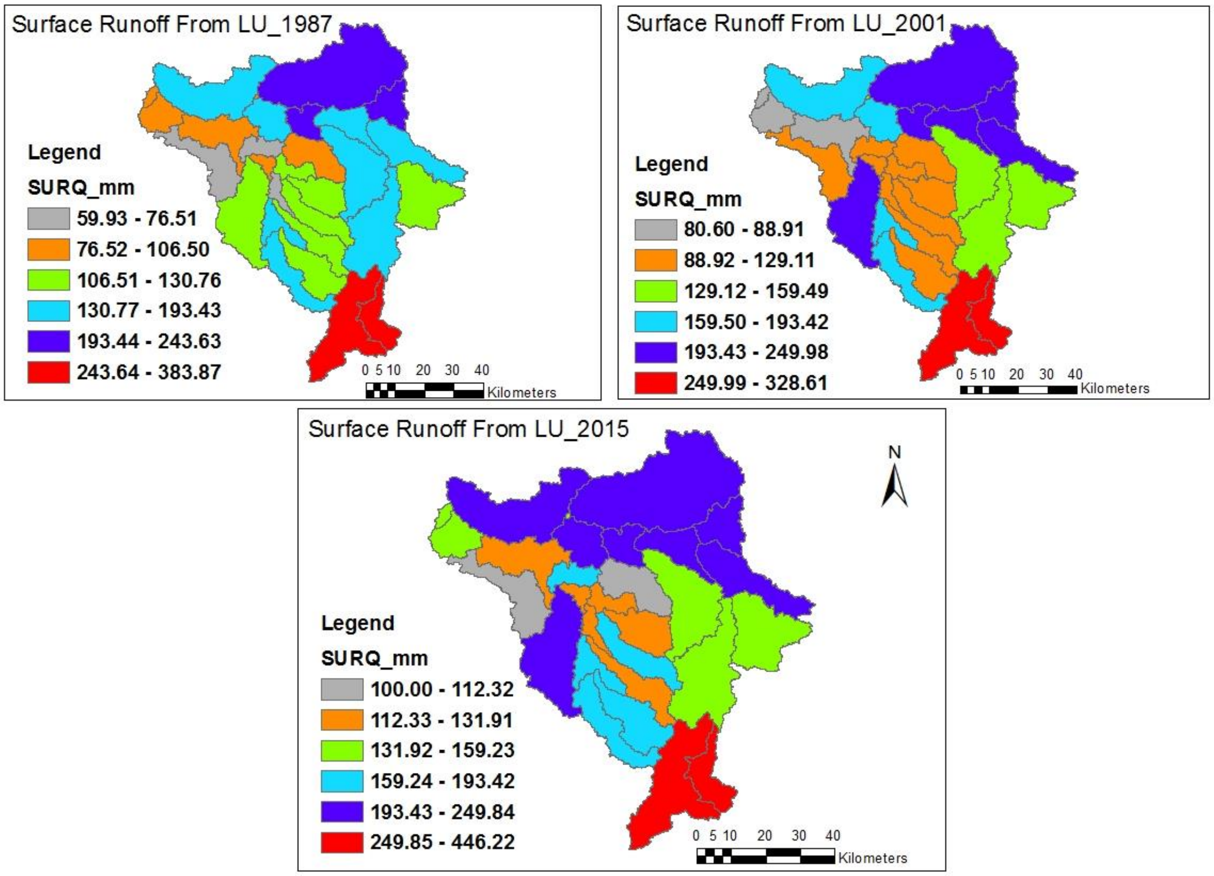

Figure 5. 7. Spatial distribution of simulated surface runoff using land use map of 1987, 2001 and 2015

