Simulation of Hydrological Effects of Land Use/ Land Cover, Climate Change and Effect of Dam at Gilgel Abay River Basin, Ethiopia

Thesis

Submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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SURATHKAL, MANGALORE - 575025

OCTOBER, 2016

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D E C L A R A T I O N

I hereby declare that the Research Synopsis entitled **Simulation of Hydrological Effects of Land Use/ Land Cover, Climate Change, and Effect of Dam at Gilgel Abay River Basin, Ethiopia** which is being submitted to the National Institute of Technology Karnataka, Surathkal in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in the Department of Applied Mechanics and Hydraulics Engineering is a bonafide report of the research work carried out by me. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

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C E R T I F I C A T E

This is to certify that the Research Synopsis entitled **Simulation of Hydrological Effects of Land Use/Land Cover, Climate Change, and Effect of Dam at Gilgel Abay River Basin, Ethiopia** submitted by AREGA MULU ADAL (Register Number: AM13F01) as the record of the research work carried out by him, is accepted as the Research Thesis submission in partial fulfilment of the requirements for the award of degree of Doctor of Philosophy.

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Arega Mulu Adal

Dedication

This thesis is dedicated to

My late grandfather Ato Alem Yismaw, my mother Genet Alem and my father Ato Mulu Adal

My lovely wife w/ro Yengusie Simenh, lovely daughters Bitania Arega and Rakeb Arega

ABSTRACT

Water is the most essential resource for survival of living things and it is the most crucial resource associated with land use/ land cover (LU/LC) and climate changes. Hence, it is very important to make evaluations of the expected impact on the hydrology and water resources. Flood is the most chronic and hazardous phenomena all over the world and causes loss of human life, natural resources as well as infrastructures. In addition, dams have been designed and constructed for various purposes. However, dams have effects on water and sediment transport, which determines overall morphology of river. Ethiopia has many dams; one of these dams is Koga dam which was constructed across Koga River, which is tributary to Gilgel Abay River, but information on effects on river hydrology and sediment transport was not evaluated. Therefore, this research was conducted at Gilgel Abay River Basin to address the following objectives; (1) to develop a hydrological model to evaluate the effect of land use/ land cover and climate change over the years on stream flow in the river basin, (2) to simulate stream flow to Lake Tana (3) to estimate future daily annual peak stream flow and flood frequency, and (4) to identify effect of dam on river hydrology and sediment transport. Precipitation Runoff Modeling System (PRMS), which is a modular-design, deterministic, distributed-parametric modelling system was used to evaluate the impacts of various combinations of precipitation, climate, and land use changes on stream flow as well as for predicting future annual daily peak stream flow. System inputs are daily time-series values of precipitation, minimum and maximum air temperature, and parameter files which are generated from Geographical Information System Weasel (GIS Weasel). The methods which were used to evaluate combined effects of LU/LC, vegetation type, vegetation density and climate changes on stream flow were two different periods` LU/LC, vegetation type, vegetation density and climate changes, these were: period one (1990-2000) and period two (2001-2010) of LU/LC, vegetation type, vegetation density and climate changes. These gridded maps as well as soil maps were used in GIS Weasel to generate parameters for PRMS model. Hence, these generated parameters within different time series data fed to PRMS model to simulate stream flow. To estimate future daily annual peak stream flow and flood frequency, the values for historical climate changes in the basin were adjusted on the basis of changes that are projected for 21^{st} century at Gilgel Abay river basin. Air temperature was adjusted by temperature values of no change, $+1.5^{0}$c and $+3^{0}$c of historical temperatures by adjusting model parameters rather than adjusting input variables. Precipitation was adjusted by two different precipitation values ranging from -10% to 10% of observed precipitation by adjusting input variables. In addition, Effect of Koga dam on river hydrology and sediment transport was evaluated by using hydrograph variations before and after the construction of dam as well as sediment yield at the catchment outlet of Koga river basin before and after the construction of dam by using Revised Universal Soil Loss Equation (RUSLE) and Sediment Delivery Ratio (SDR). As climate and LU/LC, vegetation type and vegetation density changed from period one to period two, stream flow increased by 13.5% and ET decreased by 18.3% compared to baseline period (1993-2000). Future annual daily peak stream flow with 50% and 1% AEPs will increase by 14.3% of historical modeled value of peak stream flow at the end of 21^{st} century when temperature is held constant and precipitation increases by 10%, but for other combinations, there is a decrease of stream flow. There is reduction of 5.9 t/year of sediment yield at the outlet of Koga river due to the construction of Koga dam. Generally, combined effects of LU/LC and climate change are more on stream flow and ET than individual effects, and Future annual daily maximum peak stream flow and flood frequency will decrease by large amount as temperature increases. In addition, construction of dam has an effect on river hydrology and sediment transport.

Key words: PRMS, LU/LC Change, Climate Change, Peak Stream Flow, Future Flood, Catchment Sediment Yield

CONTENTS

CHAPTER 5 ESTIMATION OF FUTURE ANNUAL DAILY PEAK STREAM FLOW AND FLOOD FREQUENCY …………………………………………69

CHAPTER 6 EVALUATING IMPACT OF DAM ON RIVER HYDROLOGY AND SEDIMENT FLOW ……………………………………………………75

LIST OF FIGURES

Captions **Page no**.

LIST OF TABLES

Captions **Page no.**

LIST OF ABBREVATIONS

Abbreviations	Descriptions
A1	Rapid economic growthfollowed by rapid introduction of new and more effient techniques
A2	A very heterogenous world with an emphasis on family values and localtraditions
A1B	A balanced emphasis on all energy sources
A1F1	Fossil fuel intensive
AEPs	Annual Exceedance Probabilities
AOI	Area Of Interest
ASTER	Advanced Space borne Thematic Emission and Reflection
BAU	Business As Usual
B1	Introduction of clean technologies
C	cover and management factor
cfs	Cubic feet per second
CMIP5	Coupled Model Intercomparision Project Phase 5
DEM	Digital Elevation Model
E	Efficiency
ECHAM5	Fifth Generation Atmospheric General Circulation Model
ERDAS	Earth Resource Data Analysis System
ET	Evapotranspiration
ETM+	Landsat Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization
GCMs	General Circulation Models
GIS	Geographical Information System
GUI	Graphical User Interface
HADCM3	Global circulation model output of Hadley centre
HEC-RAS	Hydrological Engineering Center-River Analysis system
HRUs	Hydrological Response Units
HYMOS	Hydrological database

IPCC	Inter-governmental Panel on Climate Change
IBIS	Integrated Biosphere Simulator
ITCZ	Inter Tropical Convergence Zone
K	Soil Erodibility Factor
KINEROS	Kinematic Runoff and Erosion Model
LS	Slope Length Steepness Factor
LU/LC	land use/ land cover
MMS	Modular Modelling System
MRC	Mekong River Commission
M.S.L	Mean Sea Level
PCM	Parallel Climate Model
PDA	Personal Digital Assistant
PRMS	Precipitation Runoff Modeling System
R	Rainfall Erosivity Factor
RCPs	Representative Concentration Pathways
$RegCM_3$	Regional Climate Model
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
RVA	Range of Variability Approach
S	support practice factor
SCS-CN	Soil Conservation Service Curve Number
SDSM	Statistical Downscaling Model
SRTM	Shuttle Radar Topographic Mission
SSC	Suspended Sediment Concentration
Strmflow	Stream Flow Modules
SWAT	Soil and Water Assessment Tool
THMB	Terrestrial Hydrology Model with Biodiversity
TSS	Total Suspended Solids
USGS	United States Geological Survey
VIC	Variable Infiltration Capacity
WQMN	Water Quality Monitoring Network

CHAPTER 1

INTRODUCTION

1.1. GENERAL

Water is the most essential resource in the world for the survival of living things and it is the most critical resource associated with climate change impacts. Therefore, it is very important to make evaluations of the expected impact on the hydrology and water resources due to climate changes (Ringius et al., 1996). Hydrological assessments on stream flow in many catchments in Ethiopia are limited though emphasis must be given to support water resource management. The Ethiopian high land is a major source of water for Blue Nile River basin, hence reliable runoff information from the region is very important for the sustainable management of water resources. Gilgel Abay catchment is one of the largest catchments in the Blue Nile basin that drains to Lake Tana and it is the origin of Blue Nile River.

Human activities and natural phenomena have an influence on the hydrological water balance of this catchment. Kebede (2009) reported that an increase in population caused changes in land use/land cover and various hydrological processes of upper Blue Nile river basin. Therefore, it is important to address the effect of land use/land cover changes on hydrological processes. The Land use/Land cover (LU/LC) change effects in the basin need to be addressed; hence assessing the impact of land use change on the hydrological response is important. In addition, global climate change puts further constraint on the already limited and unevenly distributed freshwater resources in the basin. Hence, climate and land use/land cover changes are important factors affecting the terrestrial hydrological cycle and water resources (Cuo et al., 2009). Land use/land cover change influences the hydrological cycle and water resources availability by changing canopy interception, surface roughness, soil properties, albedo and evapotranspiration, whilst climate change alters basic components of hydrological cycle such as precipitation, temperature, evaporation, soil moisture, groundwater availability, magnitude and timing of runoff (Wang et al., 2013).

Many studies have considered the impact of climate change and land use change on hydrological response of river basins separately (Dirk et al., 2000; Christensen et al., 2004; Bewket et al., 2005; Soliman et el., 2009; Cuo et al., 2013). But few studies have examined the combined impacts of land use change and climate change on stream flow response (Ranjan et al., 2006; Choi, 2008; Franczyk and Chang, 2009; Tu, 2009; Qi et al., 2009). However, many researches at Gilgel Abay River basin also did not take in to consideration of the combined effects on stream flow by using the Precipitation Runoff Modeling System (PRMS). To manage a river basin adaptively given climate change, it is necessary to fully understand the combined effects (Juckem et al., 2008), and also to distinguish the roles that land use change and climate change play in the evolution of hydrological time series. Considering these factors together has progressively become a focus of researchers (Beguería et al., 2003; Juckem et al., 2008; Cuo et al., 2009). Therefore, in this research the hydrological PRMS was used to evaluate the impact of land use/land cover and climate change on Gilgel Abay river basin.

Constructing dams in river basins have different advantages as dams designed for flood control, trapping sediments, hydropower generation, and irrigation and provide water for municipal and industrial uses. Large dams are effective for reducing peak discharge of flood events and increase low discharge during dry periods. However, downstream changes of the river flow and sediment regime caused by dams can vary significantly between river reaches and over time. The influence of dams on flow and sediment regime and subsequent channel morphology has long been a concern of fluvial geomorphologists and hydraulic engineers (Graf, 1980, 1999, 2000; Williams and Wolman, 1984). Dams alter downstream river flow and sediment regime over a range of time scales: hourly and yearly (Petts and Gurnell, 2005). In addition dams have an impact on global sediment flux and caused loss of 1% sediment storage volume per year (Salomons and Brils 2004).

Several studies form the theoretical background had been carried out to evaluate the impacts of dams on sediment transport (Hay, 1994; Abam, 1998; Snoussi et al., 2002; Salomons, 2004; Yang and Zhang, 2005 and Dia et al., 2008). All these studies summarized sediment transport effects such as changes in basin sediment budgets, sediment yield, bed and suspended sediment loads, and the distribution of sediment sizes along the stream.

In addition, these studies include channel morphology associated with dam construction and also address ecological effects of sediment accumulation. Generally, researchers have used various methods to identify and assess impact of dams by analysing empirical relationships between before and after the construction of dam on sediment transport to predict response. The information on sources of sediment yield within a catchment also used as a perspective on the rate of soil erosion occurring within that catchment for this study and the amount of sediment load passing the outlet of a catchment forms its sediment yield. The Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1996) and Sediment Delivery Ratio (SDR) (Williams and Berndt's (1972) are frequently used for the estimation of surface erosion and sediment yield from catchment areas as well as catchment outlet.

Ethiopia has many dams which are serving for hydropower generation, irrigation, and water supply and other multipurpose applications. One of these dams is Koga dam which was constructed at Koga River (which is tributary to Gilgel Abay River), many studies have been carried out on Gilgel Abay but information on effects on river hydrology and suspended sediment transport are too minimum. Therefore, in this research work relevant issues on identifying the effect of Koga dam on sediment transport were also considered. In view, this study offered itself as a large-scale research on assessing impact of dam on suspended sediment flow to Gilgel Abay River.

1.2. LAND USE/ LAND COVER CHANGE

Land cover refers to the physical and biophysical characteristics of Earth‘s surface and captured in the distribution of vegetation, water, desert, ice and other physical features of the land, and natural land cover. Whereas, land use refers to the use of piece of land by human beings for artificial contributions. Thus, land use involves both the manner in which the biophysical attributes of land are utilized, such as for agriculture, grazing, and are more subtle changes that affect the character of the land cover without changing its overall classification (FAO, 1998a). LU/LC Change is conversion or modifications of land use and land cover, and it has important environmental consequences or impacts on soil and water, biodiversity, and microclimate, and causes degradation of watershed (Stolbovoi, 2002; Lambin et al., 2003). The fundamental causes of LU/LC are (1) scarcity of resources leading to an increase in the pressure of production on resources (population of resource users, labour availability, quantity of resources, and sensitivity of resources); (2) changing opportunities created by markets (market prices, production costs, transportation costs, and technology); (3) outside policy intervention (subsidies, taxes, property rights, infrastructure, and governance); (4) loss of adaptive capacity and increased vulnerability (exposure to external perturbations, sensitivity, and coping capacity), and (5) changes in social organization, in resource access, and in attitudes (resource access, income distribution, household features, and urban-rural interactions) (Lambin, et al., 2003).

The study of LU/LC is very important to know the nature, the extent and the rate at which these changes have an impact on stream flow. Furthermore, some studies tried to comprehend the effect of changes in upstream LU/LC, resulting alterations in the movement of water and water availability at the downstream. Increased consciousness of these impacts enhanced their importance of estimating, forecasting and modelling at the regional scales. However, quantifying impacts of LU/LC and managements practices at a watershed scale is still complex because of the inherent variability and complex interactions among the different factors. Thus, in order to provide foundations for effective management of natural resources, an understanding must be built on the variability in time and space of the resources and role of human cultures and institutions in bringing those variations (Thomas, 2001; Awasthi et al., 2002). As a result, general statements about impacts of LU/LC and water interactions need to be continuously identified to determine whether they represent the best available information or not support of decision-making processes (FAO, 2002; Bewket and Sterk, 2004).

1.3. CLIMATE CHANGE

Water resource management planners are facing considerable uncertainties on future demand and availability of water. Climate change and its potential hydrological effects are increasingly contributing to this uncertainty. The second assessment of the Intergovernmental Panel on Climate Change (IPCC, 1996) reported that an increasing concentration of greenhouse gases in the atmosphere is likely to cause an increase in global average temperature between 1 and 3.5 Degrees Celsius over the coming century. This will lead to a more vigorous hydrological cycle, with changes in precipitation and evapotranspiration rates. These changes will in turn affect water availability and runoff and thus may affect the discharge regime of rivers. The potential effects on discharge extremes that determine the design of water management regulations and structures are of particular concern, since changes in extremes may be larger than changes in average figures.

It is widely accepted that Global Circulation Models (GCMs) give useful large-scale spatio-temporal information, and correctly represent the physics of a CO_2 increase (Gates et al., 1992). On the other hand, only few consistent model simulations are available to perform spatially distributed hydrological studies at the catchment scale (Dooge, 1992; Arnell, 1996; Loaiciga et al., 1996). Over the past decades many studies on the impacts of climate change on water resources have been carried out (Leavesley, 1994; Arnell, 1998). These studies have used models to translate the assumed climate changes into hydrological responses. Depending on the objectives of the study, the spatial and temporal scales, and the data availability, different model conceptualisations and parameterisations have been applied (Leavesley, 1994).

1.4. SOIL EROSION

Soil erosion is one of the biggest global environmental problems resulting on the site. Soil loss is a serious problem in developing countries because lack of money and knowledge to cope it and to replace lost nutrients. These countries have also high population growth which leads to expansion of agricultural activities to marginal and fragile lands, which lead to increase of soil erosion and decrease of productivity, causing to population poverty land degradation cycle. Rapid population growth leads to cultivation on steep slopes, clearing of forests and overgrazing. These are the main factors that aggravate soil erosion in Ethiopia. The annual soil loss in the country is higher than the annual rate of soil formation. That is annually, Ethiopia loses 1.5 billion topsoil from the high lands to erosion which could have added about 1.5 million tons grain to the country`s harvest (Tamene and Vlek, 2008).

1.5. SCOPE OF THE PRESENT STUDY

Rapid population growth has forced farming families to expand their fields onto the steeper slopes. As a result, large areas, which were once under forest cover, are now exposed to heavy soil erosion resulting into a massive environmental degradation and serious threat to sustainable agriculture and sedimentation. The loss of the vegetative cover has resulted in flash floods which in turn resulted in formation of big gullies and hence loss of farms in both sides of river embankments. This also causes seasonal flooding of farmlands and sedimentation of rivers. Increased sediment accumulation in river systems can raise the level of the riverbed, subsequently increasing water levels. This deposition can have significant implications for flooding, and may cause floods, which would pose a risk to human settlements if not be contained by banks and levees. Crops frequently washed away due to flood from the main rainy season, which has resulted in reduced yield or total crop failure, on the lowlands.

In addition, Ethiopia is following agricultural based industrialization, which strongly linked with climate changes and being a large part of the country is arid and semi-arid. Water supplies from rivers and lakes are characterized by their unequal natural geographical distribution and accessibility, and unsustainable water use. By 2025, water availability in Eastern Africa is limited to 1000-1700 m^3/person/year. These estimates are based on population growth rates only and climate change has the potential to impose additional pressures on water availability and accessibility (IPCC, 2008).

Hence, understanding the combined effects of Land Use/Land Cover (LULC) and climate change on runoff is necessary to make significant advances in documenting the rates and causes of LULC and climate changes. Our current understanding of historic LULC and climate change in area is not adequate. So future understanding of LULC and climate changes will need great improvement with systematic methods and designs addressing land use and climate change research. Therefore, this research work addresses relevant issues on various combinations of land use/land cover, vegetation type, vegetation density and climate change effects on stream flow, flood and flood frequency analysis.

Gilgel Abay river basin has sub Basin of Koga River, where Koga dam is constructed and water is mainly used for irrigation purpose. This dam is allowing the passage of water through controlled hydro mechanical gates, as a result, obstruction of the water discharge and sediment discharge for the entire period took place. The outflow compared to the inflow from this reservoir is negligibly small, because most of the water is diverted to irrigation command areas. Therefore, identifying the impacts of this dam on the river hydrology and sediment is very important for management of resources. Hence, this research will be helpful to study the interference of dams on river hydrology and sediment transport of Ethiopian rivers, since such studies are not conducted so far in Ethiopia.

1.6. OBJECTIVES OF THE STUDY

The present study is carried out for Gilgel Abay River Basin with a view to:

- Develop a hydrological model to evaluate the effect of land use/ land cover and climate change over the years on stream flow in the river basin
- Simulate stream flow of the Gilgel Abay river basin to Lake Tana
- Estimate future daily annual peak stream flow events and flood frequency
- Identify effect of dam on river hydrology and sediment transport at Gilgel Abay river basin.

1.7. ORGANISATION OF THE THESIS

The present thesis is divided into seven chapters.

Chapter 1 : Provides a brief introduction on impact of LU/LC and climate change on stream flow and the impact of dams on river hydrology and sediment transport followed by the scope of the present study in Ethiopian situations, and objectives of the study.

Chapter 2: Reviews the literature pertaining to LU/LC studies, climate change studies, LU/LC and climate change studies as well as impact of dam on river hydrology and sediment transport.

Chapter 3. Contains description of study area, data as well as software used.

Chapter 4. Includes modeling and simulation of stream flow to assess the Hydrological effects of LU/LC and climate changes on stream flow.

Chapter 5. Gives information about prediction of future annual daily peak stream flow of Gilgel Abay River basin and.

Chapter 6. Deals with Identifying impact of dam on river hydrology and sediment transport.

Chapter 7. Provides summary and conclusions of the present study and suggestions for the future study.

CHAPTER 2

LITERATURE REVIEW

2.1. GENERAL

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and the variability of its properties and that persists for an extended period, typically decades or longer, Intergovernmental Panel on Climate Change (IPCC, 2007). Now a day climate change is a severe problem that is happening all over the world. It is widely accepted that change is already happening and further change is expected; over the last 100 years, that is between1906 and 2005. The average global temperature rose about 0.74^{o}C from 1910s and 1940s and more strongly in 1970s to the present (IPCC, 2007a).

Land use change is the conversion of land for a particular production or purposes, which was not used before for crop production. Land is used to meet a multiplicity and variety of human needs and to serve numerous and diverse purposes. When the users of land decide to employ its resources towards different purposes, land use change occurs producing both desirable and undesirable impacts. The analysis of land use change is essentially the analysis of the relationship between people and land. Quantitative assessment on the impacts of land-use change is vital for basin environment protection and water resources sustainable development, because it has a significant effect on the hydrological processes at the watershed level (Li et al., 2013).

Dams used for various purposes such as for hydropower, irrigation, flood control and navigation. However, dams have influences on water and sediment transport, which determines over all morphology of river. Several groups of studies form the theoretical background had done to evaluate the impacts of dams on stream flow (Chang and Crowely, 1997; Abam, 1998; Kummu and Varis, 2000; Maingi and Marsh, 2002; Grant et al., 2003 and Graf, 2006) and on sediment transport (Hay, 1994; Abam, 1998); Snoussi et al., 2002; Salomons, 2004; Yang and Zhang, 2005 and Dia et al., 2008). All these summarize hydrological effects occurring downstream of impoundments, sediment transport effects such as changes in basin sediment budgets, sediment yield, bed and suspended sediment loads, and the distribution of sediment sizes along the stream. In addition, these studies include channel morphology associated with dam construction and also address ecological effects of sediment accumulation. Generally, researchers have used various methods to identify and assess impact of dams by analysing empirical relationships between before and after construction of dam on river hydrology and sediment transport to predict response.

2.2. LAND USE / LAND COVER CHANGE STUDIES

Changes in land cover has an effect on overall health and function of a watershed, hence investigations on the impacts were reported as land cover change and rainfall spatial variability affect the rainfall runoff relationship to watershed in the study area (Hernandez et al., 2000). They applied event-based with one-minute time step Kinematic Runoff and Erosion Model (KINEROS), and a continuous model with a daily time step Soil and Water Assessment Tool (SWAT) incorporated with Geographical Information System (GIS) and Remote Sensing (RS) data as well as rainfall and stream flow data from 1966 to 1974.

Bewket et al., (2005) studied the dynamics of land use/land cover change of Chemoga River basin, Ethiopia. They investigated that total annual stream flow and rainfall decreased at the rate of 1.7 mm per year and 0.29 mm per year for 1960 and 1999 periods respectively. They also analysed the dry season stream flow and found that there is a significant decline of 0.6 mm per year, but there was no significant change during the wet season. Extreme low and high flows were examined at monthly and daily time periods and revealed that low flow decline with time; whereas extreme high flows did not significantly change. Generally, observed changes are due to land use/land cover changes such as degradation or destruction of natural vegetation covers, expansion of crop cover, over grazing and increased area for plantation of Eucalyptus tree.

According to Li et al., (2006), analysis on numerical simulations of idealized deforestation and overgrazing performed for the Niger and Lake Chad basins of West Africa. They used a terrestrial ecosystem Integrated Biosphere Simulator (IBIS) model and an aquatic transport model Terrestrial Hydrology Model with Biodiversity (THMB) to evaluate effect of land use change. They found that tropical forests situated in the regions of highest rainfall have a disproportionately large impact on the water balance of the entire basin. They also identified that the hydrological response to progressive land cover change is non-linear and exhibits threshold effects of land use/land cover change on water yield and river discharge for deforestation, over grazing for savanna and grass lands is 50%, 70% and 80% respectively. This means there is significant change on water yield and river discharge when deforestation is greater than 50 percent and when over grazing in Savanna and grassland is greater than70% and 80% respectively.