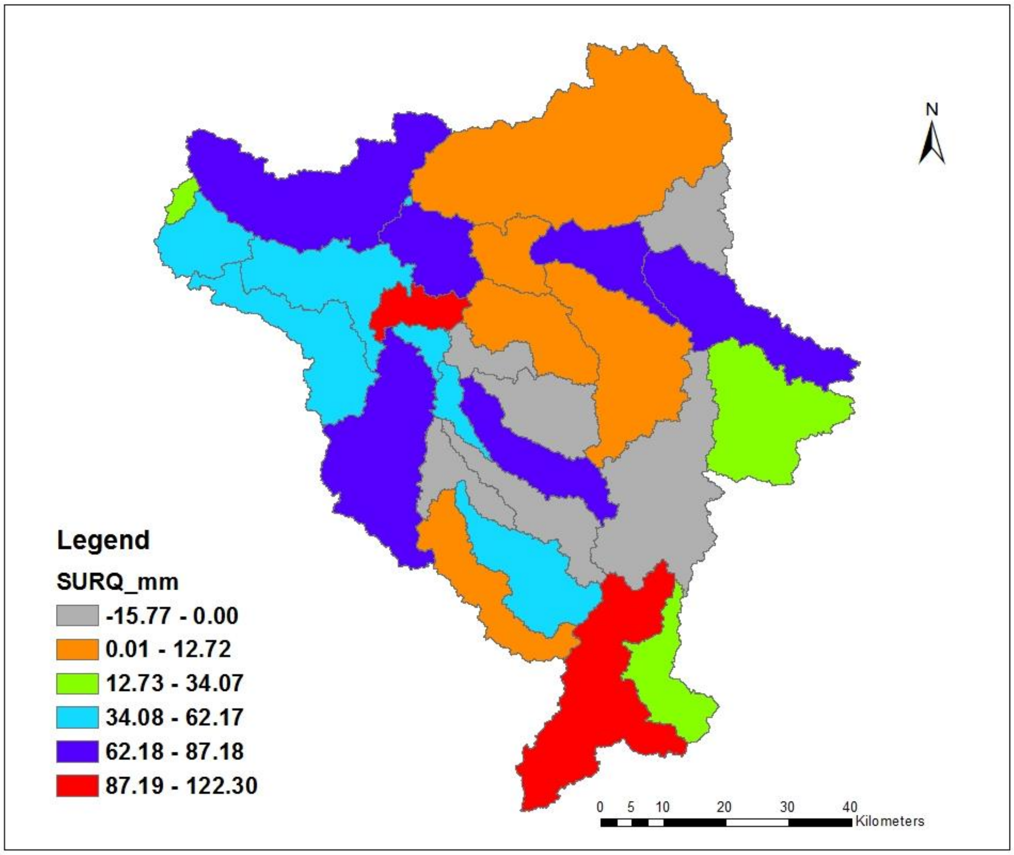

Figure 5. 8. Spatial distribution of change in surface runoff due to land use changes between 1987 and 2015

5.5. Land Use and Land Cover Change on Water Yield and Sediment Loading

To understand the effects of land use and land cover change on water yield and sediment loading the analysis was made by comparing the simulation results of the model from 1987, 2001 and 2015 land use and land cover maps. Table 5.14 demonstrates the average annual simulated sediment loading and water yield and it's change statistics for the period of 1987, 2001 and 2015. During the periods of 1987 and 2001 land use and land cover change, the water yield increased from 175 m^3/s to 180.34 m^3/s (increased by 4.36 m^3/s) and the sediment loading increased from 23 t/ha to 25.80 t/ha (increased by 1.92 t/ha). In between 2001 and 2015, the water yield increased from 180.34 m^3/s to 191.61 m^3/s (an increase of 11.27 m^3/s) and the sediment loading increased from 25.80 t/ha to 41.92 t/ha (increased by 16.12 t/ha). In general, within the periods of 30 years (1987 to 2015) land use and land cover change leads to increased water yield by 15.64 m^3/s (75.27 mm) and sediment loading by 18.03 t/ha. This increment was explained as the water yield is increased by 0.52 m^3/s and the sediment loading is increased by 0.60 t/ha annually. These results showed that the land use and land cover change has significant change on surface runoff, water yield and sediment loading.