Santillant et al., (2010) examined the impact of land cover change during rainfall events in tropical watersheds of Philippines by integrating RS, GIS and hydrological model Soil Conservation Service Curve Number (SCS-CN), and they found that land cover change offers available tool for watershed planners and decision makers for evaluating the effect of land cover rehabilitation strategies in minimizing runoff during rainfall events in watershed ecosystem. For model parameterization, landsat Enhanced Thematic Mapper (ETM+) and Landsat Multispectral Scanner (MSS) images were used to prepare land cover map and to find the corresponding changes.

Li et al., (2013) examined the sensitivity of rainfall- runoff relationship to rainfall with different types of land use and its impact on rainfall-runoff relationships in China. They used GIS and SWAT model during 1980s, 1990s and 2000s. They analysed the relationship of rainfall-runoff sensitivity for different types of land use/land cover changes and its impacts on rainfall-runoff sensitivity and investigated that the rainfall- runoff relationship to rainfall decreased in farmland, paddy field, and woodland.

Mkaya et al., (2013) studied the impact of land use change on catchment hydrology of Wundanany River in Kenya by using GEOVIS software, GIS and SWAT model. They investigated that forestland declined by 57% while agricultural land and built-up area expanded by 10% and 156% respectively. In addition, they found that increasing of surface runoff from 4.2 to 110.96 mm and sediment yield from 0.43 to 20.10 tons per year for periods 1975 to 2001.

Yeshaneh et al., (2013) studied land use/land cover dynamics in Koga catchment, Ethiopia. They used 1:50,000 scale aerial photographs, MSS, TM and landsat ETM+ images, Advanced Space borne Thematic Emission and Reflection (ASTER) images together with ground truth data collected through field surveys. They revealed that from 1950s to 2010 woody vegetation decreased from 5,576 ha to 3,012 ha. There is an increasing trend of deforestation, but most of the deforestation took place between 1970s and 1980s. Agricultural area such as pastures and croplands showed no significant change since 1950s. However, there was tremendous increase in population year to year, due to this, there was increase in settlement area, hence the bare land, which was unused, found totally covered with land cover/land use classes.

Zheng et al., (2013) identified the effect of land use change on stream flow in Chaobai river basin in China by using data of forest and bare land from 1978 to 2008 with principles of elasticity method. They investigated that influence of forest on the annual runoff was significant and increased gradually from 1978 to 2008; whereas the effect of bare land is insignificant on annual runoff in all times periods from 1978 to 2008. They had concluded that the effects of land use/cover changes are the main factors that affect stream flow especially in summer season in the study area.

Madugundu et al., (2014) studied detection of LU/LC changes in Diras region of Saudi Arebia using landsat TM/ETM images of 1980-1990, 1990-2000 and 2009-2010. They found that there is a significant land use changes occurred from 1980 to 2010 due to rapid expansion of agriculture and urbanization.

Babar and Ramesh (2015) identified the response of stream flow LU/LC change over the Netheravathi river basin, India using SWAT model. They evaluated its effect on stream flow using LU/LC images from 2003 to 2013 and identified that there is a decrease of 4.5% evapotranspiration, but an increase of 0.9% and 1.12% runoff and ground water respectively.

2.3. CLIMATE CHANGE STUDIES

Muller et al. (2000) examined the response of river catchment to climate change by using downscaled GCM output and hydrological model in Northern Germany and reported that there may be a significant increase in river discharge in the coming decades because of increased rainfall.

Christensen et al., (2004) studied potential effects of climate change on the hydrology and water resources of the Colorado river basin. They compared simulated hydrologic and water resources scenarios derived from downscaled climate simulations Parallel Climate Model (PCM) to scenarios driven. They used historical (1950-1999) climate as a control and related with periods 2010-2039, 2040-2069, and 2070-2098. They found that analysis of water management operations using a water management model driven by simulated stream flows showed that stream flows associated with control and future Business As Usual (BAU) climatic scenario would significantly degrade the performance of the water resources system relative to historical conditions. Average total basin storage reduced by 7% for the control climate and 36%, 32% and 40% for Periods 2010-2039, 2040-2069, and 2070-2098, respectively.

Quantifying the hydrological response to an increased atmospheric CO_2 concentration and climate change is critical for the proper management of water resources within agricultural systems. Ficklin et al., (2009) analysed the hydrological response to variations in atmospheric CO_2 (550 and 970 ppm), temperature (+1.1 and +6.4 ^{0}C), and precipitation (0%, ±10%, and ±20%) based on Intergovernmental Panel on Climate Change projections by using SWAT model. They found that atmospheric CO_2, temperature and precipitation change have significant effects on water yield, evapotranspiration, irrigation water use, and stream flow. Finally, they concluded that the San Joaquin watershed hydrology in California is very sensitive to potential future climate changes.

Climate changes have an impact on hydrological process of Blue Nile river basin. Soliman et el., (2009) examined impact of future climate changes in Blue Nile river basin by using Regional Climate model ($RegCM_3$) with European Centre for

Medium Range Weather Forecasts (ECHAM5) General Circulation Model. They related runoff data with temperature and precipitation data for 1985-2000 and found that the future changes in rainfall might vary over different areas of the Upper Blue Nile catchment in Ethiopia.

The effects of climate change on hydrological regimes have become a priority area for water and catchment management strategies, hence Gupta et al., (2011) studied the climate change impact on the runoff of river basins of India by using the global circulation model output of Hadley centre (HADCM3); Scenario for 2080 (A_2 scenario indicating more industrial growth) and curve number for runoff modelling. They compared normal climatic change during 1951-1980 with observed climatic change and found that there is a decline in the future runoff in most of the river basins of India compared to normal runoff.

Skoulikaris and Ganoulis (2011) examined the impact of climate change in Nestos river basin in Southern Europe by using downscale procedure and coupling refined Regional Global Models ($RegCM_3$) with spatial distributed hydrological models and investigated that impact of climate change affected all water related sectors as well as ecosystem. Finally, simulation model results on trans-boundary river basin demonstrates a future 14.5% and 24.1% reduction of runoff for B1(global cooperation) and A1B (a balanced emphasis on all energy sources) emission scenarios respectively, as well as the occurrence of extreme floods and droughts during simulation periods.

Faramarzi et al., (2012) examined the impact of climate change on fresh water availability in Africa for periods 2020-2040 by using GCM under IPCC emission scenarios and SWAT model and reported that for Africa as a whole, the mean total quantity of water resources is likely to increase with climate. They also found and identified that the dry regions have higher uncertainties than the wet regions in the projected impacts on water resources.

Potential impacts of future climate change on precipitation and runoff to stream flow in Colorado river basin in the southwest United States suggested that runoff reduced in response to increasing temperatures and decreasing precipitation (Kevin and Andrew (2013). They considered eight sub-basins and analysed by using time series method and reported statistically significant temperature increases in all sub-basins were with persistently non-stationary time series in the recent record relative to the earlier historical record. However, tests of precipitation and runoff did not reveal persistent reductions, indicating that they remain stationary processes.

Taddele et al., (2013) identified the impact of climate change on the Gilgel Abay River, Upper Blue Nile basin by using Statistical Downscaling Model (SDSM) and SWAT model for the periods 2010-2100 with an interval of 30 years. They used 1990-2001 as the baseline period and found that annual mean precipitation may decrease in the first 30 year period but increase in the following two 30 year periods. They concluded that climate change would result an increase in annual inflow volume for the Gilgel Abay River.

Aich et al., (2014) compared impacts of climate change on stream flow in four large African rivers (Niger, Upper Blue Nile, Oubangui and Limpopo) using Soil and Water Integrated Model (SWIM). They also used five bias corrected Earth system models of Coupled Model Intercomparision Project Phase 5 (CMIP5) for the Representative Concentration Pathways (RCPs) 2.6 and 8.5. They found tendency for increased stream flows in Niger, Upper blue Nile and Limpopo but not for Oubangui river.

Musau et al., (2015) studied hydrological response to climate change in Mt. Elgon watersheds using SWAT model and by using data from 10 climate models and three greenhouse gases emission scenarios downscaled delta change method. They identified that stream flow changed due to climate change.

Azari et al., (2016) studied impacts of climate change on stream flow and sediment yield in the North of Iran using SWAT model for simulation and SUFL-2 algorithm for parameter optimization. They used three emission climate change scenarios (A1F1, A2 and B1) for 2040-2069 periods and found that there is an increase of stream flow by 5.8%, 2.9% and 9.5% and sediment yield by 47.7%, 44.5% and 35.9% for A1F1, A2 and B1 emission scenarios respectively.

2.4. LAND USE / LAND COVER AND CLIMATE CHANGE STUDIES

Legesse et al., (2003) investigated the impact of climatic and land use changes on water resources in data scarce Tropical Africa by using a distributed precipitation-runoff modelling system based on sensitivity analysis, and they reported that 10% decrease in rainfall produced 30% reduction on the simulated hydrologic response of the catchment, while 1.5^0C increases in air temperature would result in a decrease in the simulated discharge of about 15%. Converting the present day dominantly cultivated/grazing land in the studied river basin by woodland would decrease the discharge at the outlet by about 8%.

Guo et al., (2008) examined the effect of land use /land cover and climate change effect on annual and seasonal stream flow in China by using SWAT model and found that climate change is dominant in annual stream flow. While land cover change may have a moderate impact on annual stream flow, and it strongly influences seasonal stream flow and alters the annual hydrograph of the basin because of the vegetation and associated seasonal variations of its impact on evapotranspiration.

Li et al., (2009) observed the effects of land use/land cover and climate change on hydrology in an agricultural catchment in loess Plateau of China by using SWAT model for the period 1981-2000. They reported that about 4.5% of the catchment area changed mainly from shrubland and sparse woodland to medium and high grassland, and climate changed to warmer and drier. The integrated effects of the land use change and climate variability decreased runoff, soil water contents and evapotranspiration. Both land use change and climate variability decreased the runoff by 9.6% and 95.8%, respectively, and decreased soil water contents by 18.8% and 77.1%. Evapotranspiration increased by 8.0% while climate variability decreased by 103.0% because of land use change. The climate variability influenced the surface hydrology more significantly than the land use change in the catchment during this period.

Qi et al., (2009) examined the potential impacts of climate and land use change on the monthly stream flow of Trent River basin by using PRMS. They suggested that stream flow of the Trent River would decrease with an increase in air temperature, and increase (or decrease) with an increase (or decrease) in precipitation. Stream flow was more sensitive to prescribed changes in precipitation than to air temperature for the study area. From seven hypothetical land use change scenarios, forest conversion to croplands and urban areas indicated that the water yield increased by 14% to 20%.

Legesse et al., (2010) examined the impact of climate and land cover change on stream flow in Meki River, in Ethiopia by using PRMS and delta-change method for simulating scenarios into climatic and land use change during 1981-2002. They analysed that the basin is more sensitive to increase in rainfall (+80% for +20%) than to a decrease in rainfall (−62% for −20%). The rainfall elasticity is 4:1 for a 20% increase in rainfall while it is 3:1 for a 20% reduction. Fifteen degree centigrade increase in temperature resulted in a 6% increase in potential evapotranspiration and 13% decrease in stream flow. They concluded that the watershed is more elastic to rainfall increase than temperature. The proposed land cover scenario of converting areas between 2000 to 3000m above Mean Sea Level (M.S.L) to woodland, also resulted in a significant decrease in stream flow by 11.8%.

Cuo et al., (2013) examined the impact of climate change, land use/land cover transition on the hydrology in the upper yellow river basin, China by using Variable Infiltration Capacity (VIC) model, and found that seasonal stream flow and annual stream flow decreased in wet and warm season. They reported that more stream flow generated in the early part of the year compared to the latter part due to the combined effects of changes in precipitation, evapotranspiration, rainfall runoff and base flow. Changes in snowmelt runoff were negligible over the past decades due to this; snowmelt runoff appeared to play only a modest role in the changing hydrology of the region.

Wang et al., (2013) analysed impact of land use/land cover and climate change on decadal stream variation in Chaohe watershed in Northern china during 1963-

2008. They considered 1970 - 1979 as base line period and relating with 1980–1989, 1990-1999 and 2000–2008. They used a simple eco-hydrological approach, an elasticity differential analysis, and a calibrated physically based MIKE SHE model, and identified that stream flow decreased greatly during 1980–1989 and 2000–2008, whilst it changed slightly during 1990–1999, this was due to the effects of less soil water storage capacity on hydrological impact of land use change. However, the change impacts (i.e., land use change and climate change impacts) for 1980–1989 and 2000–2008 periods seem different between the approaches. Climate change was almost similar to land use change for these two periods according to eco-hydrological approach, whilst climate change from the differential elasticity based analysis showed only 33% and 45% and from MIKE SHE modelling 51% and 78% for 1980–1989 and 2000–2008 respectively.

Investigation of impact of climate and land use changes on hydrological processes and sediment yield in the Be river catchment by using SWAT model during 1978-2000 and found that deforestation had increased the annual flow by 1.2% and sediment load by 11.3%. In addition, they investigated that climate change had also significantly increased the annual stream flow (26.3%) and sediment load (31.7%).The coupled climate and land-use changes increased the annual stream flow and sediment load by 28.0% and 46.4%, respectively. In general, climate change had influenced the hydrological processes more strongly than the land-use change in the Be River Catchment during the 1978–2000 (Khoi et al., 2014).

Chawla et al., (2015) studied isolating the impacts of land use and climate change on upper Ganda river basin in India using variable Infiltration capacity (VIC) model. They also used three scenarios (sensitivity of stream flow to land use changes under invariant climate, changes in stream flow due to change in climate assuming constant land use and combined effects of changing land use and climate on stream flow of the basin. They identified that the combined effects land use and climate change on stream flow is more than individual effects.

2.5. IMPACT OF DAMS ON RIVER HYDROLOGY

Chang and Crowely (1997) studied downstream effect of Sam Rey burn dam on stream flow in East Texas and found that annual stream flow did not show any change, but monthly stream flow changed. Hence, it becomes higher during summer and duration of high flows, spring peak flows and flood conditions reduced because of reservoir operation and management. They used flow data before and after construction of dams for their analysis.

Abam (1998) examined the effect of dams on hydrology of Niger Delta by relating discharge and peak floods before and after construction of dams. The hydrographs showed that the reduction of peak flood due to impoundment of dams. He also analysed and found that the total discharge reduced because dam controls runoff and sediment loads.

Dams have downstream effect on hydrology and sediment release and the effect depends up on location, environment, substrate, and released water flow and released sediment. Analysis had done by relating changes on stream flow and sediment load before and after construction of dams (Brandt 2000).

Kummu and Varis (2000) examined the impact of reservoirs on total suspended solid, suspended sediment concentration and hydrology on lower Mekong basin. They used Mekong River Commission (MRC) Hydrological database (HYMOS) including Suspended Sediment Concentration (SSC) from1962-2002, MRC Water Quality Monitoring Network (WQMN) database including Total Suspended Solid (TSS) from 1985-2000 with daily discharge and sediment sampling. They compared SSC and TSS concentrations and fluxes before and after construction of dams and found that reservoirs increase down stream flow during dry season and decrease during wet season, hence increase water level fluctuations. Generally, it has negative and positive effects.

Impact of large dam construction on Tana River in Kenya was analysed using flood frequency analysis and computational variance by taking daily pre- and post-dam discharge data. The results showed statistically increase of minimum river flows and reduction in peak flows. Another analysis on frequency flooding of 71 vegetation sample plots located on various parts of the river flood plains by using Hydrological Engineering Center-River Analysis system (HEC-RAS) model showed that plots at elevation greater than1.8m above the dry season river level experienced statistically significance in dry flooded from pre- and post- dam periods (Maingi and Marsh, 2002).

Garland and Moleko (2000) examined the effect of dams on flow delivery to downstream of Mgeni River, South Africa by comparing pre dam (1960-1981) and post dam (1990-1997) discharges. They reported that mean annual discharge of river reduced to 4%.

Grant et al., (2003) examined the effect of dams on rivers by using a conceptual and analytical frame work and reported that Basin geology influences watershed and channel processes through a hierarchical set of linkages. They developed an analytical framework based on two dimensionless variables of sediment supply below and above the dam and the fractional change in frequency of sediment-transporting flows which predicts geomorphic responses to dams depending on the ratio and holds promise for predicting the magnitude and trend of downstream response to other dammed rivers.

Construction of dams has a sharp reduction of water and sediment fluxes Sebu and Moulouya Rivers in Morroco. Snoussi et al., (2003) studied by comparing the water discharge of these rivers before and after construction of dams by taking data on water flow and suspended sediment concentration from 1940 to 1995. They found that the water discharge of the Sebu and Moulouya rivers decreased by 70% and 47% and sediment fluxes by 95 and 93% respectively, during 19440 and 1995.

The quantity of downstream impact of reservoir in flow regime and channel plate form change over 75 km length in lower Trinity river, Texas, was evaluated by using historical daily discharge data to constructed flow duration curves and peak discharge data. In addition, digital historic aerial photographs of the area to establish base line study and three measures of channel activity applied using GIS. They compared pre- and post- dam flow conditions and identified that in high flow condition no changes happen following impoundment, because it regulates discharge, while low flows showed significant changes (Wellmeyer et al., 2005).

Graf (2006) studied the hydrologic and geomorphic effects of large dams on down streams in American rivers by analysing 72 stream gauge records (36 pairs). He made one member of each pair an unregulated reach above a dam whereas the other regulated stream down from the same structure. He compared regulated with unregulated reaches and found that very large dams on average decreased annual peak discharge, ratio of annual maximum/mean flow and rates of ramping by 67, 60, 64 and 60 respectively. However, there was increase the number of reversals in discharge by 34%. He also evaluated that dams affect timing for high and low flows and timing for maximum and minimum yearly flows. Dams also have a geomorphic difference between regulated and unregulated reaches as 32% larger for low flow channels, 50% smaller for high flow channels.

Dams affect the river hydrology of the downstream flow system by changing the frequency, magnitude and timing of flows. Rahiman et al., (2009) analysed the effect of 14 dams in Periyar river basin in India on river hydrology. They analysed and compared the monthly hydrograph and annual runoff variations over a period of 25 years of Periyar river basin with basin Netravathi river with no major dams on the upstream side of gauging station. They found that the net runoff on the Periyar River is reduced by 41% because of the impoundment of dams.

Zuo and Liang, (2015) studied the effects of dam river flow regime using Range of Variability Approach (RVA) method. They used 55 years of measured daily discharge data at Jieshou hydrologic station and divided these data in to pre and post period and identified that dams have a strong influence on river hydrology.

2.6. IMPACT OF DAMS ON SEDIMENT FLOW

Hay (1994) studied impact of dams on sediment transport of Turkish rivers to Black sea by using sediment data before and after construction of dams. He analysed and found that there is sharp reduction of sediment from 70 M tons/year to 28 M tons/year due to construction of dams across Yasil Irmak and Kizi Irmak rivers.

According to Abam (1998), construction of 49 dams in Niger Delta with the reservoir capacity of 36 million m^3 reduced the amount of suspended sediment and bed load delivery to the coast. It was found by comparing Niger sediment load with other West African rivers. This reduction in percentage of sediments was due to construction of dams, which vary with design of individual dams and its location in river basin.

Sherman et al., (2002) studied the magnitude of the cumulative impacts of sediment impoundment in 28 coastal dams and 150 debrises in 8 watersheds are more than 4 million m^3 per year which is proportional to potential derivatives of beach sand of roughly $3m^3$/year per meter of shore line in 5 Southern coastal countries. Eight watersheds are the Santa Ynez, Ventura, Santa Clara, Los Angeles, San Gabriel, Santa Ana, San Dieguito, and San Diego. They assessed by direct measurement of sediment impoundment rates in the watersheds of stream gauging stations.

Impact of dams on sediment fluxes on Sebou and Molouya rivers in Morroco was studied by Snoussi et al., (2002) and found that there was reduction of sediment fluxes by 95% and 93% for Sebou and Molouya rivers respectively. The analysis was carried out through comparing suspended sediment concentration data before and after the construction of dam over a period of 55 years.

According to Salomons (2004), the impact of damming on global sediment flux estimated that about 25-30 % of the sediment flux trapped behind dams. He also reported that existing sediment storage volume in the world lost 1% each year. Trap efficiency of large dams (volume >10 Mm^3) is greater than 99%, depending on the characteristics of the sediment, inflow, and the reservoir capacity (Williams and Wolman 1984).

One hundred thirty eight reservoirs with initial volumes between 1 Mm^3 and 1230 Mm^3 in Romania were studied for reservoir sedimentation and found that siltation was very serious for 15 reservoirs with average dimensions of 8 Mm^3 and have siltation time between 2 and 10 years. Consequently, thirty reservoirs with average capacities of 35 Mm^3 had siltation time of 10 and 50 years. Over all, Romania`s rivers faced total erosion rate of 40-50 million tons per year from an average total erosion rate of 125 million tons per year of Romania`s territory (Radoane 2005).

Yang and Zhang (2005) studied impact of dams on river sediment supply to sea and delta intertidal wetland response and found that the sediment discharge rate of Yangtze River would most likely decrease to below 150 M tons/year in the coming 10 years. They investigated that the sediment discharge rate strongly decreased from 1960s to 2003. They also identified the relationship between intertidal wet lands growth with river sediment supply by regression analysis and found that intertidal wet lands at the delta front decreases when the sediment discharge rate reaches threshold level less than 263 M tons/year.

Analysis conducted by Dia et al., (2008) on the impact of dams on sediment flux of Pearl River in China found that the total storage capacity of the basin had reached 65,000 Mm^3 by 2005, which is 23 % of annual discharge of the Pearl River. They also found total deposition rate in the reservoirs had reached 600 million tonnes per year, which is nearly 15 times higher than the annual sediment flux of Pearl River into the sea. Starting the mid of 1980s the sediment flux of the Pearl river decreasing radically mainly due to deposition in reservoir and further expected to decrease in sediment flux in to the sea in the river in the future.

Dwarakish et al., (2009) compared Periyar river basin which is having 14 dams and concluded that the total amount of sediment trapped in all reservoirs in Periyar River up to 2006 was estimated as 225 million tons which was nearly 30 times the total sediment load transported to Cochin coast by Periyar River during 1978-2002 periods. Total sediment loss to Cochin coast is 200 million tons. The results were also compared with Nethravati river basin with no dams.

Issa et al., (2012) evaluated the effect of operation of Mosul dam on sediment transport in its reservoir using a physical distributed model with moveable bed having a vertical scale 1;100 and a horizontal scale 1:1000 and using four different discharges of 500, 1000, 1500 and 2000 m^3/s. They identified that bed load transport rate was decreasing when the water level with its reservoir was increasing.

Kameya et al., (2013) studied Hydrological and sediment transport simulation to assess the impact of dam construction in Mekong river main chain channel using MIKE and MIKE 11and river discharge and suspended sediment data before (1996) and after (2003). They identified there is a decrease of peak discharge volume and an increase of sediment transportation budget in months after the rainy season.

2.7. REVIEWER`S POINT OF VIEW

The following are the major reviewers` points made, based the literature reviewed.

- Land use land/cover change has an influence on stream flow
- Climate change has an influence on stream flow
- Land use/land cover and climate change has an influence on stream flow
- Dams influence the flow within river network
- Dams have an influence on sediment transport in streams
- The long-term sustainability of lakes depends on periodic deliveries of sediments from rivers and streams.

CHAPTER 3

STUDY AREA AND DATA PRODUCTS USED

3.1. DESCRIPTION OF THE STUDY AREA

Gilgel Abay River Basin has an area of 5000 km^2 and it is the largest of the four main sub-catchments (Gilgel Abay, Gumara, Megech and Rib) of Lake Tana, and provides about 60% of the lake inflow. It has a geographical coordinates of $10^0$56' to $11^0$51' N latitude and $36^0$44' to 37^0 23' E longitude with an elevation range of 1787 m to 3524 m above M.S.L (Figure 3.1). The southern part of the catchment is mountainous and it has undulating topography and its periphery in the West and Southeast, while the remaining part is low laying plateau with gentle slope. The geology is composed of quaternary basalts and alluviums. Clay and clayey loam soils are the most dominant soil types.

As Mohammed et al. (2005) stated that the rainfall over Gilgel Abay river basin originates from moist air coming from the Atlantic and Indian oceans following the North-South movement of the Inter Tropical Convergence Zone (ITCZ). June to September is the main rainy season, during which the study area receives about 70 to 90% of the average annual rainfall in the study area (Tarekegn and Tadege, 2005; Kebede et al., 2006). The rainfall data from meteorological stations indicate significant spatial variability of rainfall following the topography, with a decreasing trend from South to North. The temperature variations are small throughout the year (BCEOM, 1999).

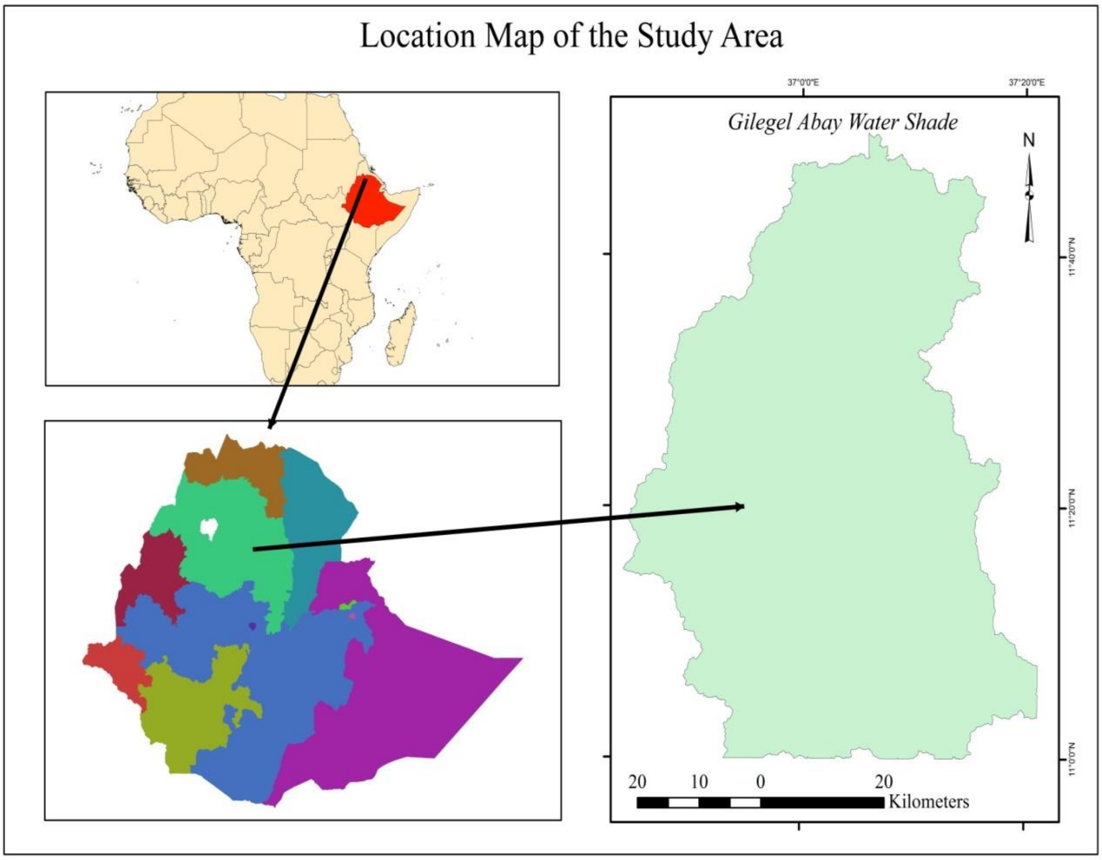

Figure.3.1. Location map of Gilgel Abay River Basin, Upper Blue Nile, Ethiopia.

The Gilgel Abay River has a number of small tributaries. It is mainly drained by river Koga around Merawi and river Kiliti that joins downstream before flowing in to the Lake. Some other tributaries include Hawashe, Gudbela, Andod and Amerit. The area of the catchment is covered with the volcanic rock which is vesicular basalt of plain topography with very low drainage network. Gilgel Abay River, where almost all its watershed is found in this formation has a very big base flow. There are also numerous seasonal small streams and drainage channels that have large flow during wet season but they dry up in the dry season.

The soils in most of the Gilgel Abay catchment are derived from the weathered basalt profiles, and are highly variable. In low lying parts of Gilgel Abay, soils have been developed on alluvial sediment (SMEC, 2008). The major soil groups in the catchment are Eutric Fluvisols, Haplic Alisols, Lithic Leptosols, Chromic Luvisols and Eutric Vertisols. The land use pattern of the Gilgel Abay catchment ranges mainly from dominantly cultivated crop land to only few areas of shrub lands. The majority of the catchment is cultivated land.

The geology of the study area is characterized by outcrops of Tertiary, Quaternary volcanic rocks and alluvial deposits. Basement rocks in the Gilgel Abay catchment consists Precambrian metamorphic and granitic rocks. Although, they are not exposed in the study area it is believed from regional geology that occur in the catchments' subsurface. The basement rocks are overlain by extensive deposits of Mesozoic sedimentary rocks, which are outcrop in the Blue Nile gorge in the southeast and western lowlands. These sediments are not exposed in the Gilgel Abay catchment, but from recent geophysical study by Hautot et al., 2006 in the catchment, a 1.5-2 km thick deposit of Mesozoic sediments beneath 0-250 m thick continental flood basalt have been identified.

Figure 3.2. Gilgel Abay Hydrometric Station (Field visit photo)

Figure 3.3. Koga dam site before impounded by water (Field visit photo)

Figure 3.4. Mild Slope Plateau portion of Gilge Abay Catchments (Field visit photo)

Figure 3.5. Mixed forest around Wetet Abay (Field visit photo)

The factors which are instrumental in selection of study area include:

- Availability of data,
- High potential area for agriculture along river in both sides
- There is a lot of settlements near to the river basin,
- It is the largest of upper Blue Nile catchments and it is the origin of Blue Nile river basin,
- It is the major contributor (60%) of inflow (water or sediment) to lake Tana.
- In addition, across this river there is highway which crosses it,
- At one of sub-basin there is Koga irrigation dam which has potential of irrigating 7000 ha of land and it is using as demonstration site for civil and water resources engineering students during their study in universities, and

- Beyond this river there is a dam which has a capacity of generating 460 MW hydroelectric power in connection with other basins and Lake Tana.

3.2. DATA PRODUCTS USED

Conventional data are more site-specific and accurate; but data collection is expensive, time-consuming, requiring more manpower and may not be extrapolated to a larger area. Remotely sensed data has got advantages due to repetitive and synoptic coverage of the large, inaccessible areas quickly and economically. By combining the conventional and remotely sensed data the dual advantages can be achieved.

In the present study, both conventional and remotely sensed data were used, for the LU/LC change studies, Climate change studies and combined LU/LC and climate change studies on stream flow as well as river hydrological studies and river sediment load analysis. These studies were conducted to assess the effect of LU/LC change, climate change and combined effects on stream flow as well as flood and flood frequency. In addition, these data were also used to evaluate effect of Koga dam on river hydrology and sediment flow. Gilgel Abay River originates from the Southern and discharge into the Lake Tana. Koga river basin is one of the tributary rivers in Gilgel Abay river basin and Koga dam is constructed across Koga River. The various conventional and remotely sensed data used for the present study are given in Table 3.1.

Table 3.1. Data products used for the present study.

Types of Data		Period	Source	Description	Purpose
Conventional Data	Precipitation (Rainfall)	1993-2012	Ethiopian Metrological Agency	Daily rainfall	Hydrological analysis For R (rainfall erosivity factor) analysis
	Stream flow	1993-2012	Ethiopian Minister of Water Resources	Mean daily river discharge	Hydrological analysis
	Temperature	1993-2012	Ethiopian Metrological Agency	Daily max. and min. air temperature	Hydrological analysis
	Soil data		Survey of Ethiopian soil		For additional information
Remotely sensed data	FAO soil Map Soil data	1998-2012	FAO	Harmonized World Soil Database V 1.2	Hydrological analysis K (soil erosivity factor) analysis
	LU/LC, vegetation type, vegetation density	1990-2000, 2001-2010, 2001, 2013	Satellite image and gridded global maps	Landsat 7 and Landsat 8	For parameter generation, For C (land cover) and P (management practice) analysis
	Digital Elevation Model (DEM)	2000	SRTM image USGS	30m resolution	For HRU delineation and parameter generation,Slope, flow accumulation

3.2.1 Software Used

The software GIS Weasel, ERDAS Imagine of 10.2 and Arc GIS 10.2 were used for generating standard parameters for PRMS model, the digital image processing of satellite data and for the creation of maps respectively.

3.2.1.1 GIS Weasel

The GIS Weasel provides Geographic Information System (GIS) tools to help create maps of geographic features relevant to a user's model and to generate parameters from those maps. It provides inputs to distributed parameter hydrologic or other environmental models. The GIS Weasel software system uses a GIS-based graphical user interface (GUI), the C programming language, and external scripting languages. The software will run on any computing platform where ArcInfo Workstation (version 8.0.2 or later) and the GRID extension are accessible. The user controls the processing of the GIS Weasel by interacting with menus, maps, and tables (Viger and Leavesley, 2007). GIS Weasel generates standard parameters for PRMS model from data_bin (LU/LC, Vegetation type, Vegetation density and soil maps) as shown in appendex I.

3.2.1.2 ERDAS Imagine

Earth Resource Data Analysis System (ERDAS) Imagine 10.2 is designed specifically for satellite image processing. ERDAS Imagine is a suite of software tools designed specifically to process geospatial imagery. It allows extracting data from images like a seasoned professional, regardless of the experience or education. With its large and easy-to-use selection of image processing tools, ERDAS Imagine both simplifies and streamlines the workflow.

3.2.1.3 Arc GIS 10.2

Arc GIS is the name of a group of GIS software product lines produced by ESRI. At the desktop GIS level, ArcGIS includes: Arc Reader, which allows one to view and query maps created with the other Arc products; ArcView, which allows one to view spatial data, create maps, and perform basic spatial analysis; Arc Editor which includes all the functionality of ArcView and consists of more advanced tools for manipulation of shape files and geodatabases. There are also server-based ArcGIS products, as well as ArcGIS products for Personal Digital Assistants (PDA).

CHAPTER 4

HYDROLOGICAL MODELING AND SIMULATION OF STREAM FLOW BASED ON LU/LC AND C LIMATE CHANGE

4.1. GENERAL

The main focus of the present study was to evaluate the relative performance of hydrological model to identify effect of LU/LC, vegetation type, vegetation density and climate changes on stream flow as well as describes the methods how to develop scenarios. PRMS model was applied to Gilgel Abay river basin which is located in the Southern part of Lake Tana, Ethiopia using historical records of relevant data such as climate, LU/LC, soils, topography and other data.

The present chapter describes a details description hydrological model used for simulating stream flow, the study watersheds, data inputs as well as software used. In addition, it describes the methods used for applying the models and a detailed discussion of results obtained.

4.2. DESCRIPTION OF PRMS MODEL

PRMS is a modular-design, deterministic, physically based and distributed-parameter modelling system that has been developed by the US Geological Survey (USGS) to evaluate the impacts of various combinations of precipitation, climate, and land use on stream flow, sediment yield, and general basin hydrology (Leavesley et al., 1983). Basin response to normal and extreme rainfall and snowmelt can be simulated to evaluate changes in water-balance relationships, flow regimes, flood peaks and volumes, soil-water relationships, sediment yield, and ground-water recharge. Parameter-optimization and sensitivity analysis capabilities are provided to fit selected model parameters and to evaluate their individual and joint effects on model output (Leavesley et al., 1983, 2002). The modular design provides a flexible framework for continued model-system enhancement and hydrologic-modelling research and development.

In data scarce Tropical Africa a hydrological model precipitation-runoff modelling system at a catchment scale used to investigate the impact of climatic and land use change on water resources (Leggess et al., 2003). PRMS divides a watershed into smaller modelling subunits based on its physical characteristics of slope, aspect, elevation, vegetation type, soil type, land use, and precipitation distribution. HRU can be considered as the equivalent of one flow plane, or it can be delineated into a number of flow planes. In this study, the model operated the daily mode and monthly mode for modeling daily and monthly stream flows.

The Modular Modelling System (MMS) used to build a suitable Precipitation Runoff Modelling System (PRMS) for the study area. Distributed parameter capabilities of PRMS enabled by portioning catchment into subareas that are assumed to be homogeneous in their hydrologic response by using GIS Weasel. FAO digital soil map and satellite image derived land use/land cover, vegetation type and vegetation density integrated in GIS Weasel to generate parameters for PRMS model.

HRU delineation and generation of input parameters for PRMS model were done by using GIS Weasel (Viger et al., 1998). The GIS Weasel provides a GIS tools to help create maps of geographic features essential for user`s model and to generate parameters from those maps. It has three phases: set up, delineation and parameterization. In the setup phase of the GIS Weasel processing sequence, a variety of topographic surfaces are generated from the user-supplied DEM. The most important of these products is a version of the DEM useful for routing hydrologic flow, a surface of flow direction values, a surface of flow accumulation values, and a map describing the area of interest (AOI). The setup phase of a GIS Weasel processing session establishes many of the most commonly needed GIS data sets for delineating geographic features essential to most environmental simulation models. In delineation Phase, once the setup phase is completed, the GIS Weasel gives tools, through the tool panel, to delineate maps of different kinds of geographic features within the AOI. In Parameterization Phase, after the user has created maps of the different kinds of geographic features that depict the geographic domain to be modeled, parameters generated from those maps can be as input to the model as identified from Table 4.1. For Generating parameters using GIS Weasel in parameterization phase data_bin of grided forests, vegetation density, LU/LC and soils for the Area of Interest (AOI) were utilized (Viger and Leavesley, 2007).

The soil-zone reservoir represents that part of the soil mantle that can lose water through the processes of evaporation and transpiration. Average rooting depth of the prominent vegetation covering the soil surface defines the depth of this zone and the average root zone depth in this research is about 30 meter. Water storage in the soil zone is increased by infiltration of rainfall and snowmelt and depleted by evapotranspiration. Maximum retention storage occurs at field capacity; minimum storage (assumed to be zero) occurs at wilting point. The soil zone is considered as a two-layered system. The upper layer is termed as the recharge zone, losses from this zone are assumed to occur from evaporation and transpiration, whereas losses from the lower zone occur only through transpiration (Figure 4.1).

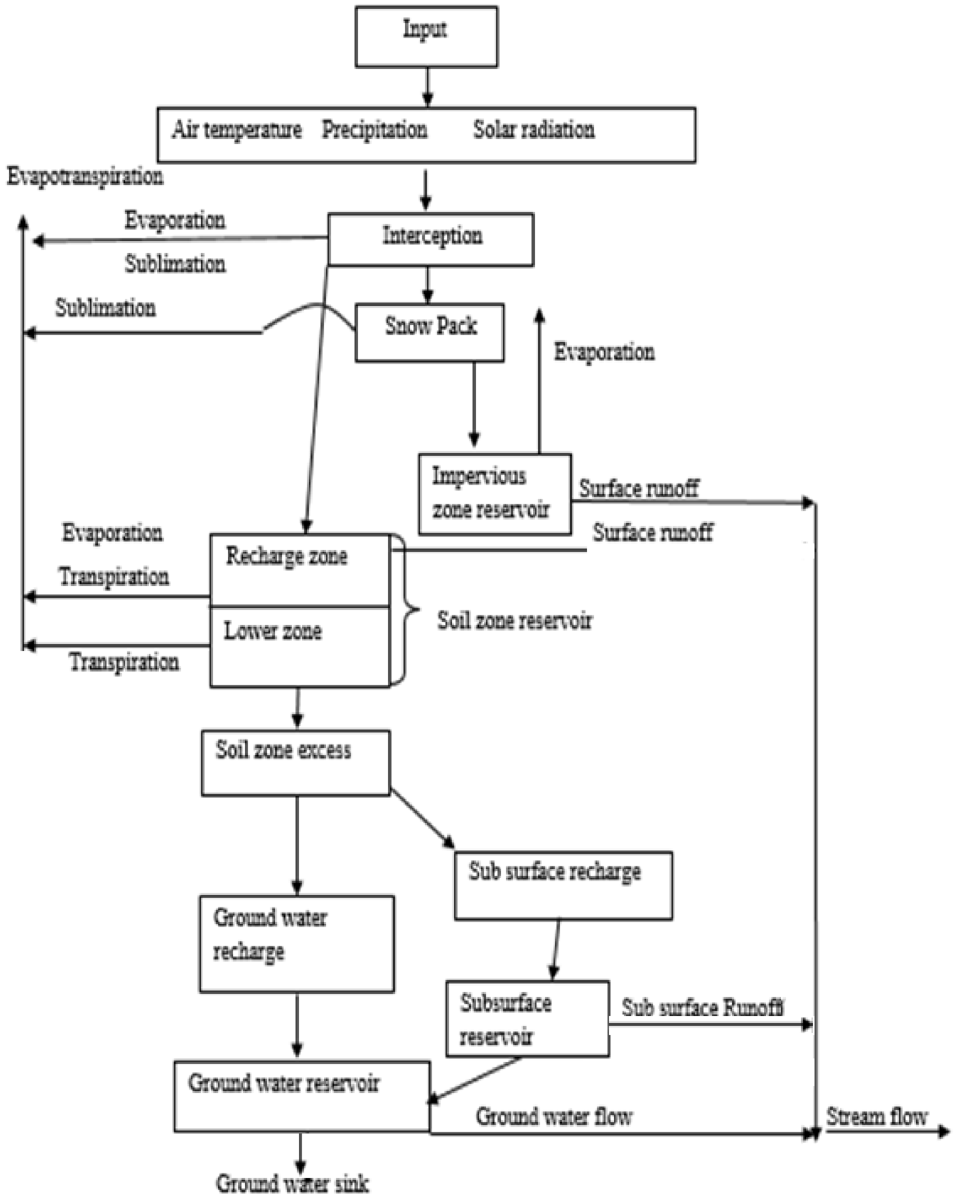

Figure.4.1. Schematic representations for different components of PRMS model (Source: Leavesley et al., 1983).

The calculation of infiltration into the soil zone is influenced by whether the input source is rain or snowmelt. All snowmelt is assumed to infiltrate until field capacity is reached. At field capacity, any extra snowmelt is partitioned between infiltration and surface runoff. At field capacity, the soil zone is assumed to have a maximum daily snowmelt infiltration capacity. All snowmelt in excess of this capacity contributes to surface runoff. Infiltration in excess of field capacity first is used to fulfill recharge to the groundwater reservoir, having a maximum daily limit. Excess infiltration, above this limit, becomes recharge to the subsurface reservoir. Water available for infiltration as the result of a rain-on-snow event is treated as snowmelt if the snowpack is not diminished and as rainfall if the snowpack is depleted (Figure 4.1).

4.2.1. Surface-Runoff Modules: srunoff_smidx and srunoff_carea

The Surface-Runoff Modules calculate surface runoff from infiltration excess and soil saturation by using a variable-source-area concept, where the runoff generating areas of the watershed surface vary in location and size over time (Dickinson and Whiteley, 1970; Hewlett and Nutter, 1970). Module srunoff_smidx calculates these values by using a non-linear, variable-source-area method, whereas module srunoff_carea calculates them by using a linear, variable-source-area method. The user chooses a Surface Runoff Module by setting control parameter srunoff_module in the Control File to either srunoff_carea or srunoff_smidx.

Rain throughfall, snowmelt, and any cascading Hortonian surface runoff from an upslope HRU are partitioned to the pervious, impervious, and surface-depression storage portions of each HRU on the basis of the fraction of impervious area (parameter hru_percent_imperv) and surface-depression storage area (parameter dprst_area) of the HRU. Both modules calculate retention storage, evaporation, and runoff on impervious and depression storage areas of each HRU by using continuity. Both modules calculate seepage from surface-depression storage. Surface runoff because of infiltration excess and exceeding impervious storage capacity are summed and referred to as Hortonian surface runoff (Horton, 1933).

4.2.2. Impervious Storage and Evaporation

If the sum of rain throughfall, snowmelt, and the antecedent impervious storage (*avail_water*) suppasses retention storage capacity on the impervious portion of an HRU for a time step, impervious Hortonian surface runoff is generated. Water up to the impervious storage capacity (parameter imperv_stor_max) is retained until evaporated. Hortonian surface runoff from the impervious portion of an HRU (*hru_sroffi*) for each time step is calculated from continuity equation as follows:

$$avail_{water} = imperv\_stor_{HRU}^{t-1} + net\_rain_{HRU} + snowmelt_{HRU} \quad (4.1)$$

If $avail\_water$ > imperv_stor_max$_{HRU}$, then the impervious Hortonian surface runoff (*hru_sroffi*) for an HRU is calculated as:

$$hru\_sroffi_{HRU} = (avail\_water - imperv\_stor\_\max_{HRU})x \; hru\_percent\_imperv_{HRU}, \quad (4.2)$$

Otherwise

$$hru\_sroffi_{HRU} = 0 \quad (4.3)$$

Evaporation from the impervious portion of an HRU (*hru_impervevap*) for each time step is based on the available water and unsatisfied PET. Available water (*avail_water*) and unsatisfied PET (*avail_et*) are calculated as:

$$avail\_water = imperv\_stor_{HRU}^{t-1} + net\_rain_{HRU} + snowmelt - \frac{hru\_sroff_{HRU}}{hru\_percent\_imperv_{HRU}} \quad (4.4)$$

$$avail\_et = potet_{HRU} - snow\_evap_{HRU} - hru\_\text{int}\,cpevap_{HRU} - dprst\_evap\_hru_{HRIU,} \quad (4.5)$$

Where,

$dprst\_evap\_hru_{HRU}$ is evaporation, in inches, from any surface-depression storage

If *avail_et* is greater than or equal to *avail_water*, then the evaporation from the impervious portion for an HRU for each daily time step is calculated as

$$hru\_impervevap_{HRU} = avail\_waterx(1 - snow\,\text{cov}\_area_{HRU})x \; hru\_percent\_imperv_{HRU} \quad (4.6)$$

If *avail_et* is less than *avail_water*, then the evaporation from the impervious portion for an HRU for the time step is calculated using:

$$hru\_impervevap_{HRU} = avail\_etx(1 - snow\cos v\_area_{HRU})x$$
$$hru\_percent\_imperv_{HRU} \quad (4.7)$$

Storage on the impervious portion of an HRU is calculated from continuity for each daily time step as:

$$hru\_impervstor_{HRU} = hru\_impervstor^{t-1}_{HRU} - hru\_sroffi_{HRU} - imperevap_{HRU}$$
$$+(net\_rain_{HRU} + snowmelt_{HRU})xhru\_percent\_improv_{HRU} \quad (4.8)$$

4.2.3. Pervious Hortonian Surface Runoff and Infiltration

Infiltration excess on the pervious portion of each HRU exists when the throughfall, snowmelt, and any upslope Hortonian surface runoff available for infiltration is greater than the capacity of the soil. The Hortonian surface runoff from the previous portion of an HRU (*hru_sroffp*) is calculated as:

$$hru\_sroffp_{HRU} = ca\_fractionx$$
$$(upslope\_hortonian_{HRU} + net\_rain_{HRU} + snowmelt_{HRU}) \quad (4.9)$$

Where,

ca_fraction is the fractional variable-source area for the pervious portion of an HRU.
Module srunoff_carea computes *ca_fraction* on the basis of the antecedent (*soil_rechr*) and maximum (parameter soil_rechr_max) soil-moisture content of the capillary reservoir recharge zone as:

$$ca\_fraction = carea\_\min_{HRU} +$$
$$\left[(carea\_\max_{HRU} - carea\_\min_{HRU})x\left(\frac{soil\_recher^{t-1}_{HRU}}{soil\_recher\_\max_{HRU}}\right)\right] \quad (4.10)$$

Module srunoff_smidx calculates the antecedent soil-moisture content of the capillary reservoir (*soil_moist*) as:

$$avail\_et = potet_{HRU} - snow\_evap_{HRU} -$$
$$hru\_\text{int}\, cpevap_{HRU} - dprst\_evap\_hru_{HRU} \quad (4.11)$$

$$ca\_fraction = smidx\_coef_{HRU} x (10)^{smidx\_evap_{HRU} x smidx} \quad (4.12)$$

If *ca_fraction* > carea_max$_{HRU}$, then *ca_fraction* is set to carea_max$_{HRU}$.