Table 5. 14. Annual average simulated total sediment loading and water yield with their change statistics from land use map of 1987, 2001 and 2015

Year	1987	2001	2015	2001-1987	2015-2001	2015-1987
Water yield (mm)	847.11	868.12	922.38	21.01	54.26	75.27
(m^3/s)	175.97	180.34	191.61	4.36	11.27	15.64
Sediment loading (t/ha)	23.89	25.80	41.92	1.92	16.12	18.03

5.6. Implication of Land Use Change on Stream Flow

To understand the implication of land use and land cover change on stream flow in Sore and Geba watershed the stream flow obtained from the whole watershed were used that simulated from (1996-2005) using land use map of 1987, 2001 and 2015. Simulated mean monthly stream flow resulted from using land use map of 1987, 2001 and 2015 are shown in Table 5.15. The highest mean monthly stream flow simulated using land use map of 1987 occurred in August which is equal to 499.70 m^3/s and the minimum stream flow occurred in March which is 7.73 m^3/s. From land use map of 2001 the simulated highest mean monthly stream flow is occurred in August which is equal to 499.73 m^3/s and the minimum stream flow is 8.31 m^3/s which is occurred in March. The highest mean monthly streamflow simulated using land use map of 2015 occurred in August which is equal to 501.42 m^3/s while the minimum flow occurred in February and equal to 10.05 m^3/s. The mean annual stream flow simulated using land use map of 1987, 2001 and 2015 is 188.06 m^3/s, 187.92 m^3/s and 190.84 m^3/s, respectively (Figure 5.9). The highest mean annual stream flow is obtained from the simulated result of land use map of 2015. This is because of the highest cultivated land in 2015 than 2001 and 1987. The mean annual stream flow obtained from land use map of 2001 is lower than 2015 and 1987 because of the highest area coverage of open forest. The stream flow is increased by 2.78 m^3/s due to land use and land cover change occurred between the periods of 1987 and 2015. In general, within the periods of 1987 and 2001 there is no significant change on stream flow because of the similarity of area coverage of land use types.

Table 5. 15. Mean monthly stream flow simulated using land use map of 1987, 2001 and 2015

Month	Mean monthly streamflow (m^3/s)		
	LU_1987	LU_2001	LU_2015
Jan	23.15	23.44	24.59
Feb	9.07	9.35	10.05
Mar	7.73	8.31	10.89
Apr	9.92	10.95	13.67
May	63.92	64.61	67.08
Jun	253.39	252.31	256.66
Jul	401.03	399.63	404.85
Aug	499.70	499.73	501.42
Sep	488.79	487.63	491.16
Oct	362.01	361.47	367.98
Nov	109.86	109.51	112.58
Dec	28.19	28.07	29.17