When no snowpack exists, infiltration to the area combination with pervious portion of an HRU is calculated as:

$$\begin{aligned} &\inf il_{HRU} = \\ &(upslope\_hortonian_{HRU} + net\_rain_{HRU} + snowmelt_{HRU} - hru\_sroffi_{HRU} - hru\_sroffp_{HRU}) \\ &x(1 - hru\_percent\_imprev_{HRU}) \end{aligned} \quad (4.13)$$

4.2.4. Surface-Depression Simulation

The Surface-Runoff Modules can simulate surface-depression processes that causes the effect of numerous, small, unregulated water bodies. Although the consquence of an individual surface depression may be negligible, numerous surface depressions can have an impact on the hydrologic response of an HRU. Typically, surface depressions provide for water storage during and immediately after precipitation and snowmelt events; however, some may retain water year round. A surface depression is distinct from a lake in that it is not large enough to warrant discretization as its own HRU. Examples of surface depressions include prairie potholes, farm and mill ponds, and storm water-retention structures. Specification of the control parameter dprst_flag with the value 1 activates the surface-depression module.

The initial concept of surface depression, as implemented in PRMS, is described by Steuer and Hunt (2001). The first direct simulation of surface depressions within PRMS was reported by Vining (2002). A subsequent implementation of surface depression simulation within PRMS was recorded in Viger et al., (2010). Surface depressions that can generate surface runoff are called “open.” Surface depressions that do not spill are called “closed.” The maximum capacity of open surface depressions (*dprst_vol_open_max*) for each HRU is computed as:

$$\begin{aligned} &dprst\_vol\_open\_\max_{HRU} = dprst\_area_{HRU} x dprst\_depth\_avg_{HRU} x \\ &dprst\_frac\_open_{HRU} \end{aligned} \quad (4.14)$$

Closed surface depressions are simulated with unlimited storage capacity. Open surface depressions produce surface runoff when their storage reaches a threshold volume (*dprst_vol_thres_open*). Threshold volume for each HRU is computed as:

$$dprst\_vol\_thres\_open_{HRU} = dprst\_vol\_open\_\max_{HRU}\ x\ open\_flow\_thres_{HRU} \qquad (4.15)$$

The initial amounts of water in open and closed surface depressions for each HRU are computed as:

$$dprst\_vol\_open_{HRU}^{t=0} = dprst\_vol\_open\_\max_{HRU}\ x\ dprst\_frac\_init_{HRU} \qquad (4.16)$$

And

$$dprst\_vol\_clos_{HRU}^{t=0} = dprst\_area_{HRU}\ x dprst\_depth\_avg_{HRU}\ x\ (1 - dprst\_frac\_open_{HRU})x dprst\_frac\_init_{HRU} \qquad (4.17)$$

Values of open and closed storage volumes for subsequent time steps are calculated on the basis of inflows and outflows and antecedent storage volumes. Cascading Hortonian surface runoff (*upslope_hortonian*), throughfall rain (*net_rain*) calculated by the Interception Module, and snowmelt (*snowmelt*) calculated by the Snow-Computation Module are added directly to open and closed surface depressions as depth, in inches, over the maximum area of the depressions. New storage volume in open depression storage for each HRU is calculated as

$$dprst\_vol\_open_{HRU} = dprst\_vol\_open_{HRU}^{t-1} + (upslope\_hortonian_{HRU}\ x sro\_to\_dprst_{HRU} + net\_rain_{HRU} + snowmelt_{HRU})x\ dprst\_area\_open_{HRU}^{t-1} \qquad (4.18)$$

The storage volume for closed surface depressions is calculated in the same manner by using the "_clos" versions of the variables in equation (4.18).

The surface area for open surface depressions for each HRU is computed, according to Vining (2002).

$$dprst\_area\_open_{HRU} = e^{va\_open\_\exp\ x LOG\left(\frac{dprst\_vol\_open_{HRU}}{dprst\_vol\_thres\_open_{HRU}}\right)} \qquad (4.19)$$

The surface area for closed surface depressions is calculated in the same manner using the "_clos" versions of the variables in equation (4.19).

4.2.5. Soil-Zone Module: Soil zone

The soil-zone hydrologic processes are simulated by either the module soil zone or the combination of deprecated modules smbal_prms and ssflow_prms. The user has the option of setting control parameter soilzone_module in the Control File to soil zone or smbal_prms. Modules smbal_prms and ssflow_prms are only retained for backward compatibility with older PRMS applications. The remainder of this section describes the soil zone Module. The smbal_prms and ssflow_prms modules are documented by Leavesley et al., (1996).

Computation of the water content of the soil zone is based on the summation of all moisture depletions and accretions. Depletions include evapotranspiration, drainage to the groundwater reservoir, fast and slow interflow, and saturation excess surface runoff (here in called Dunnian surface runoff) (Dunne and Black, 1970).

4.2.6. Description of Conceptual Reservoirs

The soil-zone module simulates three conceptual reservoirs. These reservoirs are the capillary reservoir, the gravity reservoir, and the preferential-flow reservoir. These three reservoirs are not physical layers in the soil column but rather represent, and account for, soil-water content at different levels of saturation. The water stored in each of these three reservoirs is subject to different physical processes and maximum storage capacities.

The capillary reservoir is the water content between wilting point and field capacity (*soil_moist*) for each HRU with maximum content specified by parameter soil_moist_max. This reservoir occupies the fraction of the HRU that is pervious (*hru_frac_perv*). This water is held in place by capillary forces. It is not available for drainage and is depleted only through the process of evapotranspiration. As in previous versions of PRMS, the capillary reservoir is partitioned into two zones: the recharge zone and the lower zone. The recharge zone contains water (*soil_rechr*) with a maximum content specified by parameter soil_rechr_max. The water in this zone is available for evaporation and transpiration. Thus, it is the water content of the capillary reservoir that is available for direct evaporation at the land surface. The lower zone contains water (*soil_lower*) when the water-saturation level in the capillary reservoir exceeds soil_rechr_max. Thus, the maximum available water-holding capacity of the lower zone is the difference between soil_moist_max and soil_rechr_max. Lower-zone water is available only for transpiration.

Optionally, HRUs can consist a preferential-flow reservoir when the preferential-flow density (parameter pref_flow_den) is specified greater than zero. The storage of this reservoir (*pref_flow_stor*) is limited to the water content between the preferential-flow threshold (*pref_flow_thrsh*) and total soil saturation (parameter sat_threshold). The threshold for each HRU is computed as:

$$pref\_flow\_thrsh_{HRU} = sat\_threshold_{HRU}\left(1 - pref\_flow\_den_{HRU}\right) \quad (4.20)$$

The maximum storage capacity in the preferential-flow reservoir for each HRU is computed as:

$$pref\_flow\_\max_{HRU} = sat\_threshold_{HRU} - pref\_flow\_thrsh_{HRU} \quad (4.21)$$

The storage of the gravity reservoir (*slow_stor*) is restricted to the water-content between field capacity and *pref_flow_thrsh*. Water content in the gravity reservoir and preferential-flow reservoir (*ssres_stor*) is subject to the force of gravity, hydraulic conductivity, and storage capacity. Water content in the gravity reservoir is available for recharge to the groundwater reservoir, slow interflow, flow to the preferential-flow reservoir, and Dunnian surface runoff. Recharge from the gravity reservoir is conceptualized as vertical, gravity-driven flow through pore space within the soil. Slow interflow is conceptualized as lateral subsurface flow leaving the gravity reservoir. Dunnian surface runoff is conceptualized as excess soil water flowing downslope laterally on the land surface. Water in the preferential-flow reservoir is available for fast interflow and Dunnian surface runoff. Fast interflow is conceptualized as lateral subsurface flow through soil cracks, animal borrows, or leaf litter.

4.2.7. Groundwater-Flow Module (gwflow)

The Groundwater-Flow Module simulates storage and inflows to and outflows from the groundwater reservoir (GWR). The GWR has infinite capacity and is the source of simulated base flow. Applications developed with previous versions of PRMS typically used a single GWR for the entire domain. Applications developed with PRMS-IV should have a GWR corresponding to each HRU. Total inflow to each GWR (*gwres_in*) comes from excess soil water, gravity drainage, groundwater flow from any cascading upslope GWRs (*gw_upslope*), and from surface-depression storage seepage according to:

$$gwres\_in_{GWR} = soil\_to\_gw_{GWR} + ssr\_to\_gw_{GWR} + gw\_upslope_{GWR} + gw\_dprst\_seep_{GWR} \tag{4.22}$$

If control parameter strmflow_module is set to strmflow_lake, then seepage is calculated as:

$$seepage_{lake} = \left(elevlake_{lake} - lake\_seep\_elev_{lake}\right) x gw\_seep\_coef_{GWR} \tag{4.23}$$

There are two ways by which water leaves a GWR: base flow (*gwres_flow*) and the groundwater sink (*gwres_sink*). Base flow is water that flows from a GWR to a stream segment, lake, or another GWR within the model domain, and is computed as:

$$gwres\_flow_{GWR} = gwflow\_coef_{GWR} x gwres\_stor_{GWR} \tag{4.24}$$

The groundwater sink represents groundwater flow that leaves the domain and is calculated as:

$$gwres\_\sin k_{GWR} = gw\sin k\_coef_{GWR} x gwres\_stor_{GWR} \tag{4.25}$$

Storage in a GWR (*gwres_stor*) is calculated from the inflows and outflows and the groundwater storage from the previous time step as follows:

$$gwres\_stor_{GWR} = gwres\_stor_{GWR}^{t-1} + gwres\_in_{GWR} - gwres\_ flow_{GWR} - gwres\_\sin k_{GWR} - seepage_{lake}^{t-1} \quad (4.26)$$

4.2.8. Stream Flow Modules

Stream flow is calculated by one of three user-specified options. The simplest approach is the strmflow module that calculates total stream flow leaving the domain as the sum of surface runoff, interflow, and groundwater discharge that arrive at the stream network. The muskingum module uses a Muskingum flow-routing method to calculate stream flow to and from individual stream segments. The strmflow_in_out module uses the same stream network as the muskingum module, but sets the outflow of each segment to the inflow. The user selects a Stream flow Module by setting control parameter strmflow_module in the Control File to one of three module names: strmflow, muskingum, or strmflow_in_out.

4.2.8.1.Strmflow (stream flow) Module

The Stream flow Module sums flow (surface runoff, interflow, and groundwater discharge) from the HRUs and GWRs to calculate total stream flow out of the domain. There are no input parameters to the strmflow module. Total stream flow out of the watershed, in inch-acres per day (*basin_stflow*) is calculated as:

$$base\_stflow = base\_sroff + ba\sin\_ssflow + ba\sin\_gwflow \quad (4.27)$$

4.2.8.2. Muskingum Module

The Muskingum module was originally developed for PRMS by Mastin and Vaccaro (2002) and developed further by Markstrom (2012). The stream network used for Muskingum routing is conceptualized as a single-direction sequence of connected stream segments as specified by parameter to segment. Typically, one segment is associated with each one-plane HRU or the pair of left- and right-bank HRUs, as specified by parameter hru_segment. This module has been modified from past versions (module musroute, Mastin and Vaccaro, 2002) to make it more stable for stream network routing in watersheds with stream segments with varying travel times. The Muskingum module has an internal structure that allows for a different computational time step for each segment within each PRMS daily time step. Flow values calculated at these finer time steps are clustered for each segment. The Muskingum routing equation (Linsley et al., 1982) assumes a linear relation between storage and the characteristics of the inflow (*seg_inflow*) and outflow (*seg_outflow*). Storage in a stream segment, for internal time step Δt, is calculated as:

$$storage^{t}_{segment} = K\_coef_{segment} x \left(\left(X\_coef_{segment} x seg\_\inf low_{seg}\right) + \left(1 - X\_coef_{segment}\right) x seg\_outflow^{t}_{seg}\right) \quad (4.28)$$

Assuming that the average flow during an internal time step is equal to the average flow at the start and end times of the internal time step, the continuity equation can be expressed as:

$$\Delta storage^{t}_{segment} = storage^{t}_{segment} - storage^{t-1}_{segment} = \left(\frac{seg\_\inf low^{t}_{segment} + seg\_\inf low^{t-1}_{segment}}{2}\right) x \Delta t_{segment} - \left(\frac{seg\_outflow^{t}_{segment} + seg\_outflow^{t-1}_{segment}}{2}\right) x \Delta t_{segment} \quad (4.29)$$

Substituting and solving for the stream-segment outflow, for the internal time step, results in:

$$seg\_outflow^{t}_{segment} = \left(cO_{segment} x seg\_\inf low^{t}_{segment}\right) + \left(cI_{segment} x seg\_\inf low^{t-1}_{segment}\right) + \left(c2_{segment} x seg\_outflow^{t-1}_{segment}\right) \quad (4.30)$$

Where,

$$cO_{segment} = \frac{-\left(K\_coef_{segment} + X\_coef_{segment}\right) + \frac{\Delta t_{segment}}{2}}{\left(K\_coef_{segment}\right) - \left(K\_coef_{segment} x X\_coef_{segment}\right) + \frac{\Delta t_{segment}}{2}}; \quad (4.31)$$

$$c1_{segment} = \frac{\left(K\_coef_{segment} xX\_coef_{segment}\right) + \frac{\Delta t_{segment}}{2}}{K\_coef_{segment} - \left(K\_coef_{segment} xX\_coef_{segment}\right) + \frac{\Delta t_{segment}}{2}} \quad (4.32)$$

$$c2_{segment} = \frac{K\_coef_{segment} - \left(K\_coef_{segment} xX\_coef_{segment}\right) - \frac{\Delta t_{segment}}{2}}{K\_coef_{segment} - \left(K\_coef_{segment} xX\_coef_{segment}\right) + \frac{\Delta t_{segment}}{2}} \quad (4.33)$$

The internal time step (Δt) used in the above equations is calculated by the Muskingum module for each stream segment according to

$$\Delta t_{segment} = \left\| \frac{21}{\left\| \frac{24}{\left| K\_coef_{segment} \right|} \right\|} \right\| \quad (4.34)$$

which is the travel time, in hours, rounded down to an even divisor of 24.

PRMS-IV is restricted to daily time steps, so travel time, in hours, can never be greater than 24. This means that the travel time of any segment in the stream network (parameter K_coef) must be less than one day. Consequently, stream flow must be aggregated when flowing from segments with shorter Δt to segments with longer Δt. Likewise, stream flow must be disaggregated when flowing from segments with longer Δt to shorter Δt.

4.3. METHODOLOGY

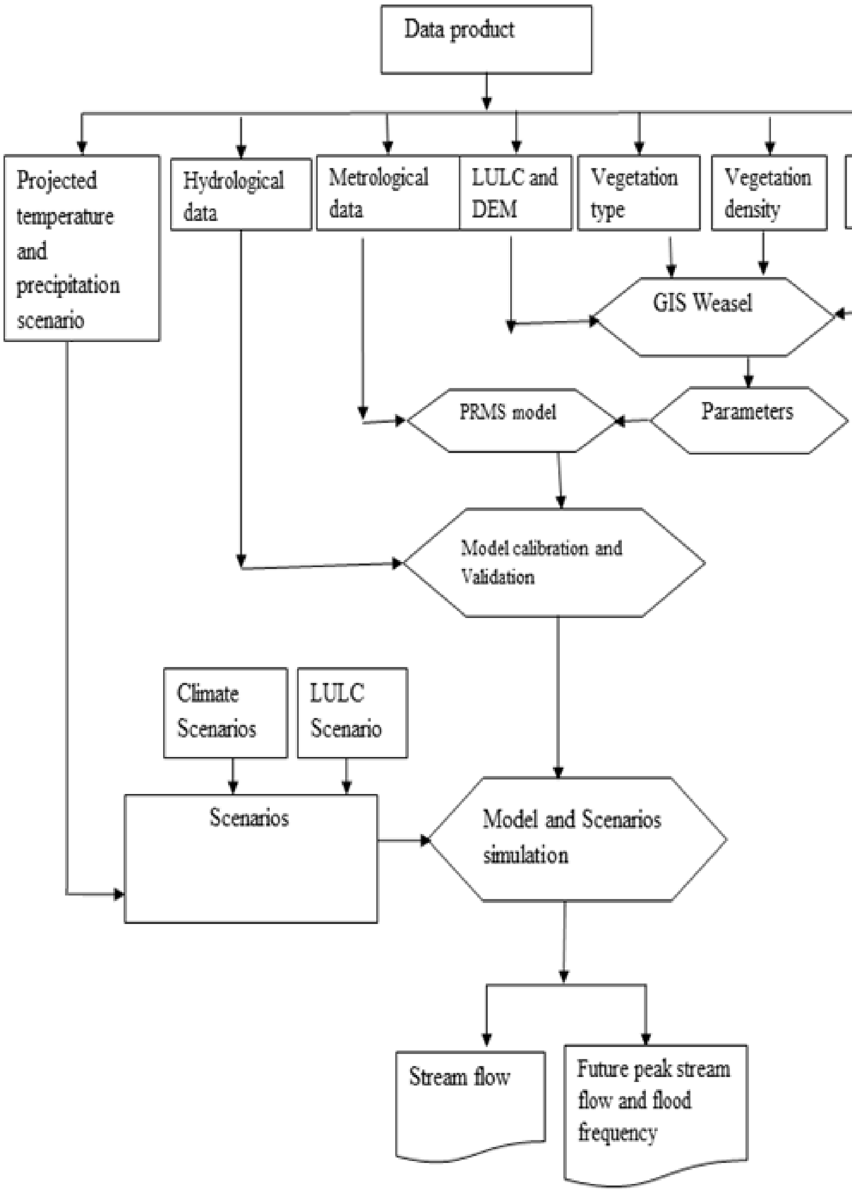

Figure.4.2. Conceptual Framework of Methodology for Modeling Stream Flow

4.3.1. Sensitivity Analysis

Sensitivity analysis provides an understanding of the relationship between the model parameters and model output (Mc Cuem, 1973). For environmental modeling, sensitivity methods are classified by two techniques, local and global. Local techniques evaluate one parameter at a time, while the global technique evaluates the sensitivity over the entire user defined parameter space (Van Griensven et al., 2006). Ideally, global techniques are applied because they evaluate the parameters sensitivity and the interactions between parameters; however global techniques require a high number of evaluations for every increase in the number of parameters (Campolongo et al., 2007). But for this study sensitivity analysis was done using Fourier Amplitude Sensitivity Test (FAST) and manual methods. Based on these methods sensitive parameters were identified and used for model calibration and validation as shown in Table 4.1.

Table.4.1. Key and sensitive parameters used for PRMS model for Gilgel Abay river basin

Parameters	Description	Range	default	Range in values in 26 HRUs
Carea_max	Maximum possible area contributing to surface runoff (decimal)	0-1	0.6	0.0299-0.03
Adjust rain	Factor to adjust measured precipitation on each HRU to account for differences in elevation and so forth	0.5-2	1	0.587503-0.587509
Soil_moist_max	Maximum water holding capacity of the soil profile (inches)	0.001-10	2	4.5-8
Soil_rechr_max	Maximum available water holding capacity (inches)	0.001-5	1.5	0.5-5
Soil2gw_max	Maximum rate of soil water excess moving to ground water (inches/day)	0-5	0	2.20000071526
Ssr2gw_rate	Coefficient to route water from the subsurface to ground water	0.05-0.8	0.1	0.004999-0.0051
ssr2gw_exp	Non-linear coefficient in equation used to route water from gravity reservoir to the GWR for each HRU	0-3	1	1.0
gwflow_coef	Ground water routing coefficient (1/day)	0.001-0.5	0.015	0.030028-0.030170
Srain_intcp	Summer rain interception storage capacity for the major vegetation type in the HRU	0-1	0.1	0.0-0.05000000074506
Covden_sum	Summer vegetation cover density (decimal)	0-1	0.5	0.08575728332996
Covden_win	Winter vegetation cover density (decimal)	0-1	0.5	0.0-0.07509090006351
Smidx_coef	Coefficient in non-linear contributing area algorithm	0.001-0.06	0.005	0.005409-0.006406
Smidx_exp	Exponent in non-linear contributing area algorithm	0.1-0.5	0.3	0.149607-0.185878
Pref_flow_den	Fraction of the soil zone in which preferential flow occur for each HRU	0-1	0	0.168938-0.169938
Soil_moist_initial	Initial value of available water in a soil profile (inches)	0-10	3	0.5
Soil_rechr_initial	Initial soil moisture for recharge zone (inches)	0-10	1	0-1
wrain_intcp	winter rain interception storage capacity for the major vegetation type in the HRU	0.0-1	0.1	0.0 -0.044361122251
jh_coef	Monthly (January to December) air temperature coefficient used in Jensen-Haise potential ET computation	0.005-0.06	0.014	0.013-0.02

4.3.2. Model Calibration and Validation

Model calibration (parameter estimation) involves adjustment of parameters to minimize the difference between measured and simulated values. Model validation involves the ability of model to the hydrologic response unit for conditions different from that used during calibration period. PRMS was calibrated using Luca, a multiple-objective, stepwise, automated procedure for hydrologic model calibration and the associated graphical user interface (GUI) (Hay and Umemoto 2006; Hay et al. 2006). The calibration procedure uses the Shuffled Complex Evolution global search algorithm to calibrate PRMS (Duan et al. 1992; Duan et al. 1993; and Duan et al. 1994). For the present work, simulation period (1993-2012) was divided in to calibration periods (1994-2005) and validation periods (2006-2012). One year period (1993) used for initiation to minimize the effects of the user`s estimate of initial value of state variables at the model start up by allowing the model to cycle a number of times. The model calibration and validation carried out by using daily and monthly mode of stream flow simulation. This involves calibrating and validating of the hydrological model using present conditions and running the model with parameters and input data corresponding to the proposed scenario conditions (a specific possibility or situation) and comparing the simulations.

4.3.3. Model Performance Evaluation

Model performance evaluation of daily and monthly scales was evaluated using standard model efficiency (E) (Nash and Sutcliffe, 1970). Nash Sutcliffe method is widely used in evaluating hydrologic modelling. The E value varies from negative infinity to 1.0, with higher values indicating good agreement between observed and simulated values. This method of evaluation is as follows:

$$E = \frac{\sum_{1=1}^{N}(Qoi - Qo)^2 - \sum_{1=1}^{N}(Qoi - Qsi)^2}{\sum_{i=1}^{N}(Qoi - Qo)^2} \qquad (4.1$$

Where,

E = Model goodness of fit efficiency

$Qoi =$ Observed stream flow for day or month i

$Qsi =$ Simulated stream flow for day or month i

$Qo =$ Mean observed daily or monthly stream flow

N= number of samples (days, months).

4.4. SCENARIO SIMULATION

Simulations were performed under different scenario conditions to identify the impacts of climate and LU/LC changes in stream flow at Gilgel Abay river basin. For simulating the hydrological response of stream flow to different scenarios, calibrated and validated hydrological model PRMS was used for comparing present conditions with proposed scenarios. PRMS model was run by using parameters generated from GIS Weasel and time series input data corresponding to proposed scenarios.

4.4.1. Effect of climate change on stream flow

Hydrologic perturbation studies are useful to explore the potential bounds of hydrologic responses for any basin (Nash and Gleick, 1991). In this study, climate change case that is 10% change in the amount of daily precipitation (during wet and dry season) and a 1.5^{o}c increase in the amount of daily temperature were chosen on the basis of general circulation model output (Jones et al., 2001; IPCC, 2001; Legesse et al., 2003; IPCC, 2007; Setegn et al., 2011). Effect of climate change on stream flow was identified by giving increased or decreased value of identified climate from time series data to PRMS model.

4.4.2. Effects of land use /land cover, vegetation type and vegetation density changes on stream flow

To identify effect of changes in LU/LC, vegetation type and vegetation density on stream flow different LU/LC, vegetation type and vegetation density data from 2000 and 2010 were considered (Figures 4.3 and 4.4). These different periods LU/LC, vegetation type and vegetation density with soil data and DEM were given to GIS Weasel to generate different parameters for PRMS model. These generated parameters together with time series data (daily minimum and maximum temperature, daily precipitation and daily stream flow) fed to PRMS model to simulate stream flow for the years 1993-2000 and 2001-2008. From the time series data, climate changes (daily maximum and minimum temperature and daily precipitations) were kept the same as baseline period (1993-2000). The stream flow of 2001-2008 compared with baseline period (1993-2000) and the effect of LU/LC, vegetation type and vegetation density was identified using PRMS model.

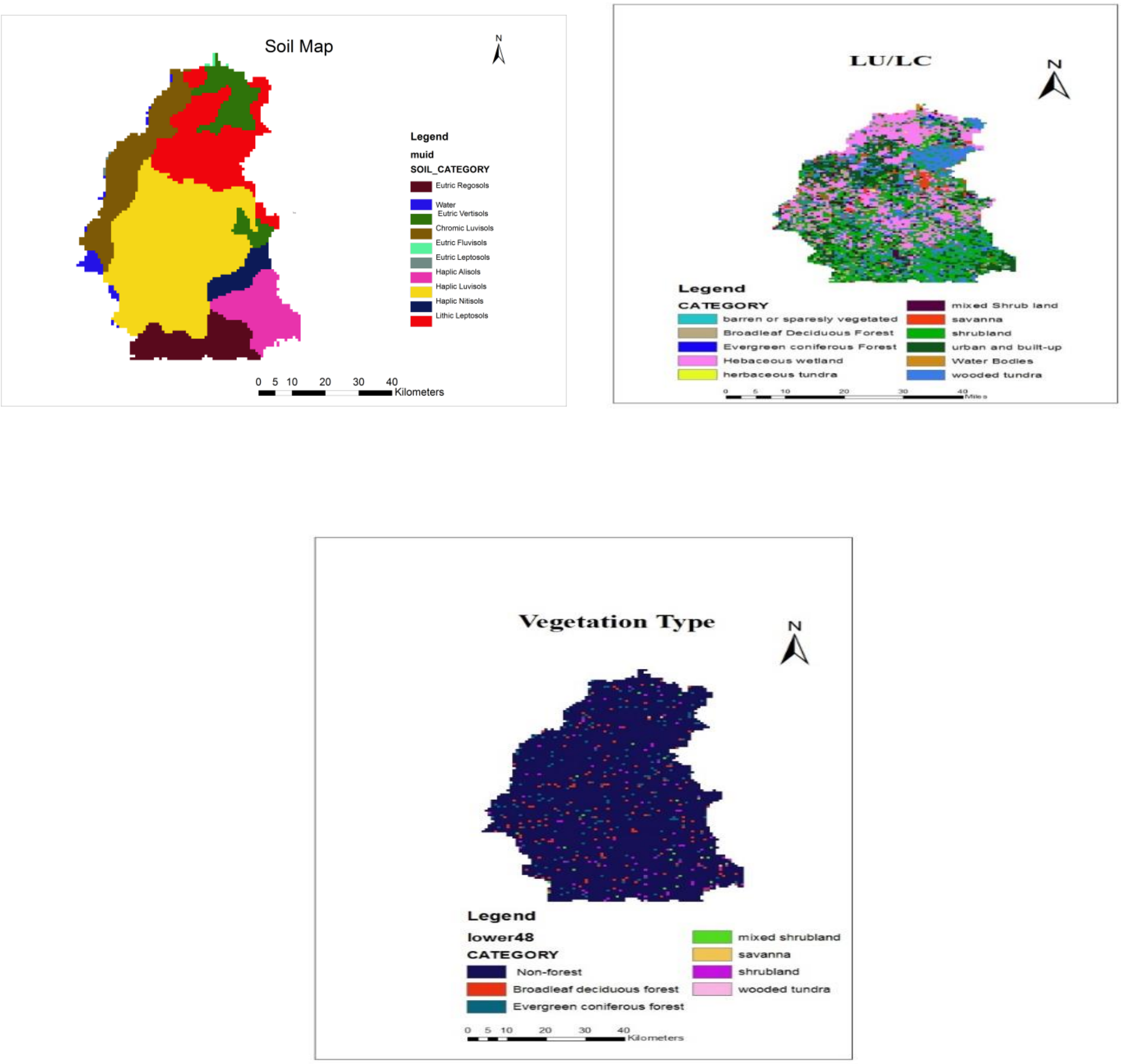

Figure 4. 3. Soil map, LU/LC and Vegetation type of 1990-2000

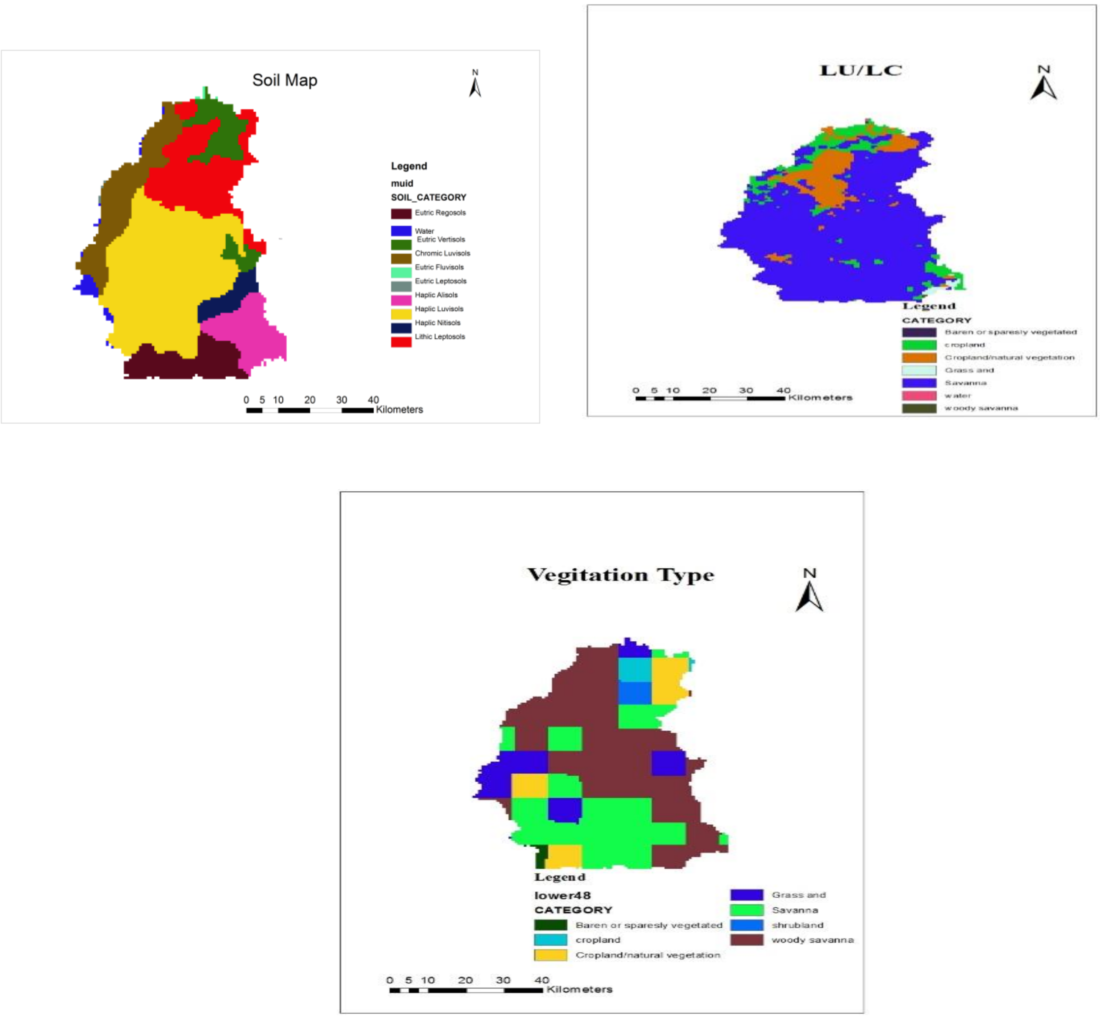

Figure 4 4. Soil map, LU/LC and Vegetation type of 2001-2010

4.4.3. Combined effects of land use land cover, vegetation type, vegetation density and climate change

To evaluate combined effects of LU/LC, vegetation type, vegetation density and climate changes on stream flow, two different seasons of LU/LC, vegetation type, vegetation density and climate changes were identified and evaluated for their effects on stream flow. Period one (2000) and period two (2010 years) were considered. LU/LC, vegetation type and vegetation density data_bins of period one and period two were given to GIS Weasel to generate parameters for PRMS model. In addition to this, soil data was given to GIS Weasel to generate parameters relating to the soil. The same FAO soil data used for both periods to generate parameters as soil changes within 10 years has negligible difference. For two periods GIS Weasel generated different value of parameters. These generated parameters for different periods within time series climate data (daily minimum and maximum temperature, daily precipitation) and daily stream flow data for different periods fed to PRMS model to simulate stream flow. By considering 1993-2000 period as baseline period, stream flow during 2001-2008 was evaluated and identified to see the combined effects of LU/LC, vegetation type, vegetation density and climate changes on stream flow.

4.5. RESULTS AND DISCUSSION

GIS Weasel was made compatable to Ethiopian catchments by developing module families of prms-cov_type, prms-incp, prms-vegden, cov-type, prms-rt_depth and other related families inside GIS Weasel software. Hence, GIS Weasel provided Geographic Information System tools which helped to create maps of geographic features relevant to PRMS model and generated standard parameters for PRMS model**.**

4.5.1. Model calibration and validation at daily and monthly modes

For the area of interest which has 26 number of Hydrological Response Units there is a good agreement between daily simulated and measured stream flow during calibration and validation periods with average E values 0.71 and 0.70 respectively. For monthly stream flow average E values for calibration and validation are 0.91 and 0.90 respectively. The monthly observed and simulated stream flow showed better agreement between observed and simulated stream flow (Figures 4.5 and 4.6). This indicates that the model is more compatible for monthly stream flow simulation than daily stream flow simulation at Gilgel Abay River Basin. It is also clear that the model simulated stream flow well in daily mode of simulation. Simulation of daily as well as monthly stream flow during calibration period indicates that there is slight under estimate of peak values on August 5 and September 8, 2003. In addition, during validation period simulation of stream flow indicates under estimate for August 20 and September 1, 2009. Since these events are only for four days over 20 years, it did not mean a problem on model structure. This may be due to variability in precipitation or stream flow recordings. Generally 1993-2012 simulation indicates that nearly 20,358 mm or 55% of precipitation (from the total 20 years 36,897 mm) returned to the atmosphere as ET and the remaining 16,538 mm or 45% of precipitation became stream flow to the river basin (Figure 4.9).

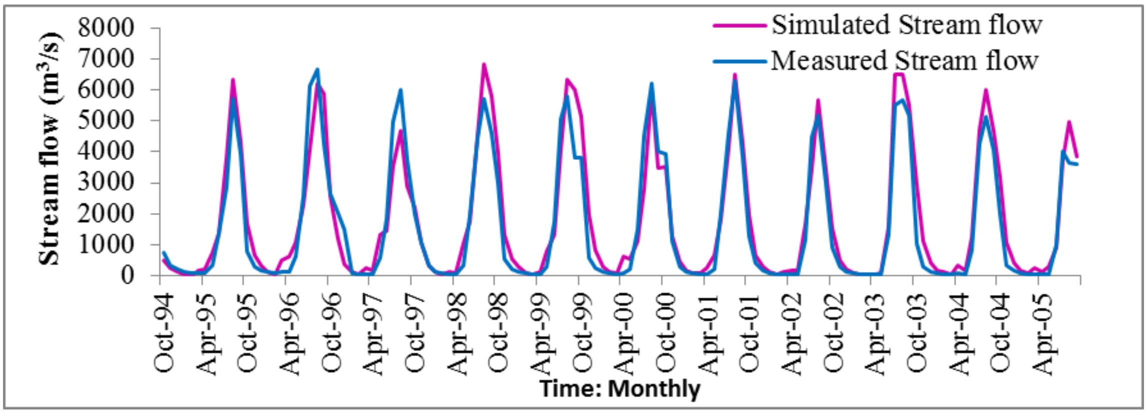

Figure 4.5. Monthly measured and simulated stream flow for calibration period (1994-2005).

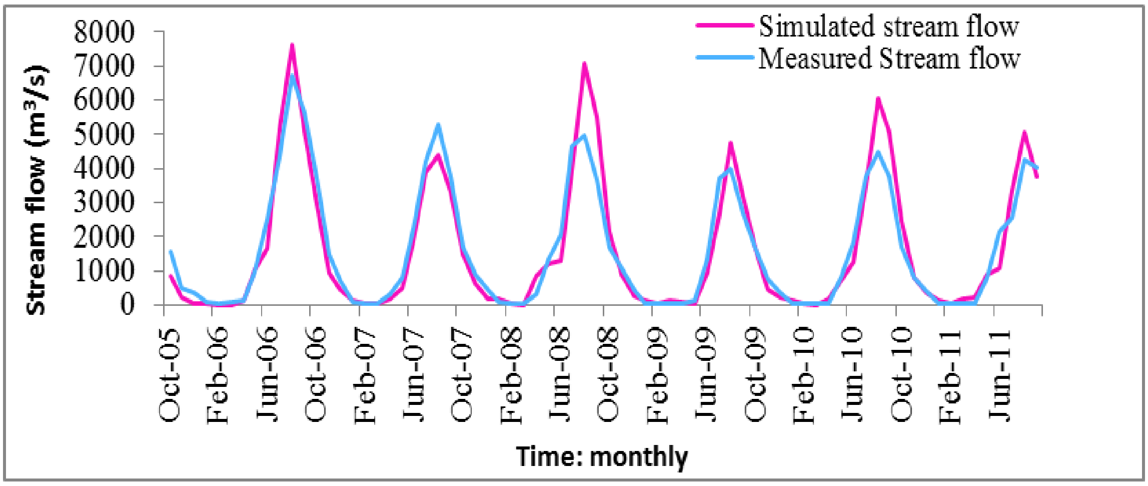

Figure 4.6. Monthly measured and simulated stream flow for validation period (2006-2012).

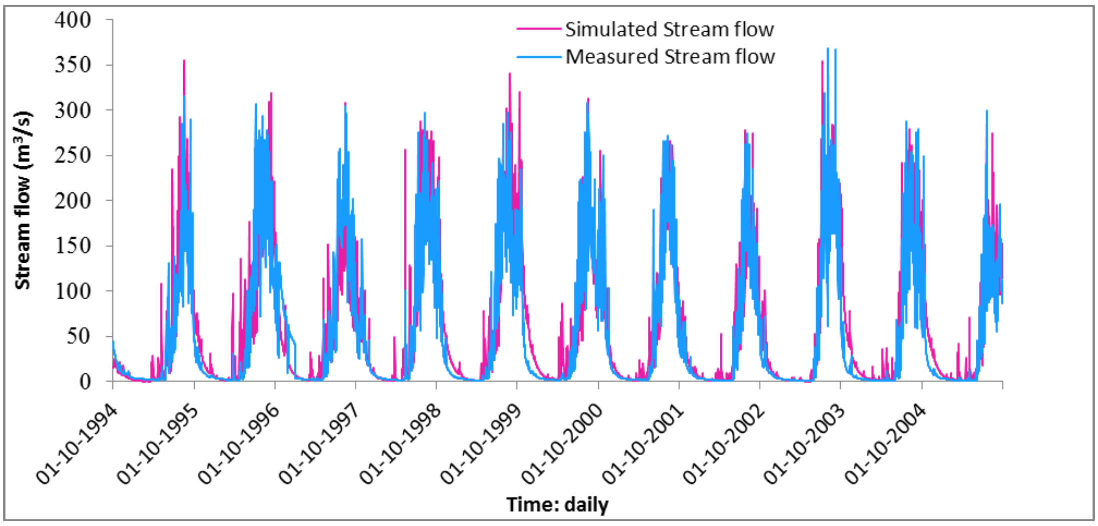

Figure 4.7. Daily measured and simulated stream flow for calibration period (1994-2005).

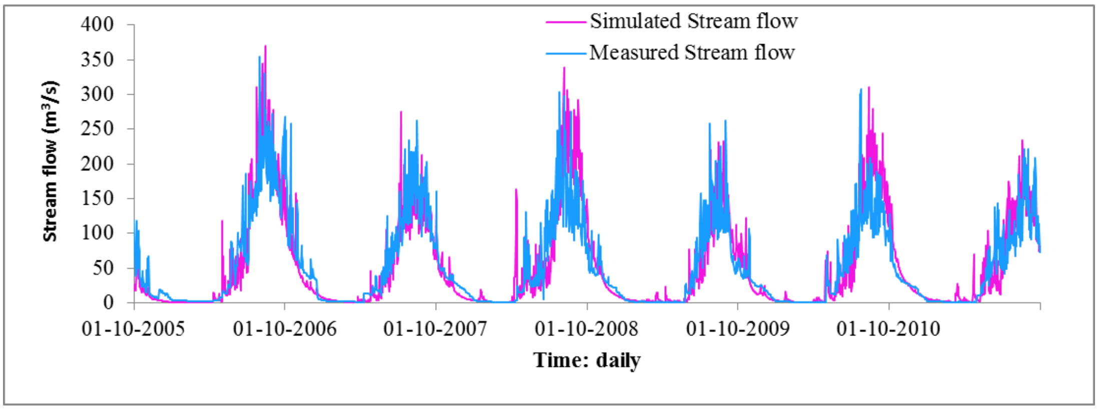

Figure 4.8. Daily measured and simulated stream flow for validation period (2006-2012).

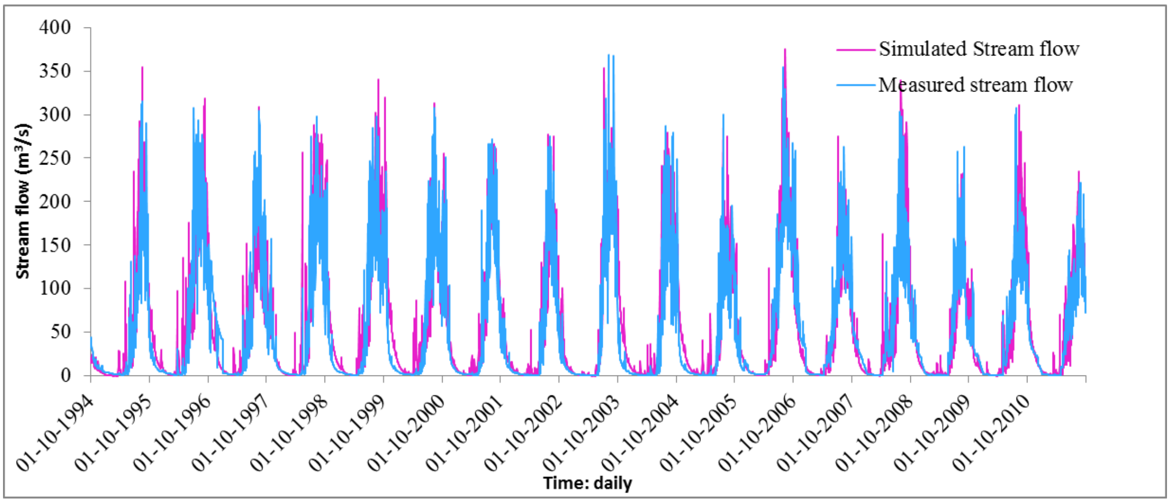

Figure 4.9. Daily simulated and measured stream flow (1993-2012).

4.5.2. Effect of climate change on stream flow

Climate scenario

To identify the effect of climate change on stream flow scenario involving 10% change in the amount of daily precipitation was chosen on basis of general circulation model output (Legesse et al. 2003; IPCC, 200, 2001; IPCC, 2007; Setegn et al., 2011). By considering 1994-2005 as a baseline period and simulating scenarios using input data of precipitation as identified and described above, and mean annual stream flow is estimated as follows. As precipitation is increased by 10% mean annual stream flow resulted in an increase of average flow of 20% (6,157 m^3/s from total average 16,979 m^3/s) compared to baseline period. The highest change occurred in 1997 (24% or 4,398 m^3/s) and the lowest change occurred in 1998 (16% or 4,317 m^3/s compared to baseline periods (18,090 m^3/s and 26,701 m^3/s respectively) as shown in Figures 4.10, 4.11 and 4.12. There is also an increase of mean annual evapotranspiration with the range of 1.3% to 4% compared to baseline periods. The highest changes occurred in 1995 (4% or 42 mm) and lowest change in 2003 (1.3% or 13 mm) compared to baseline periods (1066 mm and 1040 mm respectively).

In general, the whole simulation period (1994-2005) indicated that as precipitation is increased by 10% there is an increase of stream flow and ET 18.8%

(1748 m^3/s) and 2.3% (12 mm) respectively. Whenever there is 10% increase of precipitation on August 5 and September 8, 2003 simulation indicated under estimation of peak stream flow. This may be due to spatial variability of precipitation from original data records. On the other hand decrease of 10% precipitation resulted in decrease of 30.4% (2,835 m^3/s) average mean annual stream flow and 5.3% (27 mm) mean annual ET compared to baseline periods. The range of decrease in mean annual stream flow and mean annual ET is 24% to 36% and 2.5% to 7.5% respectively. The highest decrease in mean annual stream flow occurred in 1997 (37% or 6,655 m^3/s and lowest decrease occurred in 1995 (24% or 4,792 m^3/s compared to baseline periods (18,090 m^3/s and 19,769 m^3/s respectively) (Figures 4.10, 4.11 and 4.12). There is also a decrease of mean annual evapotranspiration with the range of 2.5% to 7.5% compared to baseline periods. In addition, the highest decrease in mean annual stream flow occurred in 1995 (7.5% or 1956 m^3/s) and lowest in 2003 (2.5% or 590 m^3/s) compared to baseline periods (26,042 m^3/s and 24,225 m^3/s respectively). For a decrease of 10% precipitation there is a decrease of 72,141 m^3/s and 713 mm of stream flow and ET respectively for whole simulation periods. From the above results it is concluded that precipitation has a direct effect of stream flow and evapotranspiration.