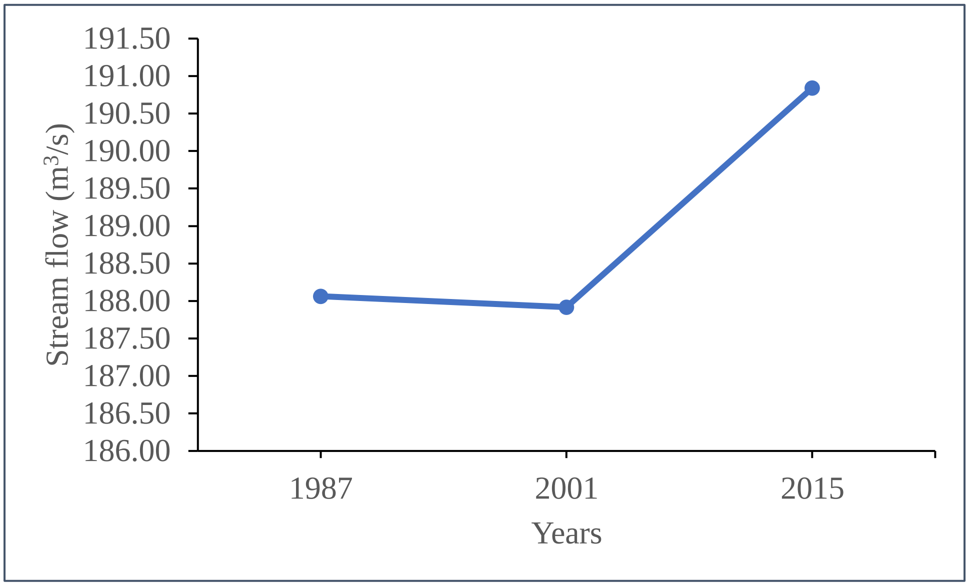

Figure 5. 9. Simulated average annual stream flow using land use map of 1987, 2001 and 2015

5.8. Environmental Implication of the Observed Surface Runoff

The change of land use and land cover has made a significant effect on the hydrology including surface runoff, stream flow, evapotranspiration, sediment loading and water yield of the study watershed. Vegetation cover helps to reduce the soil erosion by intercepting and dissipating the erosive energy of raindrops, runoff and wind. It has also a role in reducing the volume of runoff through increasing the infiltration by following the root system and increases soil organic content which increase the aggregate stability of the soil. Within the study period there has been a decline of natural forests and expansion of agricultural lands. As can be quantified in this study the expansion of agricultural lands generates highest surface runoff. This highest surface runoff will accelerate the erosion process such as detachment and transportation. Sediment loading was also highest due to the expansion of agricultural lands. All this phenomenon has an implication on the environment such as biodiversity loss, flooding and sedimentation on the downstream water storage structures.

Chapter 6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Quantifying and understanding the impacts of land use and land cover change on local hydrology is one of the most important steps in implementing land use planning and water resource management of a region. The aim of this study was to assess impacts of land use and land cover change on surface runoff in Sore and Geba watershed, the upper main tributaries of Baro river basin. To achieve this objective, satellite images, remote sensing and GIS software, and a hydrological model were used. Landsat images were used to analyze the land use and land cover change trends for the periods of three decades (1987-2015). Landsat-5-TM, Landsat-7-ETM+ and Landsat 8 image were used to identify the land use and land cover in Sore and Geba watershed for the period of 1987, 2001 and 2015, respectively. A supervised classification technique using maximum likelihood algorithm was used to conduct land use classification. Using this algorithm, the land use map of 1987, 2001 and 2015 were produced and the accuracy assessment of the three maps were checked by using the confusion matrix. Subsequently, SWAT model was developed for the region using historical data as well as those generated in this study. A sensitivity analysis was conducted to understand key parameters that control the local hydrological processes and was used to guide the calibration process. The calibrated model was independently validated using data that was held from the calibration process to make sure that the model is able to replicate hydrological conditions that are outside of the calibration period. The performance of the model in both calibration and validations periods was assessed using several statistics including the values of coefficient of determination (R^2), Nash-Sutcliffe (NS), p-factor, and r-factor, which resulted in good agreement with historical data. This provides confidence in the model in reproducing local scale hydrological processes. The impacts of land use and land cover change on surface runoff were then analyzed using this calibrated and validated model using land use maps of the year 1987, 2001 and 2015. Processing of land use data, soil data layers, digital elevation model (DEM) and post-processing of model results were conducted within a GIS environment.

Land use and land cover trend analysis within the periods of three decades from 1987 to 2015 in Sore and Geba watershed shows a significant change over the years. The area coverage of cultivated land, open forest, dense forest, wood land, and water bodies of Sore and Geba watershed in 1987 were 33%, 49%, 3%, 4% and 11% of the total watershed, respectively. Whereas, in 2015 open forest, dense forest, wood land and water bodies diminished to 44%, 0%, 1% and 5% of the total watershed respectively. Whereas the coverage of cultivated land increased to 50% of the total watershed. Cultivated land is gained from other types of land use. Scattered rural settlements that are closely associated with cultivated land were increased in the last three decades. The highest land use and land cover change was occurred during the periods of between 2001 and 2015 because of deforestation.