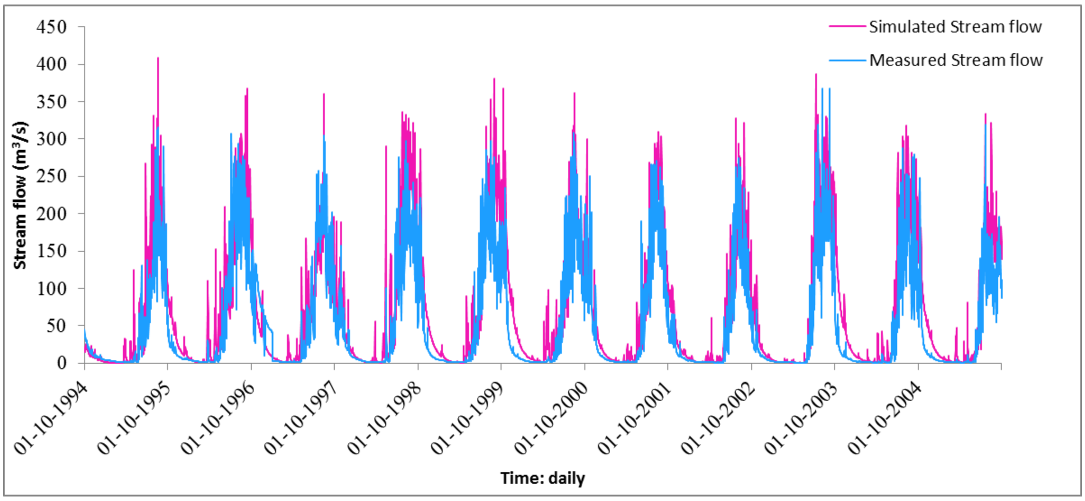

Figure 4.10. Daily simulation of stream flow under increasing 10% precipitation (1994-2005).

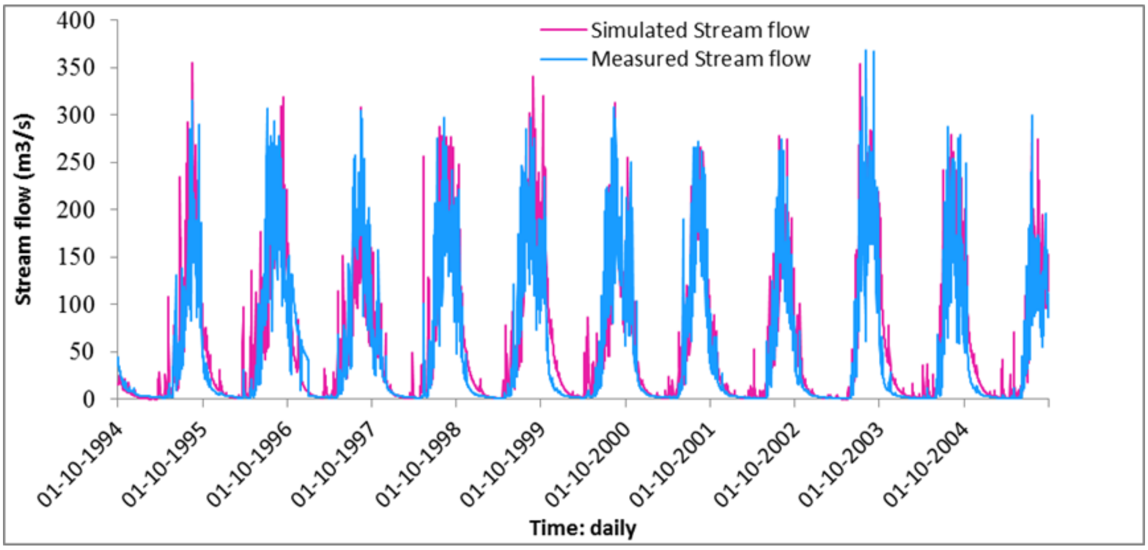

Figure 4.11. Daily simulation of stream flow on base line period (1994-2005).

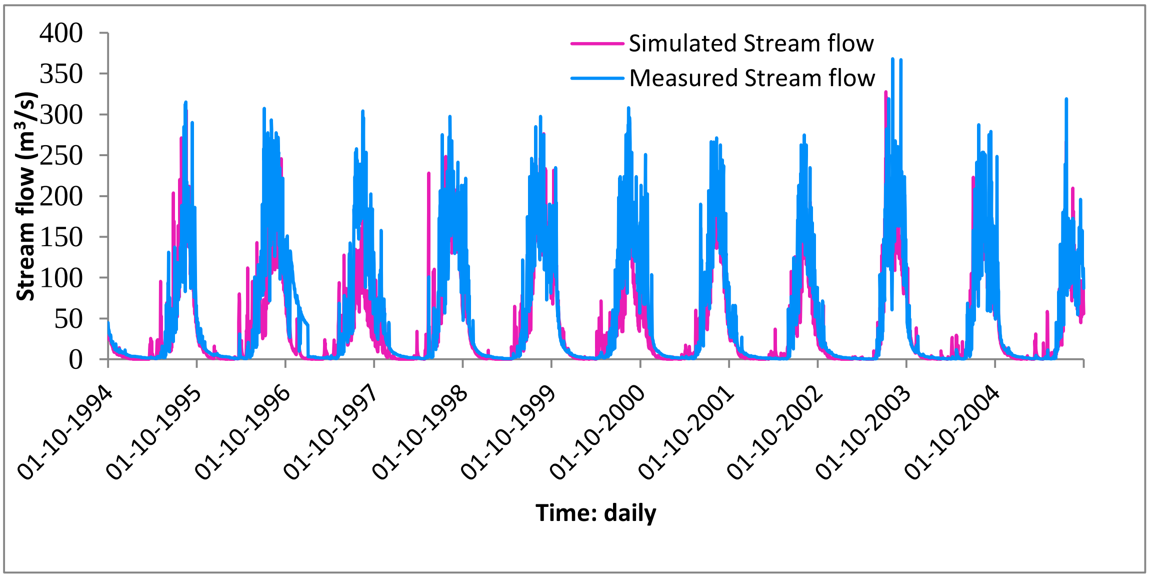

Figure 4.12. Daily simulation of stream flow under decreasing 10% precipitation (1994-2005).

On the other hand a change in 1.5°c temperature has an effect on stream flow and ET. As temperature is increased by 1.5°c mean annual stream flow resulted in a decrease in average flow by 54% (9,016 m^3/s from total average 16,979 m^3/s) compared to baseline period. The highest change occurred in 1998 (62% or 16,458 m^3/s) and lowest change occurred in 1995 (44% or 10,880 m^3/s) compared to baseline periods (26,701 m^3/s and 19,769 m^3/s) respectively (Figure 4.13). But there is an increase of mean annual evapotranspiration with the range of 30% to 61% compared to baseline periods.

The change in ET is highest in 2003 (61% or 91 mm and lowest in 1997 (30% or 430 mm) compared to baseline periods (1029 mm and 1440 mm) respectively. In general, the whole simulation period (1994-2005) indicated that there is a decrease of 59.6% (5,555 m^3/s) of stream flow and an increase of 48% (246 mm) of ET as temperature increased by 1.5^0c. An increase in 1.5^oc temperature indicated that there is a decrease of mean annual stream flow because of increasing mean annual ET.

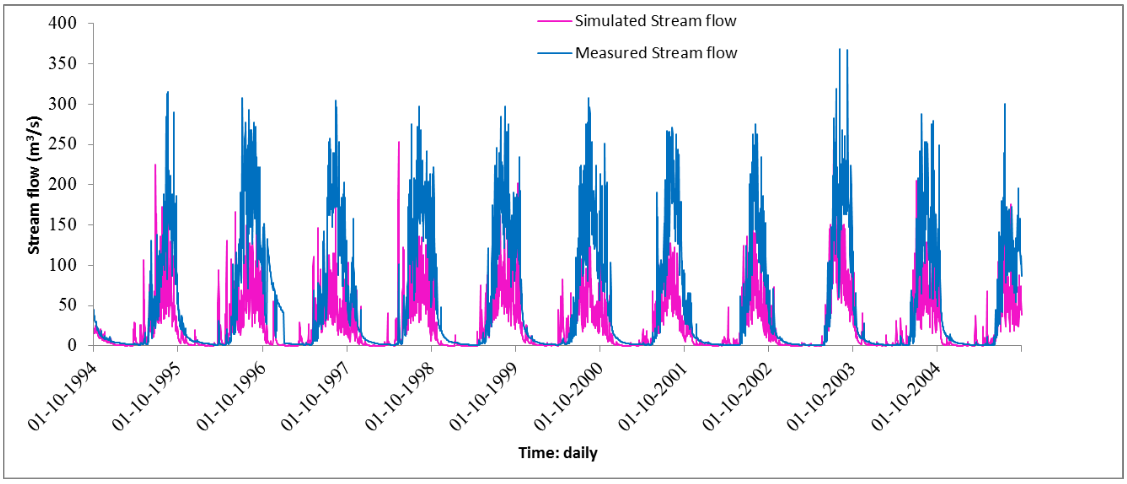

Figure 4.13. Daily simulation of stream flow due to increase of 1.5^0c temperature (1994-2005).

4.5.3. Effect of land use/ land cover change on stream flow

To identify effect of changes in LU/LC, vegetation type and vegetation density on stream flow different LU/LC, vegetation type and vegetation density data were considered with cover periods of 2000 and 2010. Analysis have been done by considering baseline period (1993-2000) and simulating stream flow for 2001-2008 periods using input parameters generated from LU/LC, vegetation type, vegetation density from 2010 with the time series data of daily maximum and minimum temperature and daily precipitation using PRMS model. Finally simulated stream flow and ET for 2001-2008 were compared with baseline period (1993-2000) and evaluated as follows. As LU/LC, vegetation type and vegetation density changed from 2000 period to 2010 period, stream flow increased from 7.8% (1482 m^3/s) to 25.3% (5000 m^3/s) and ET decreased from 4.2% (40 mm) to 20% (279 mm) from baseline period. For the whole simulation periods (2001-2008) stream flow increased by 10.8% (463 m^3/s), but ET decreased by 6.6% (16 mm) with respect to baseline periods. Hence as LU/LC, vegetation type and vegetation density changed; there is an increase of stream flow by decreasing ET. This might be happened due to deforestation which would not allow time for infiltration then to transpiration rather than giving high runoff as shown in Figures 4.14 and 4.15.

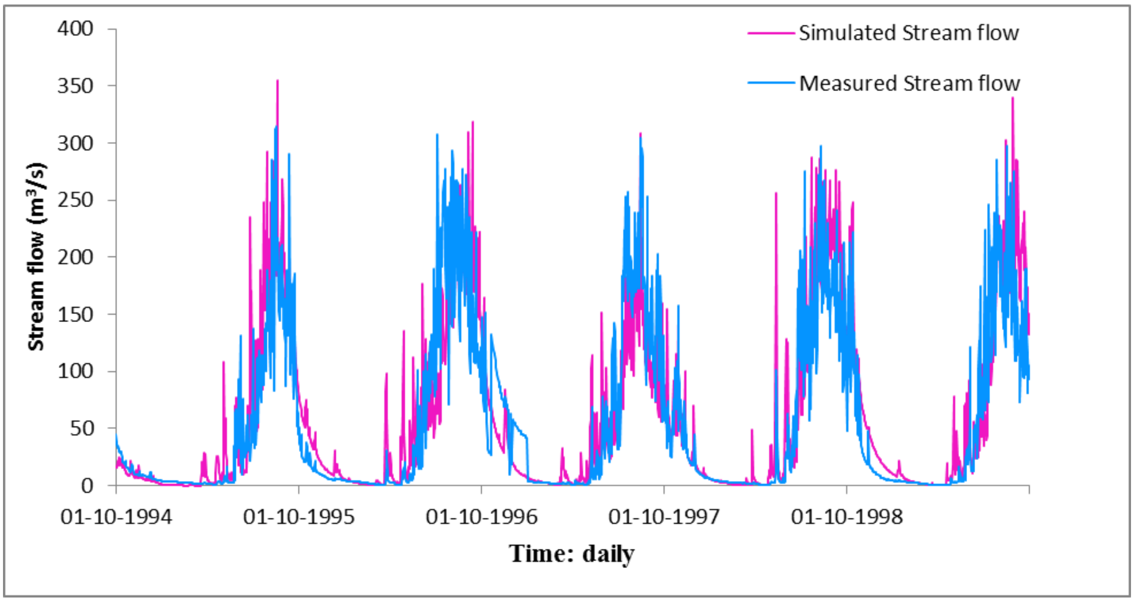

Figure 4.14. Daily simulation of stream flow (1993-2000).

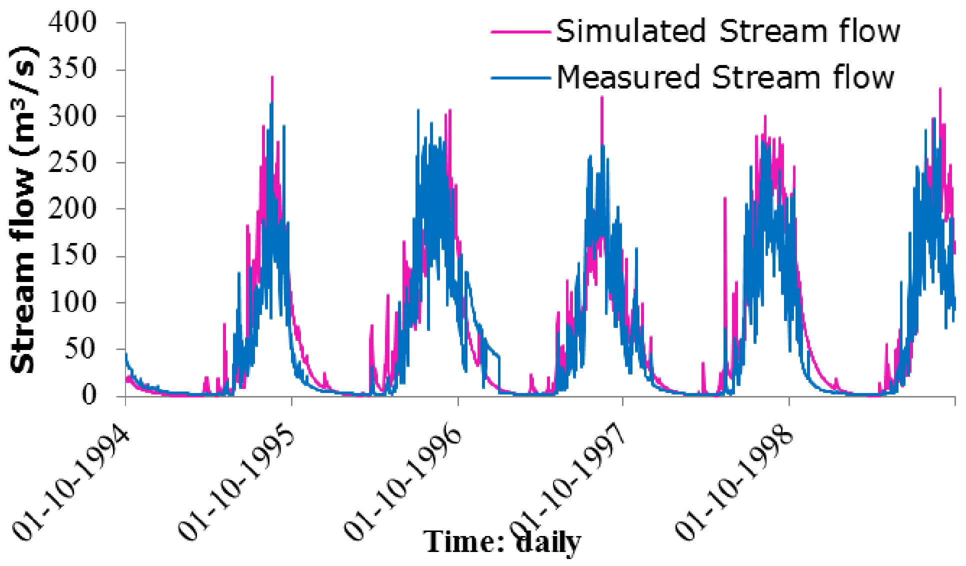

Figure 4.15. Daily simulation of stream flow (2001-2008).

4.5.4. Combined effects of land use/ land cover, vegetation type, vegetation density and climate change on stream flow

To evaluate combined effects of LU/LC, vegetation type, vegetation density and climate changes on stream flow, two periods of LU/LC, vegetation type, vegetation density and climate changes were identified and evaluated for their effects on stream flow. Combined effects are evaluated and discussed in the present section by considering period one (2000) as baseline period and relating stream flow with period two (2010 as follows. As climate and LU/LC, vegetation type and vegetation density changed from period one to period two stream flow increased with the range 3.4% (845 m^3/s) to 43.3% (6,377 m^3/s), but ET decreased with the range of 2.7% (33 mm) to 32% (463 mm) related to baseline period. Generally, for combined effects (as climate, LU/LC, vegetation type and vegetation density changed) stream flow increased 13.5% (579 m^3/s) and ET decreased 18.3% (44 mm) compared to baseline periods. Finally, when individual effects and combined effects are evaluated on stream flow and ET, combined effects are more on stream flow and ET than individual effects (effects of climate change alone or LU/LC, vegetation type and vegetation density alone) as shown in Figures 4.16 and 4.17.

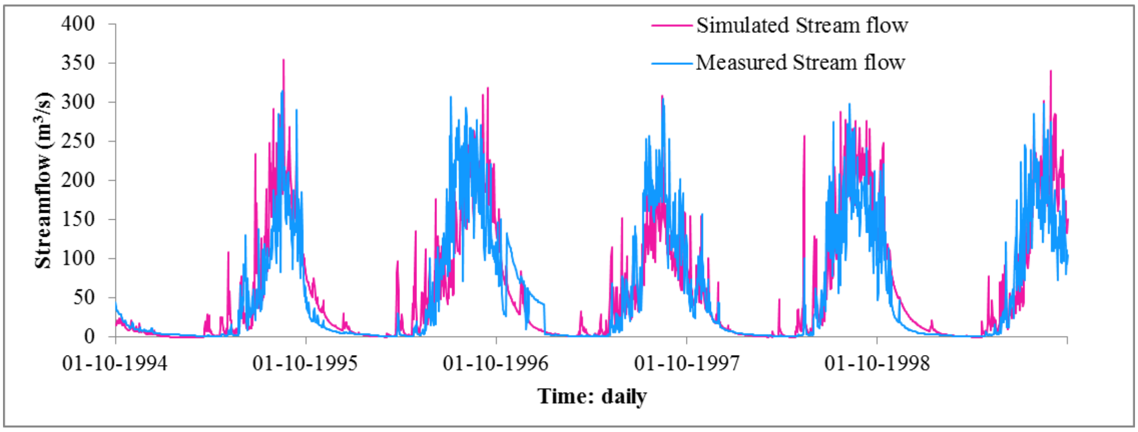

Figure 4.16. Daily simulation of stream flow (1993-2000).

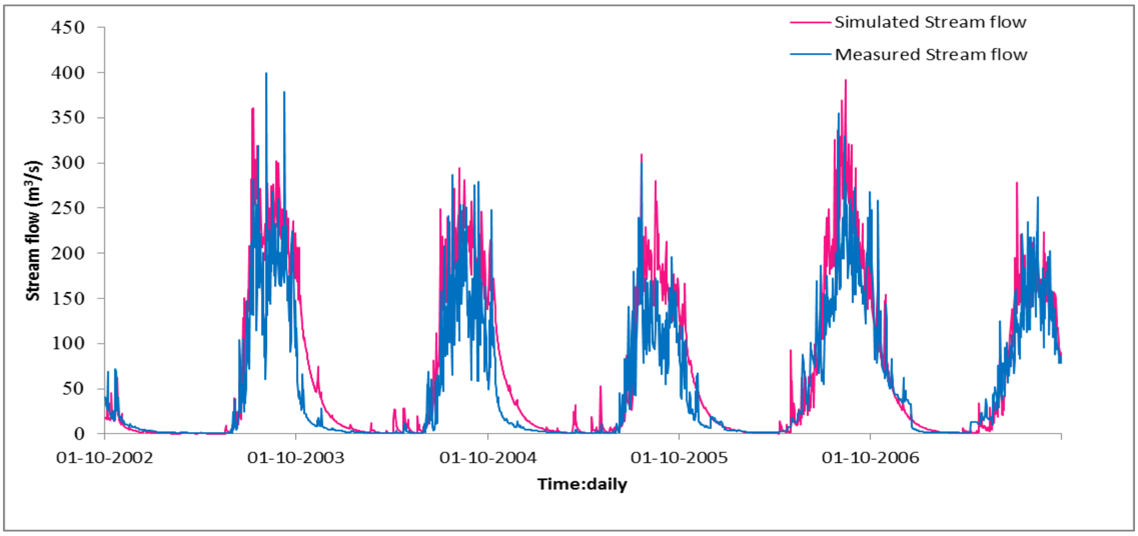

Figure 4.17. Daily simulation of stream flow (2001-2008).

4.6. CLOSURE

For the entire Gilgel Abay River Basin PRMS performed reasonably well in simulating monthly and daily stream flow with the model fit efficiency (E) value of 0.9 and 0.7 respectively. The model performs better for simulating monthly stream flow than simulating daily stream flow, because it has higher E value relating to daily mode of stream flow simulation.

LU/LC change has an effect on stream flow, as it is changed from period one (2000) to period two (2010). Hence, for the whole simulation periods (2001-2008) stream flow increased by 10.8% (463 m^3/s), but ET decreased by 6.6% (16 mm) related to baseline periods (1993-2000). Therefore, stream flow increased and ET decreased as LU/LC, vegetation type and vegetation density changed.

As climate (precipitation and air temperature) of time series data changed, there is a decrease of stream flow for the whole simulation period by 5.4% (4,190 m^3/s) and an increase of evapotranspiration by 5% (234 mm) compared to baseline periods. The highest decrease of stream flow occurred in 2010 (17% or 4317 m^3/s and the highest increasing of ET occurred in 2008 (17% or 193 mm).

In addition, as LU/LC, vegetation type and vegetation density and climate changed from 2000 to 2008, stream flow increased with the range 3.4% (845 m^3/s) to 43.3% (6,377m^3/s), but ET decreased with the range of 2.7% (706 m^3/s) to 32% (10,058 m^3/s) related to baseline period. The highest increase of stream flow occurred in 2003 (43.3% or 6,377m^3/s) and the highest decrease of ET occurred in 2006 (2.7% or 706 m^3/s). Generally, for combined effects (as climate, LU/LC, vegetation type and vegetation density changed) stream flow increased 13.5% (579 m^3/s) and ET decreased 18.3% (44 mm) compared to baseline periods. This indicates that as LU/LC, vegetation type, vegetation density and climate changed from 2000 to 2010, stream flow increases, but ET decreases for Gilgel Abay River basin. Finally, when individual effects and combined effects are evaluated on stream flow and ET, combined effects are more on stream flow and ET than individual effects (effects of climate change alone or LU/LC, vegetation type and vegetation density alone).

CHAPTER 5

ESTIMATION OF FUTURE ANNUAL DAILY PEAK STREAM FLOW AND FLOOD FREQUENCY

5.1. GENERAL

Estimation of future annual daily peak stream flow based changes on climate (precipitation, minimum and maximum temperature) was applied by using PRMS model to Gilgel Abay river basin. Climate change can affect the hydrologic components such as surface runoff, lateral flow, ground water contributions to stream and soil water content and evapotranspiration. Due to this reason it is important to evaluate future annual daily Peak stream flow resulting from variations in climate (precipitation, maximum and minimum temperature). Therefore this chapter deals on identifying future annual daily peak stream flow due to changes in air temperature and precipitation.

5.2. ESTIMATION OF FUTURE PEAK STREAM FLOW AND FLOOD FREQUENCY

To estimate future annual daily peak stream flow and flood frequency at Gilgel Abay river basin, the values for historical climate (temperature and precipitation) in the basin was adjusted on the basis of changes that are projected for 21st century at Gilgel Abay river basin. These climate changes were considered based up on (Jones et al., 2001; IPCC, 2001; Legesse et al., 2003; IPCC, 2007; Setegn et al., 2011). and the GCM out puts which were statistically downscaled. To encompass the projected future changes in climate at Gilgel Abay river basin, air temperature was adjusted by temperature values of 0^0c, 1.5^0c and 3^0c of historical temperatures. Precipitation was adjusted by two different precipitation values ranging from -10% to 10% of observed precipitation. The historical values used were from the year 1993-2012. These climate adjustments were made by adding or subtracting from magnitude of historical climate values. The 9 combinations of adjusted values for temperature and precipitation (including no change scenarios) were used as an input to PRMS model with data files. Annual daily maximum peak flow and flood frequency were calculated for each combinations. The PRMS derived peak flows from adjusted temperature and precipitation changes were then compared to unadjusted (historical) PRMS derived peak flows by using Hodge-Lehman estimator.

5.3. RESULTS AND DISCUSSION

5.3.1. Estimation of Future Peak Stream Flow (Flood) and Changes in Flood Frequency

To estimate future annual daily peak stream flow and flood frequency at Gilgel Abay River Basin, the values for historical climate changes (temperature and precipitation) in the basin was adjusted on the basis of changes that are projected for the end of 21st century at Gilgel Abay River Basin. Historically PRMS modeled annual daily peak flow and flood frequency is also compared with observed annual daily peak flow and flood frequency as shown in Tables 5.1 and 5.2. Hodges-Lehmann estimator was used to compare modelled versus observed annual daily peak stream flow and flood frequencies. The difference between modelled annual daily peak stream flow and observed annual daily peak flow is found to be very small (1.9%).