In the study watershed, nine sensitive flow control parameters were identified using SWAT-CUP computer program by SUFI-2 algorithm that were targets of the calibration process. During the calibration period, values of Nash-Sutcliffe (NS), coefficient of determination (R^2), p-factor and r-factor were 0.79, 0.8, 0.78 and 1.02 respectively. Whereas for the validation period the values were 0.54, 0.75, 0.78 and 1.26 respectively. This performance is deemed satisfactory for both calibration and validation period.

After calibration and validation of the SWAT model, the effects of land use and land cover change on surface runoff and stream flow was evaluated. The observed land use and land cover change shows a significant change on the hydrological process of the study watershed particularly surface runoff, stream flow, evapotranspiration, and groundwater flow. The simulated average annual surface runoff from land use and land cover map of 1987 was 189.28 mm while from land use map of 2015 the average annual surface runoff increased to 221.19 mm. This result showed that during the last three decades (1987-2015) land use and land cover change indicated an increase of surface runoff by 16.86%. The average annual stream flow increased from 188.06 m^3/s to 190.84 m^3/s between the periods of 1987 and 2015 land use and land cover change. The quantified land use and land cover change and surface runoff has an implication on the environment, such as loss of biodiversity, loss of top soil by erosion, flooding and sedimentation problems in the downstream communities.

6.2. Recommendation

- Land use and land cover change analysis result shows a significant increase in agricultural land use type in the area at the expense of forest lands. Therefore, promoting non-timber forest products, planning and regulating the expansion of settlements and soil fertility management activities should be implemented. This would increase existing farming productivity and help in controlling the expansion of cultivated land.
- Due to the land use and land cover change in the study area the magnitude of surface runoff and sediment loading have increased. This would affect the communities living in the area and further the downstream. Therefore, integrated watershed management activities should be practiced to control soil erosion and sedimentation related problems.

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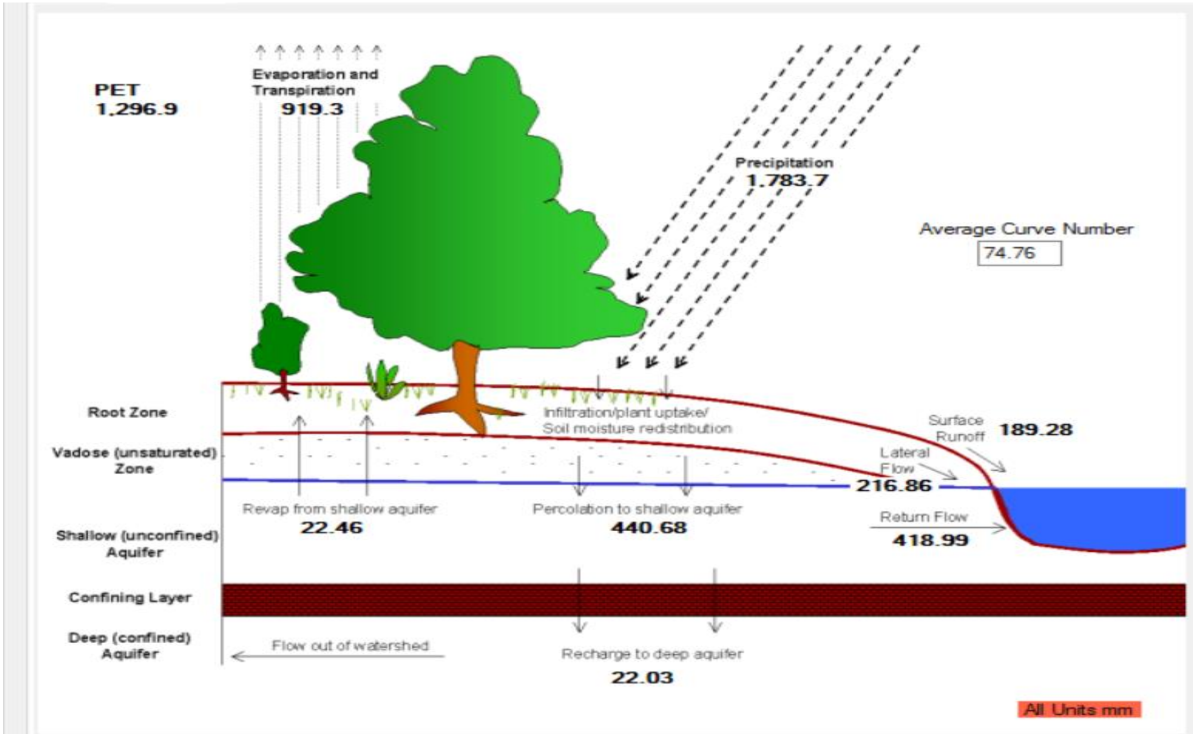
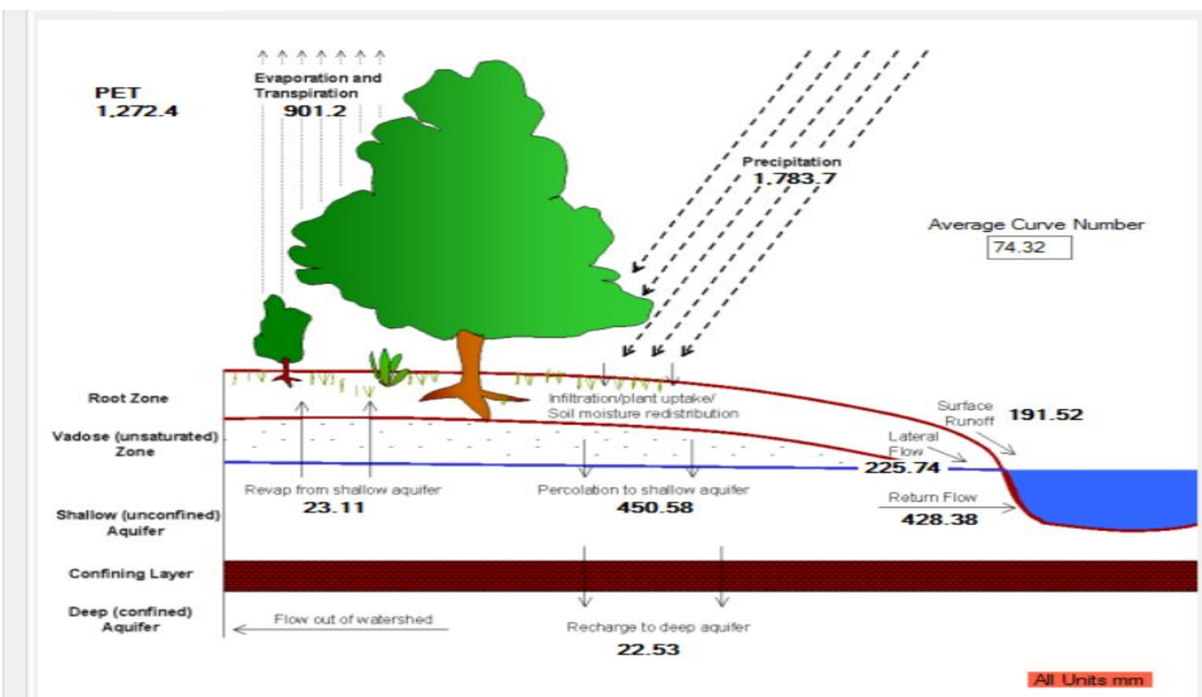
Appendix