Table 5.1. Historical modelled annual daily peak stream flow compared with observed annual daily peak stream flow

Stream flow gauging station	Period of observed record	Observed annual daily peak stream flow (m^3/s)	Historical modelled annual daily peak stream flow (m^3/s)	Percent difference
Gilgel Abay	1993-2012	368.4	375.7	1.9

5.3.2. FLOOD FREQUENCY ANALYSIS FOR HISTORICAL MODELED AND OBSERVED ANNUAL DAILY PEAK STREAM FLOW

Historical PRMS modelled and observed daily peak stream flow is compared with 50% and 1% Annual Exceedance Probabilities (AEPs) (equivalent to 2 years and 100 years recurrence interval respectively). Based up on selected AEPs percent differences of observed and modelled peak flows are 1.8% and 8.3% for 50% and 1% AEPs as shown in Table 5.2.

Table 5.2. Differences between historical modelled annual daily peak stream flow with 50% and 1% Annual Exceedance Probabilities (AEPs) and observed annual daily peak stream flow with 50% and 1% AEPs

Stream flow gauging station	Years of record	Annual exceedance probability (percent)	Observed annual daily peak stream flow (m^3/s)	Historical modelled annual daily peak stream flow (m^3/s)	Percent difference
Gilgel Abay	20	50	270	274.9	1.8
Gilgel Abay	20	1	482.6	522.5	8.3

5.3.3. Future Annual Daily Peak Stream Flow Changes on the Basis of Changes in Air Temperature and Precipitation

Nine combinations of adjusted values of temperature and precipitation (including no change scenarios) were used as inputs to PRMS model, and annual daily peak stream flow is calculated for each combination. The PRMS derived annual daily peak stream flow from the adjusted temperature and precipitation changes were compared to unadjusted (historical) PRMS derived peak flows (Table 5.3). Annual daily Peak stream flow will increase for combinations of no temperature change with +10% precipitation change (positive value). On the other hand annual daily peak stream flow will decrease for combinations +1.5^{0}c temperature change with -10% precipitation change, +1.5^{0}c temperature change with no precipitation change and +1.5^{0}c with +10% precipitation change (negative values). This indicated that as temperature increases annual daily maximum peak flow will decreases by large amount . If precipitation is held constant there will be a decrease in annual daily maximum peak stream flow when temperature is increased by 1.5^{0}c and 3^{0}c (30.4% and 32.6% respectively). If temperature is held constant there will be an increase in annual daily peak stream flow of 10.2% when precipitation is increased by 10%. But there will be a decrease by

19.5% in annual daily peak stream flow when precipitation is decreased by 10%. Generally, this result indicated that there will be a decrease in annual daily peak stream flow when temperature is increased by 1.5^{o}c and 3 ^{o}c.

Table 5.3. Percentage changes of annual daily peak stream flow changes based on changes in precipitation and air temperature.

Precipitation change	Temperature change		
	No change	+1.5^{0}c	+3^{0}c
-10 % change	-19.5	-41.2	-41.5
No change	0.0	-30.4	-32.6
+10 % change	10.2	-16.5	-18.1

5.3.4. Future Flood Frequency Analysis on the Bases of Changes in Air Temperature and Precipitation

Future flood frequency at Gilgel Abay River basin estimated based up on adjusted temperature and precipitation changes and tabulated in Tables 5.4 and 5.5. Fifty percent and one percent annual exceedance probability peak stream flow (equivalent to 2 year and 100 year recurrence interval annual daily peak stream flow, respectively) are calculated for Gilgel Abay River basin using PRMS and Hodges-Lehmann estimator. Percent changes for adjusted modeled AEP annual daily peak stream flow from the adjusted changes in temperature and precipitation are compared with unadjusted (historical) modelled AEP peak flows (Tables 5.4 and 5.5). Changes in percent of peak flows with 50% AEP (Table 5.4) and changes in percent of annual daily peak stream flow with 1% AEP (Table 5.5) are similar to changes in annual daily maximum stream flow described in Table 5.3, except variation in magnitude of changes. These percent change values are future annual daily peak stream flow and flood frequency values at the end of 21st century compared to unadjusted (historical) modelled annual daily peak stream flow and flood frequency. This indicated that as temperature increases, annual daily peak stream flow will decrease by large amount. If precipitation is held constant and when temperature is increased by 1.5^0c and 3^0c, there will be 34.4% and 36.9% decrease in annual daily peak stream flow with 50% AEP respectively. If temperature is increased by 1.5^0c and 3^0c and when precipitation is increased by 10%, there will also be a decrease in annual daily peak stream flow with 50% AEP by 23.8% and 24.9% respectively. For one percent AEP changes are the same as explained above except difference in magnitude. Large increase in annual daily peak stream flow (14.3%) with 50% AEP will occur when temperature is held constant and precipitation is increased by 10%.

Table 5.4. Fifty percent annual exceedance probability, annual daily peak stream flow changes based on changes in precipitation and air temperature

Precipitation change	Temperature change		
	No change	$+1.5^0$c	$+3^0$c
-10 % change	-18.3	-43.8	-44.1
No change	0.0	-34.4	-36.9
+10 % change	14.3	-23.8	-24.9

Table 5.5. One percent annual exceedance probability, annual daily peak stream flow changes based on changes in precipitation and air temperature

Precipitation change	Temperature change		
	No change	$+1.5^0$c	$+3^0$c
-10 % change	-17.8	-42.4	-42.7
No change	0.0	-32.1	-34.2
+10 % change	14.3	-20.5	-21.7

5.4. CLOSURE

Future annual daily peak stream flow at 50% and 1% AEPs will increase by 14.3% of historical modeled value of stream flow at the end of 21st century at Gilgel Abay river basin when temperature is held constant and precipitation increases by 10%. On the other hand, as temperature is increases by 1.5^0c and precipitation is decreased by 10%, annual daily peak stream flow at 50% AEPs will decrease by 17.8% of historical modeled value of stream flow. This indicated that during designing of Hydraulic structures and economic evaluation of flood protection projects, considering changes in magnitude and frequency of annual daily peak stream flow in the future based on changes in climate (precipitation and air temperature) is very essential for minimizing failures in hydraulic structures. This is also important for resource managers to have information to protect resources from risk.

CHAPTER 6

EVALUATING IMPACT OF DAM ON RIVER HYDROLOGY AND SEDIMENT FLOW

6.1. GENERAL

Constructing dams in river basins have different advantages as dams designed for flood control, trapping sediments, hydropower, irrigation and provide water for municipal and industrial uses. Large dams are effective for reducing peak discharge of flood events and increase low discharge during dry periods. Dams can cause hydrograph variation, changes in peak stream flow and magnitude of flood frequency. Therefore, it was important to evaluate impact of dam on river hydrology using stream flow data and sediment transport by using RUSLE and SDR.

6.2. EVALUATING IMPACT OF DAM ON RIVER HYDROLOGY AND SEDIMENT FLOW

6.2.1. River hydrological studies

River hydrological studies mainly include hydrograph variation over 6 years, changes in peak stream flow, variation in discharge and magnitude of flood frequency at Gilgel Abay river before and after the construction of Koga dam, and the construction of dam was completed in 2006. The Hydrological impact of Koga dam at Gilgel Abay river basin studied by comparing 6 years (2001-2006) mean annual and mean daily discharge before the construction of dam with 6 years (2007-2012) discharge data after the construction of dam. In addition, to evaluating flow changes, peak stream flow and magnitude of flood frequency analysis performed based on the availability of pre- and post-dam discharge data (Figure 6.1).

6.2.2. River sediment load analysis

River sediment load analysis mainly includes sediment variation studies before and after the construction of dam in the catchment. The impact of Koga dam on Gilgel

Abay river suspended sediment flow was studied by comparing the total amount of sediment yield at catchment outlet before and after the construction of dam. This was carried out by comparing the total sediment yield at Koga catchment outlet in 2001 with 2013 (Figure 6.1).

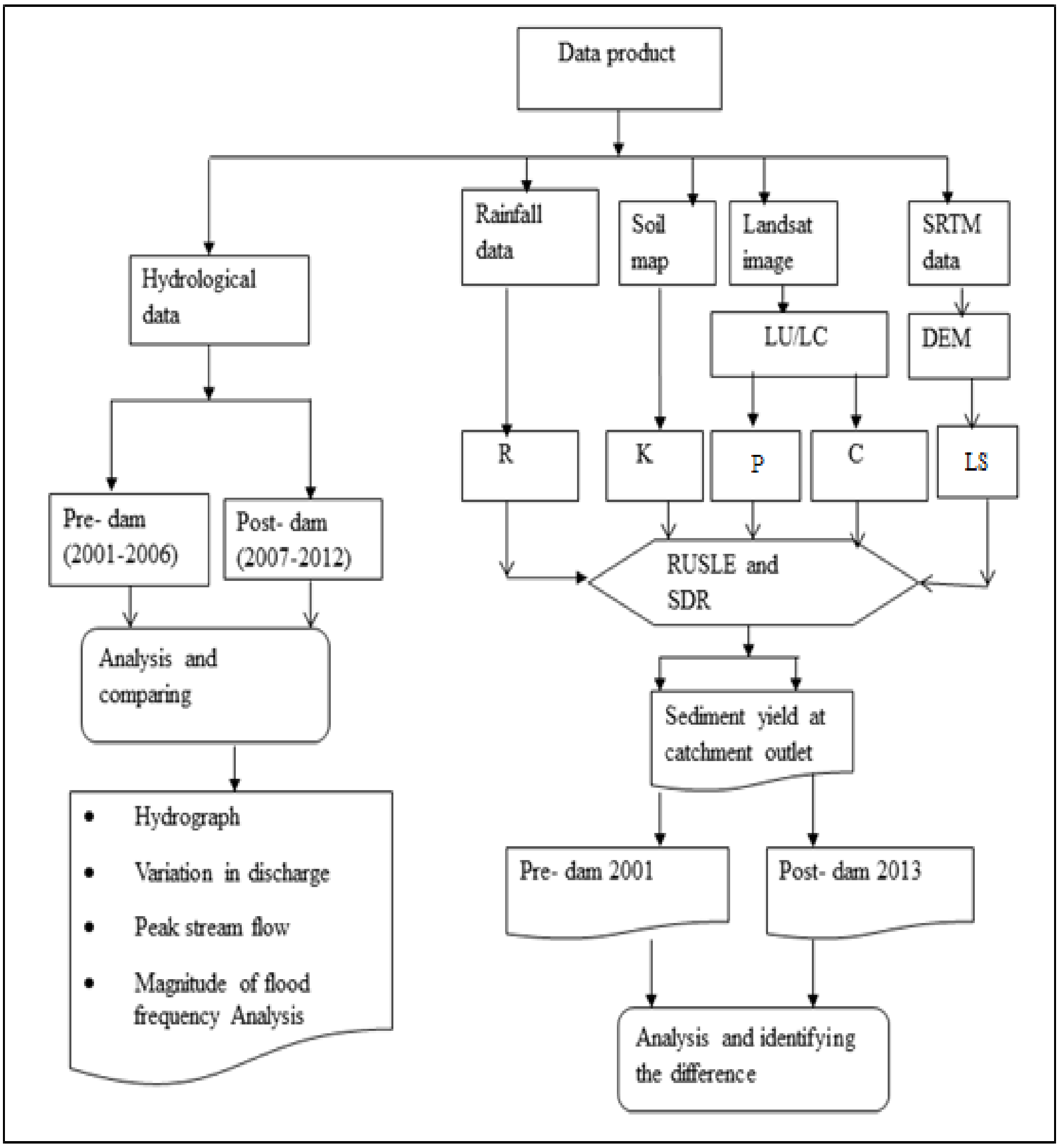

Figure. 6. 1. Conceptual frame work of methodology for identifying effect of dam.

6.2.3. Estimation of sediment yield

The sediment yield from a catchment depends on many factors such as topography, land use/land cover, hydrometeorology and the physical characteristics of rock. The Revised Universal Soil Loss Equation (RUSLE) framed with GIS and Remote Sensing techniques were used to estimate the mean annual soil loss occurred in Koga watershed before and after the construction of dam to evaluate effect of dam on sediment transport. The RUSLE is an empirical model developed by Renard et al., (1996) to estimate soil loss from fields as follows:

$$A=R*K*LS*C*P \tag{6.1}$$

Where,

A = Average annual soil loss in tons per hectare

R = Rainfall erosivity factor (MJ/ha.mm/h)

K = Soil erodibility factor (t.ha.h/ha/MJ/mm)

LS = Topographic or slope length/steepness factor

C = Cover and cropping-management factor

P = Supporting practices (land use) factor

All these factors are dimensionless, with the exception of R and K.

6.2.3.1. Rainfall Erosivity Factor (R)

The Rainfall erosivity factor (*R)* is often determined from rainfall intensity. But in Koga watershed rainfall intensity data was not available. Therefore, the rainfall erosivity factor (R) was calculated using Hurni (1985a) which was derived from a special analysis for Ethiopian conditions (Helden, 1987).

$$R = -8.12 + 0.562 \times P \tag{6.2}$$

Where,

P = mean annual rainfall (mm)

6.2.3.2. Soil Erodibility Factor (K)

Soil erodability Factor is defined as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up and down with slope with no conservation practices and on a slope of 5˚ and 22 m length (Morgan, 1994).

The soil erodibility factor determines the cohesive character of a soil type and its resistance to dislodging and transport due to raindrop influence and overland flow shear forces. The K factor is empirically determined for a particular soil type and reflects the physical and chemical properties of the soil. It contributes to its erodibility potential recommended the K values based on easily observable soil color as an indicator for the erodibility of the soil in the highlands of Ethiopia (Hurni, 1985a; and Hellden, 1987; Animka et al., 2013). Thus, for the analysis of K factor, the soil types of Koga watershed were classified based on their color according to FAO standard soil classification. Accordingly, these soil classification were Eutric Vertisols (black), Eutric Regososl and Haplic Luvisols (brown), and Haplic Nitosols and Alisols (red), and were the dominant soil classes in the study area (Gelagay and Minale, 2016).

6.2.3.3. Slope Length Steepness Factor (LS)

The slope length and slope steepness factors are commonly combined in a single index as LS and considered as the topographic factor. Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff enters a well-defined channel that may be part of a drainage network.

Soil erosion by water increases as the slope length increases due to the greater accumulation of runoff. The modified equation for computing the topographic factor (LS factor) in GIS environment was used as recommended by (Griffin, et al., 1988). Calculating slope by using GIS benefit a wide range of environmental models, because, slope attributes are essential inputs or information for landslides, land planning and construction (Dunn and Hickey, 1998). The drawbacks of slope length calculation can be solved by using the cumulative uphill length from each cell which accounts for convergent flow paths and depositional areas during the use of the Universal Soil Loss Equation (Hickey, 2000). Therefore, in the present study advanced LS factor computation method based on up slope contributing was used (Desmet and Govers, 1996a; Moore and Burch, 1985, 1986, 1992; Mitasova and Mitas, 1999; and Simms *et al*., 2003).

$$LS= (As/22.13)\ 0.6\ (\sin B/0.0896)1.3 \qquad (6.3)$$

Where,

LS = Slope steepness-length factor,

As = Specific catchment area, i.e. the upslope contributing area per unit width of contour drains to a specific point (flow accumulation *cell size), and

B = Slope angle (%).

LS factor was computed in Arc GIS raster calculator using the map algebra expression given as equation (4) (Mitasova and Mitas (1999); and Simms *et al.*, (2003).

LS = POWER [(flow accumulation)*cell size/22.13,0.6]*POWER [sin (slope)*0.01745/0.0896,1.3] (6.4)

The values of LS were directly derived from 30 meter resolution DEM and flow accumulation was derived from the DEM after conducting Fill and Flow Direction processes in Arc GIS in line with Arc Hydrology tool. Flow accumulation grid represents number of grid cells that are contributing for downward flow and cell size represents 30m*30m contributing area.

6.2.3.4. Cover and Management Factor (C)

The cover and management factor represents the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier and Smith, 1978; Morgan, 2005). Supervised classification was conducted to acquire the major land use/ land cover types in the watershed.

6.2.3.5. Support Practice Factor (P)

Erosion control practice factor is the ratio of soil loss with a specific support practice to the corresponding loss with up slope and down slope cultivation (Wischmeier and Smith, 1978). The P factor is used for understanding the conservation practices which took place in the study area. This factor considers the control practices which reduce the eroding power of rainfall and runoff by their impact on drainage patterns, runoff concentration, and runoff velocity. The supporting mechanical practices include the effects of contouring, strip cropping, or terracing (Hyeon and Pierre, 2006). Wischmeier and Smith (1978) assigned the P factor value by categorizing the land use types in to cultivated land and other lands. They sub-divided the cultivated land in to three slope classes and assigned P value for each respective slope class as many management activities are highly dependent on slope of the area. For the present study, this method of combining general land use type and slope was therefore adopted. Values for P factor were therefore assigned by considering local management practices along with values suggested in Wischmeier and Smith (1978).

6.2.3.6. Sediment Yield Estimation

In a watershed, part of the soil eroded in an overland flow region deposits within the catchment before reaching its outlet, therefore, the Sediment Delivery Ratio (SDR) was used to estimate the amount of sediment at the watershed outlet**.** The SDR is the ratio of sediment delivered at a given area in the stream to the gross erosion for that drainage area. Thus, the annual sediment yield of a watershed is defined as follows

$$SY = (A)(SDR) \tag{6.5}$$

Where,

Sy= Annual sediment yield (tons)

A = Total gross erosion computed from RUSLE,

SDR = Sediment Delivery Ratio.

A general equation for computing watershed sediment delivery ratio is not yet available in the study area, because it depends on several properties of the watershed like infiltration, roughness, vegetation cover, hydrograph or runoff drainage and other factors, which are not available in the study area to derive SDR, but some of the simple models given by different researchers have been tried to estimate sediment yield at the outlet of the basin. The one given by Williams and Berndt's (1972) was finally chosen because it gives reasonable estimate, despite using few catchment characteristics.

$$SDR = 0.627\ SLP^{0.403} \tag{6.6}$$

Where,

SLP = % Mean slope of main stream channel.

6.3. RESULTS AND DISCUSSION

6.3.1. RIVER HYDROLOGICAL ANALYSIS

The impact of koga dam on River hydrology, hydrograph variation over 6 years, changes in peak stream flow, variation in discharge and magnitude of flood frequency analysis at Koga River Basin before and after construction of Koga dam are identified and evaluated as follows.

Due to the construction of Koga dam, annual mean daily stream flow decreased as shown in Figures 6.2 and 6.3. Peak mean annual discharge decreased from 7.2 m^3/s to 5.1 m^3/s (Figure 6.2 and 6.3).

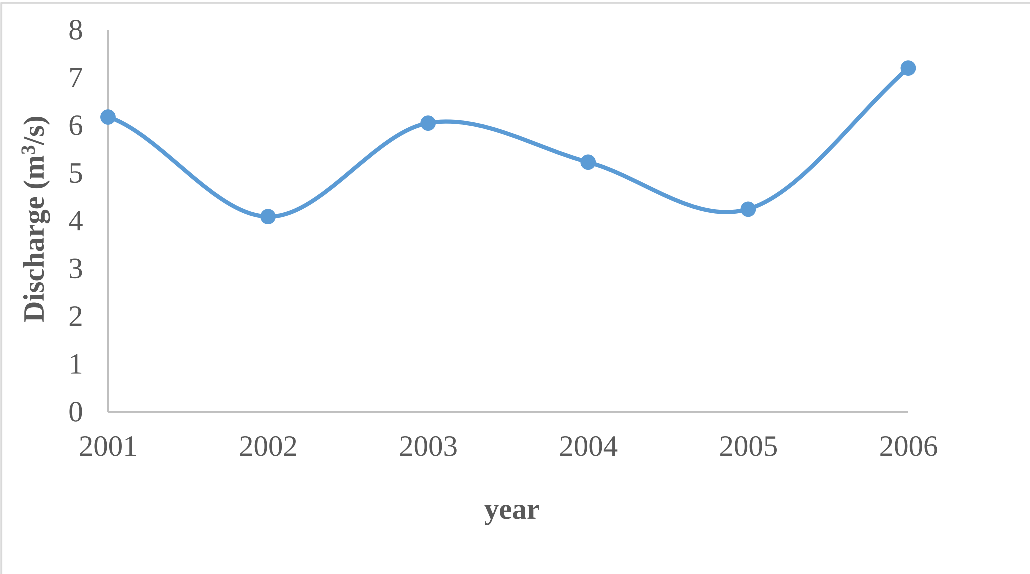

Figure 6.2. Time series of annual mean daily discharge (pre-dam)

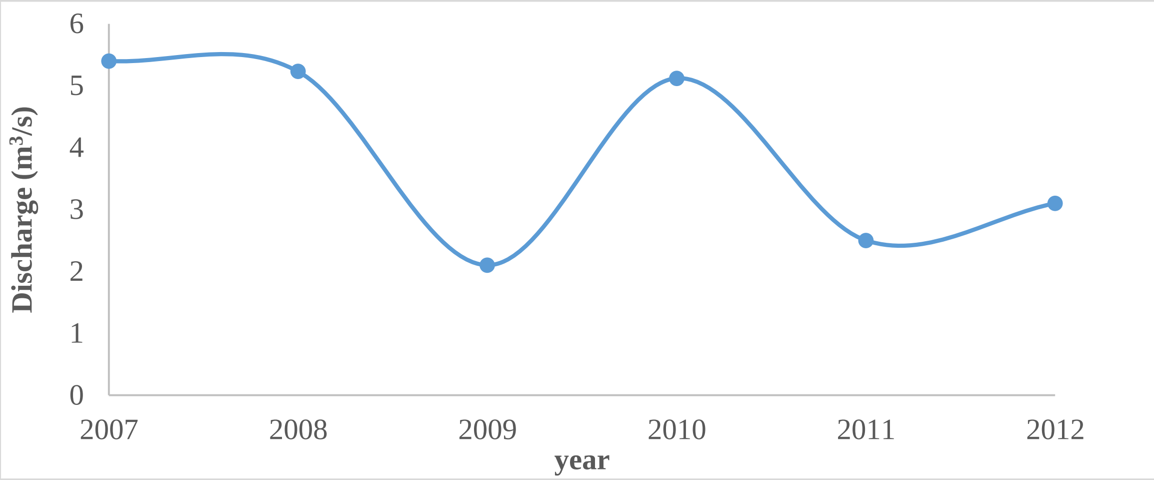

Figure 6.3. Time series of annual mean daily discharge (Post-dam)

The detailed analysis, 6 years of monthly discharge data at Koga River before the construction (2006-2007) and after the construction (2007-2012) of dam were considered and variation in each year was plotted (Figure 6.4 and 6.5). Before construction of dam the maximum monthly discharge is 28.3 m^3/s. After construction of dam maximum monthly discharge is just near to 18.8 m^3/s. This showed a decreasing trend of monthly discharge after construction of dam.