Appendix 1. Hydrologic cycle simulated from land use map of 1987, 2001 and 2015

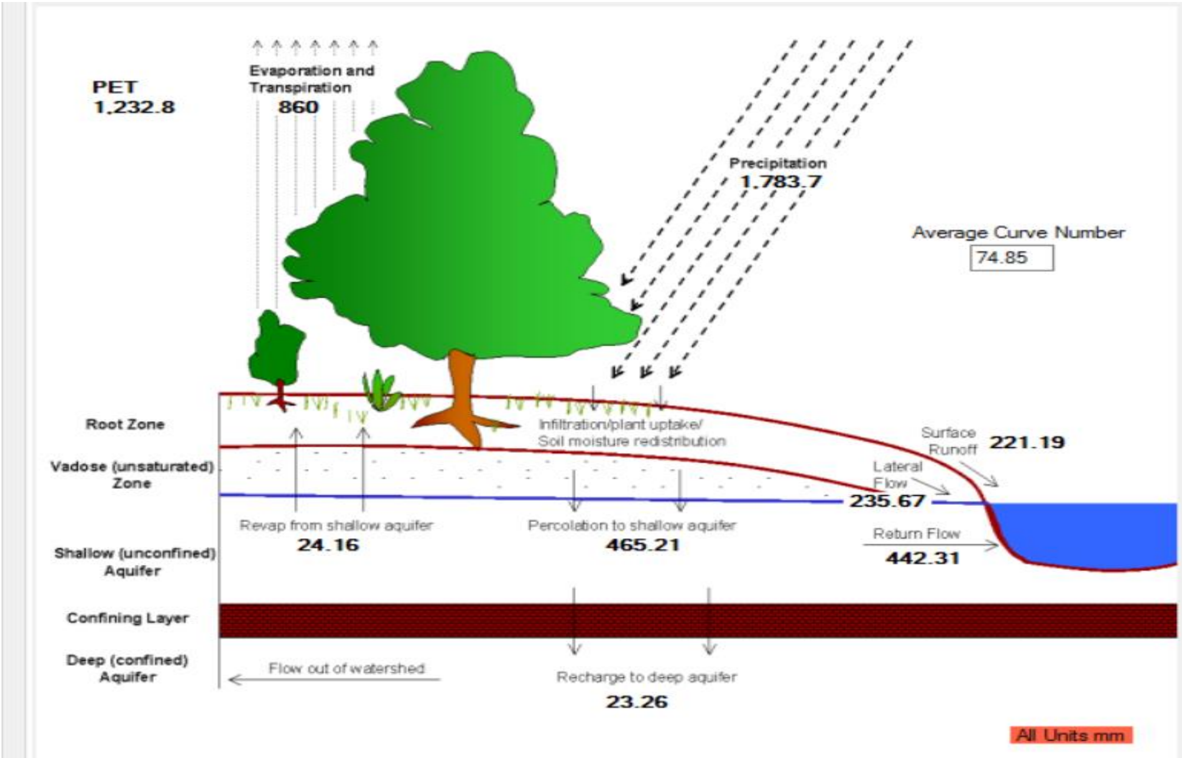
Hydrologic cycle simulated from land use map of 1987



Hydrologic cycle simulated from land use map of 2001



Hydrologic cycle simulated from land use map of 2015



Appendix 2. Measured average monthly Stream flow (m^3/s) from Sore river gauging used for calibration and validation

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	10.82	9.96	4.96	3.66	23.78	73.88	122.07	167.81	163.74	89.95	16.20	8.24
1997	4.94	3.11	2.12	7.72	15.62	59.09	84.42	157.58	117.24	85.33	80.32	18.58
1998	6.04	3.24	4.68	3.14	10.28	49.16	109.36	182.87	174.32	136.48	36.55	7.73
1999	4.61	2.26	1.08	1.75	39.85	78.07	101.04	123.63	99.96	157.60	24.27	7.70
2000	4.61	2.00	1.26	3.00	15.01	60.07	130.03	145.68	162.92	125.24	46.95	11.68
2001	6.59	4.17	3.33	3.55	12.42	52.46	129.46	135.04	151.99	88.72	29.15	10.72
2002	8.88	4.72	4.24	5.89	5.05	31.38	70.87	129.45	115.61	51.04	22.26	11.15
2003	5.77	3.85	6.10	5.62	3.87	23.22	65.64	85.83	135.09	77.77	15.06	9.44
2004	5.61	4.91	3.49	3.52	8.92	31.65	96.96	110.66	138.73	78.29	20.70	12.70
2005	7.49	3.03	5.28	5.13	11.12	30.81	62.48	121.60	150.44	92.94	40.61	14.57

Appendix 3. Statistical analysis of daily precipitation data of Gore station used for weather generator

Statistical	Analysis	of	Daily	Precipitation	Data	(1991	-	2010)			
Input	Filename	=	Gopcp.txt								
Number	of	Years	=	20							
Number	of	Leap	Years	=	5						
Number	of	Records	=	7305							
Number	of	NoData	values	=	0						
	Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD				
	Jan.	37.48	5.3813	9.6227	0.1022	0.5135	5.55				
	Feb.	27.74	3.447	5.4926	0.1425	0.367	5.45				
	Mar.	68.16	4.7527	2.8018	0.2041	0.6272	11.4				
	Apr.	117.05	7.8174	3.3833	0.293	0.6643	14.3				
	May.	213.16	9.4491	2.1289	0.4746	0.781	22.15				
	Jun.	250.94	9.8541	2.2634	0.7654	0.8439	25.95				
	Jul.	269.2	10.3834	1.8844	0.8806	0.8626	27.65				
	Aug.	288.77	11.0558	1.9559	0.9492	0.8717	28.05				
	Sep.	251.75	8.95	1.7216	0.8197	0.8738	26.95				
	Oct.	183.91	9.0046	2.9595	0.3641	0.7826	20.7				
	Nov.	69.76	5.6003	3.5347	0.2159	0.545	10.55				
	Dec.	33.29	3.4596	4.7362	0.1437	0.4643	7				
	PCP_MM	=	average	monthly	precipitation	[mm]					
	PCPSTD	=	standard	deviation							
	PCPSKW	=	skew	coefficient							
	PR_W1	=	probability	of	a	wet	day	following	a	dry	day
	PR_W2	=	probability	of	a	wet	day	following	a	wet	day
	PCPD	=	average	number	of	days	of	precipitati	in	month	
	(written	by	Stefan	Liersch,	Berlin,	August	2003)				

Appendix 4. Average daily dew point temperature used for weather generator

This	file	has	been	generated	by	the	program	'dew02.exe'	
Input	Filename	=	Godew2.txt						
Number	of	Years	=	20					
Number	of	Records	=	7305					
Number	of	NoData	Values						
tmp_max	=	0							
tmp_min	=	0							
hmd	=	0							
Average	Daily	Dew	Point	Temperature	for	Period	(1991	-	2010)
Month	tmp_max	tmp_min	hmd	dewpt					
Month	Tmax	Tmin							
Jan	25.54	14.24	66.18	14.02					
Feb	26.88	14.93	60.66	13.68					
Mar	27.07	15.05	62.95	14.4					
Apr	26.06	14.83	69.58	15.31					
May	24.19	14.02	77.7	15.69					
Jun	22.74	13.09	82.32	15.42					
Jul	21.42	13.21	85.85	15.32					
Aug	21.63	13.31	85.79	15.48					
Sep	22.56	13.22	83.5	15.58					
Oct	23.49	13.53	79.57	15.46					
Nov	24.18	13.97	75.12	15.13					
Dec	24.67	14.02	70.77	14.48					
tmp_max	=	average	daily	maximum	temperature	in	month	[°C]	
tmp_min	=	average	daily	minimum	temperature	in	month	[°C]	
hmd	=	average	daily	humidity	in	month	[%]		
dewpt	=	average	daily	dew	point	temperature	in	month	[°C]
(written	by	Stefan	Liersch,	August,	2003)				