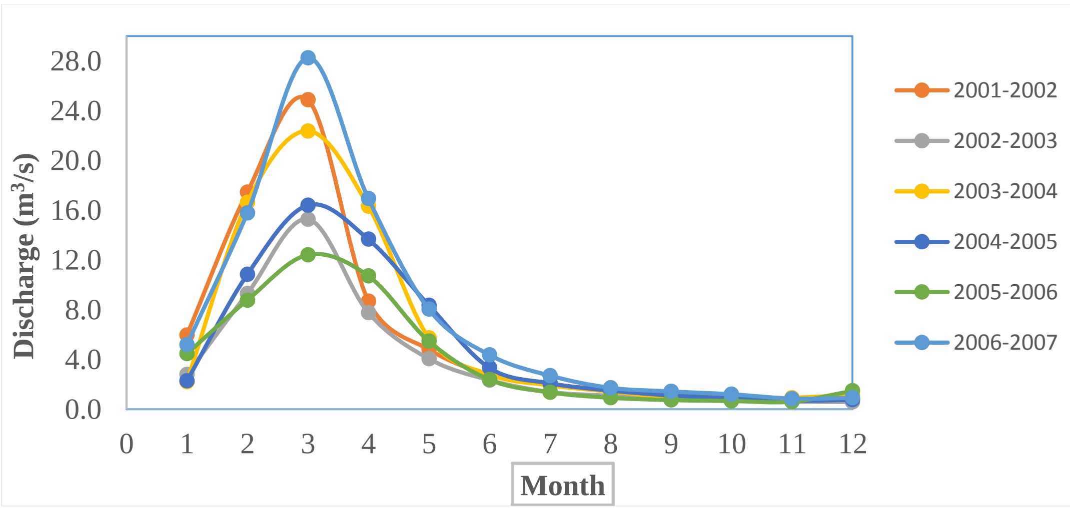

Figure 6.4.Time series of monthly discharge of Koga River (June – May) (pre-dam)

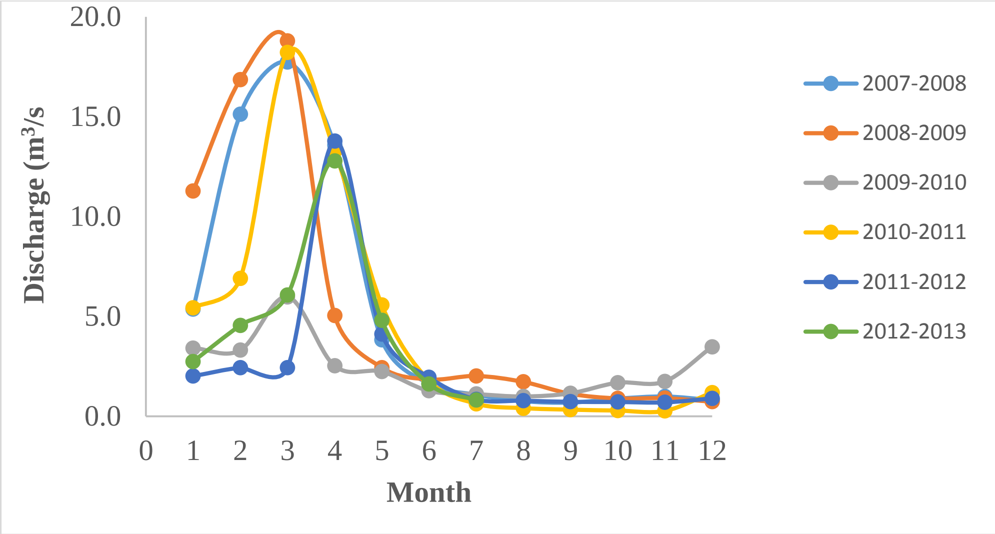

Figure 6.5. Time series of monthly discharge of Koga River (June – May) (post-dam)

Time series of daily discharge hydrograph of Koga River before (2001-2006) and after (2007-2012) construction of Koga dam showed a decrease of maximum daily discharge from 103.5 m^3/s to 63 m^3/s. It was also observed that there is a decrease in total discharge from 12,033.87 m^3/s to 8,569.40 m^3/s pre-dam and post-dam respectively (Figures 6.6 and 6.7).

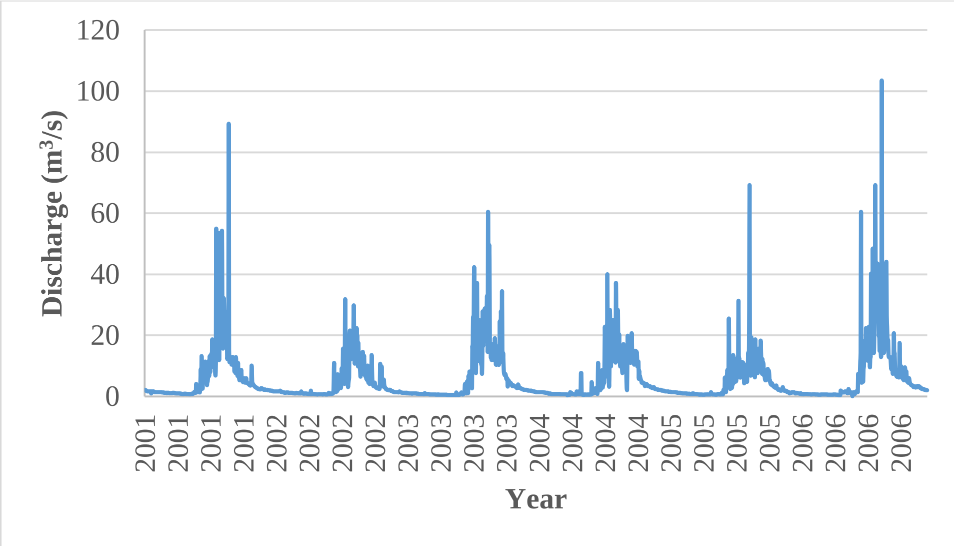

Figure 6.6.Time series of daily discharge hydrograph of Koga River (2001-2006)

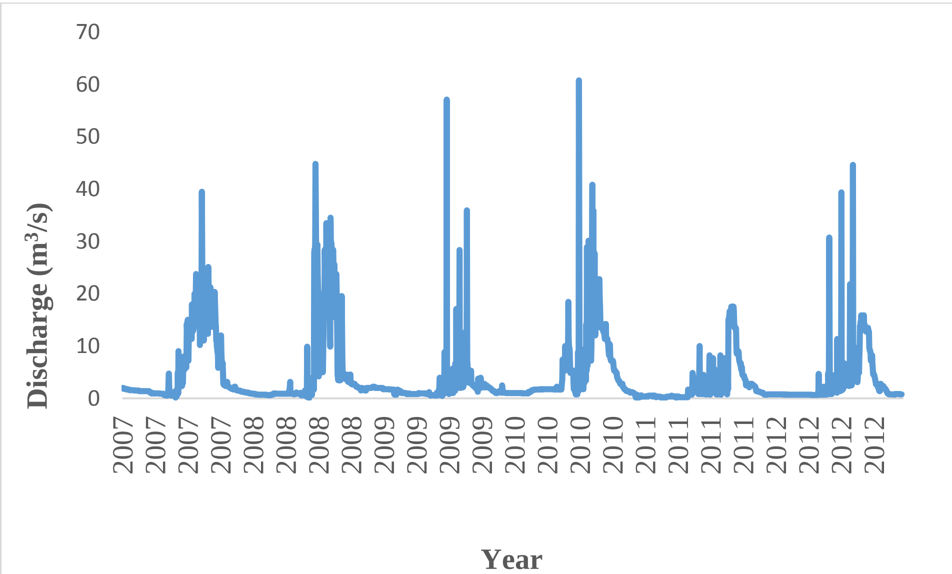

Figure 6.7.Time series of daily discharge Hydrograph of Koga River (2007-2012)

Peak discharges of Koga River before and after construction of Koga dam is analysed. The analysis indicated that peak discharge decreased from 103.5 m^3/s (post-dam) to 63 m^3/s (pre-dam) period as shown in Figures 6.8, 6.9 and 6.10).

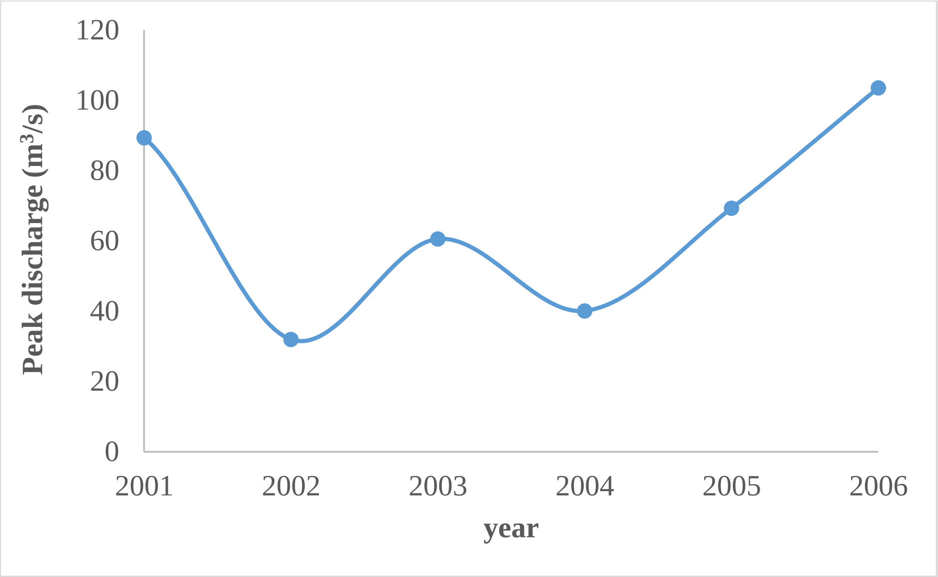

Figure 6.8.Time series of peak flood of the Koga River (2001-2006)

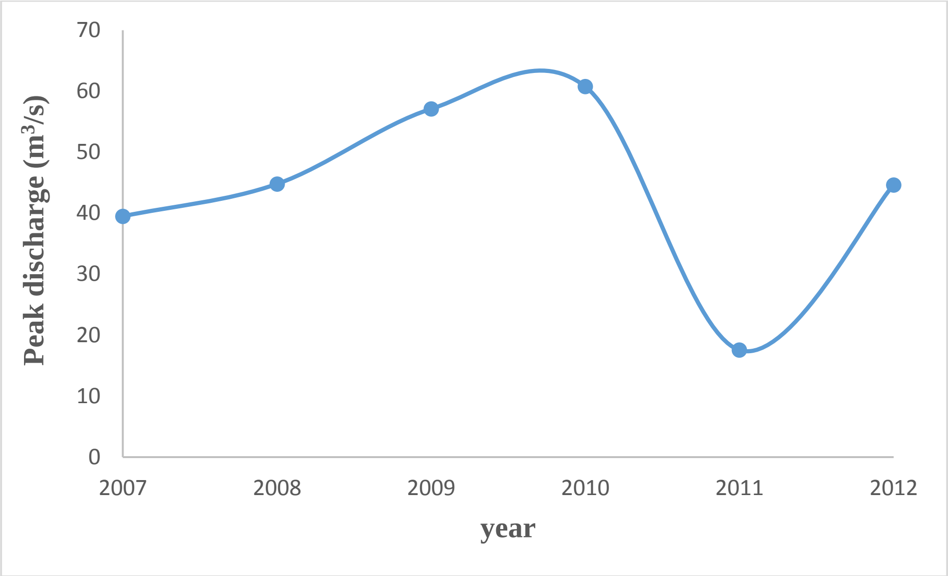

Figure 6.9.Time series of peak flood of the Koga River (2007-2012)

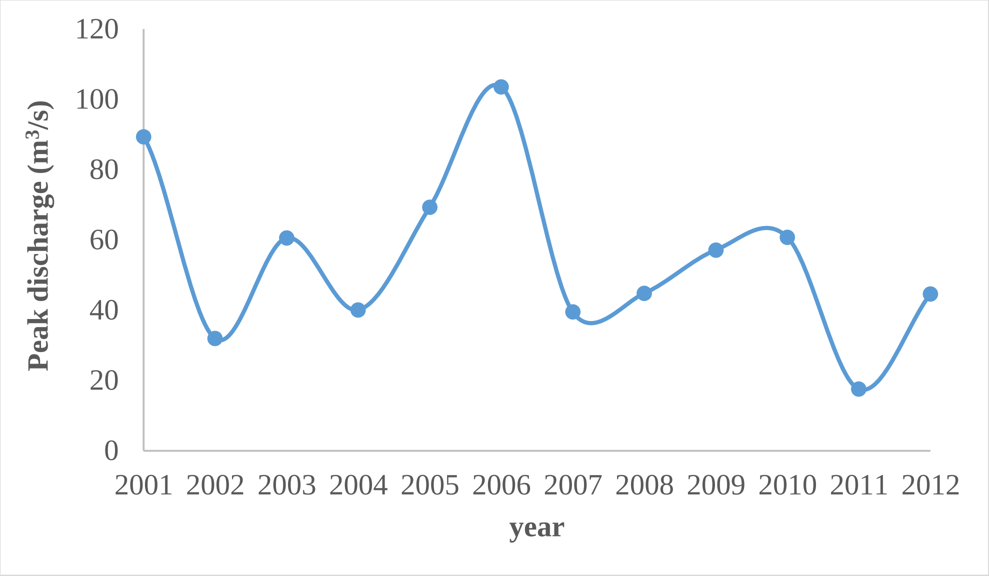

Figure 6.10.Time series of peak flood of the Koga River (2000-2012)

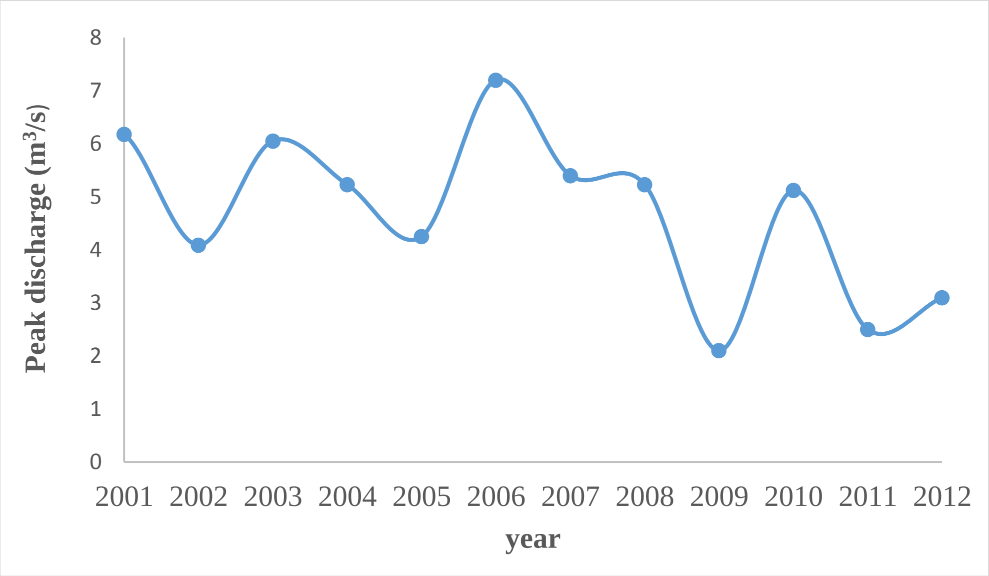

Figure 6.11.Time series of mean annual discharge of the Koga River (2000-2012)

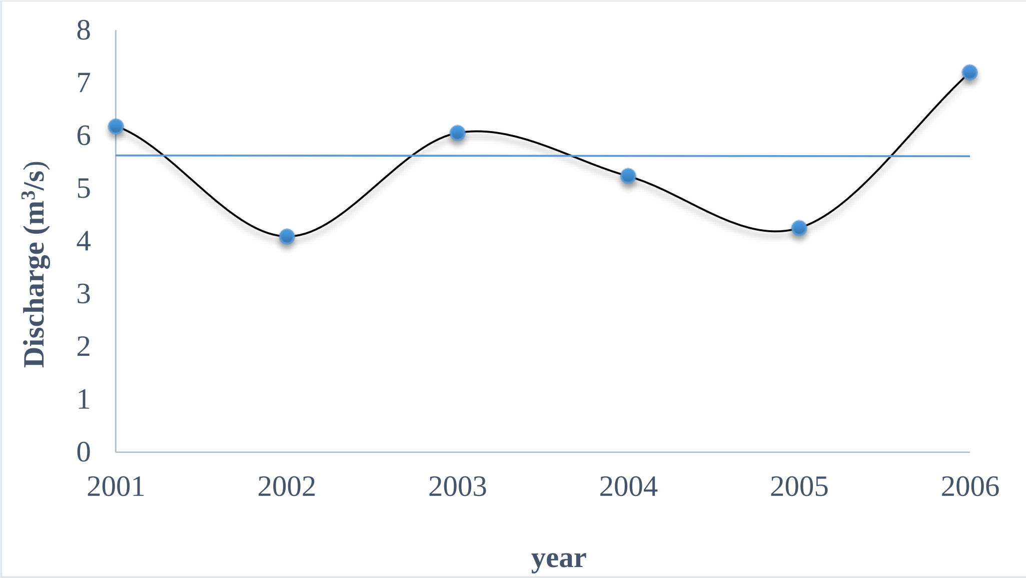

Figure 6.12. Trend line for time series of annual mean daily discharge in the Kog River (2000-2006)

The trend line for time series of Koga discharge data before and after construction of dam indicated that there is a decreasing trend of discharge due to construction of dam but there is no trend for before construction of dam (Figure 6.12 1nd 6.13).

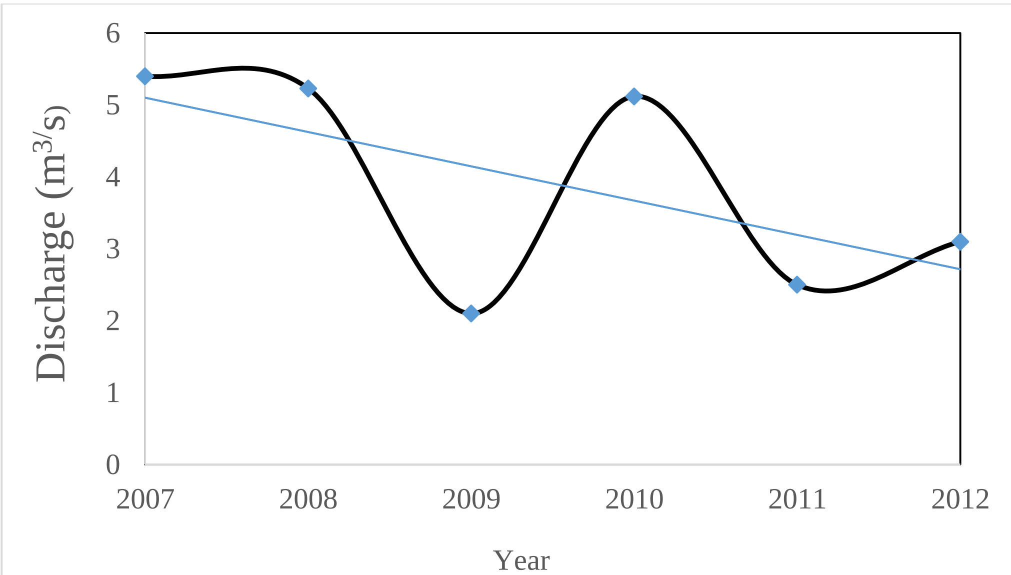

Figure 6.13. Trend line for time series of annual mean daily discharge in the Koga River (2007-2012).

6.3.2. MAGNITUDE OF FLOOD FREQUENCY ANALYSIS

The magnitude of flood frequency analysis was performed by considering stream flow before and after the construction of Koga dam. For this analysis a threshold value of 17.553 m^3/s was selected to get at least one peak stream flow per year for time series data (from 2011 time series data). This analysis gives the number of peak stream flow before and after construction of dam and this is useful for identifying effect of dam on frequency of peak stream flow. The analysis was done by considering 6 years discharge data before and after construction of Koga dam. It is identified that 145 discharge events with values greater than 17.553 m^3/s are available for 6 years of pre-dam period where as only 97 discharge events with values greater than 17.553 m^3/s available for 6 years of post-dam period (Table 6.1 and 6.2). This indicated that the reduction in peak stream flow during post period is due to obstruction of dam. The magnitude of flood frequency analysis at downstream of dam also shows the decrease in high magnitude discharges as depicted in Figure 6.14).

Table. 6.1. Discharge events more than 17.553 m^3/s before construction of Koga dam.

Date	Discharge (m^3/s)	Date	Discharge (m^3/s)	Date	Discharge (m^3/s)	Date	Discharge (m^3/s)
09-07-2001	18.745	06-08-2002	17.965	24-08-2003	44.786	30-07-2006	24.22
20-07-2001	55.014	07-08-2002	19.947	08-09-2003	19.142	31-07-2006	22.895
21-07-2001	28.415	08-08-2002	21.607	22-09-2003	24.67	01-08-2006	48.499
22-07-2001	18.353	09-08-2002	29.887	24-09-2003	18.745	02-08-2006	23.333
24-07-2001	19.543	10-08-2002	18.745	25-09-2003	27.932	05-08-2006	19.142
25-07-2001	22.462	13-08-2002	19.543	26-09-2003	22.895	06-08-2006	24.67
26-07-2001	40.062	14-08-2002	19.947	27-09-2003	18.745	07-08-2006	33.464
27-07-2001	52.359	17-08-2002	22.462	28-09-2003	34.523	08-08-2006	69.258
29-07-2001	25.581	19-08-2002	19.947	12-07-2004	22.895	09-08-2006	36.69
31-07-2001	17.581	22-08-2002	17.581	19-07-2004	40.062	10-08-2006	30.386
01-08-2001	20.356	09-07-2003	26.043	26-07-2004	28.415	11-08-2006	32.422
02-08-2001	28.415	11-07-2003	29.392	27-07-2004	19.947	12-08-2006	40.062
03-08-2001	51.706	12-07-2003	42.391	02-08-2004	18.745	13-08-2006	35.059
04-08-2001	26.98	13-07-2003	35.598	04-08-2004	25.123	14-08-2006	43.58
05-08-2001	54.344	14-07-2003	24.67	09-08-2004	25.123	15-08-2006	27.932

06-08-2001	32.941	20-07-2003	37.242	12-08-2004	37.242	16-08-2006	24.67
07-08-2001	21.607	21-07-2003	19.947	13-08-2004	24.67	17-08-2006	28.415
09-08-2001	19.947	26-07-2003	24.67	14-08-2004	19.543	18-08-2006	19.947
10-08-2001	31.907	27-07-2003	21.607	25-09-2004	20.769	19-08-2006	21.607
11-08-2001	23.392	29-07-2003	19.142	25-06-2005	25.581	26-08-2006	103.513
12-08-2001	24.67	05-08-2003	27.932	21-07-2005	31.396	27-08-2006	23.774
13-08-2001	20.356	07-08-2003	20.356	20-08-2005	28.415	31-08-2006	23.333
14-08-2001	19.142	08-08-2003	19.543	21-08-2005	69.258	03-09-2006	30.386
15-08-2001	24.67	09-08-2003	25.581	26-08-2005	19.142	04-09-2006	29.392
16-08-2001	24.67	10-08-2003	18.353	06-09-2005	18.745	05-09-2006	17.965
17-08-2001	25.581	11-08-2003	28.902	21-09-2005	18.353	07-09-2006	30.386
18-08-2001	24.67	12-08-2003	20.356	29-06-2006	60.517	08-09-2006	44.181
19-08-2001	17.965	13-08-2003	26.51	13-07-2006	22.462	09-09-2006	26.51
22-08-2001	27.932	14-08-2003	23.774	18-07-2006	22.032	10-09-2006	22.895
23-08-2001	24.67	15-08-2003	22.032	19-07-2006	19.543	11-09-2006	19.142
24-08-2001	89.338	16/8/2003/	26.51	21-07-2006	22.895	12-09-2006	18.745
16-07-2002	31.907	17-08-2003	32.941	22-07-2006	17.965	13-09-2006	18.353
30-07-2002	21.607	18-08-2003	23.774	27-07-2006	39.49	29-09-2006	20.769
31-07-2002	17.581	20-08-2003	60.517	28-07-2006	33.464	15-10-2006	17.581

03-08-2002	17.581	21-08-2003	25.581	29-07-2006	23.774	30-07-2006	24.22
04-08-2002	17.965	23-08-2003	49.132	24-08-2003	44.786	31-07-2006	22.895
09-07-2001	18.745	06-08-2002	17.965	08-09-2003	19.142	01-08-2006	48.499
20-07-2001	55.014	07-08-2002	19.947	22-09-2003	24.67	02-08-2006	23.333
21-07-2001	28.415	08-08-2002	21.607	24-09-2003	18.745	05-08-2006	19.142
22-07-2001	18.353	09-08-2002	29.887	25-09-2003	27.932	06-08-2006	24.67
24-07-2001	19.543	10-08-2002	18.745	26-09-2003	22.895	07-08-2006	33.464
25-07-2001	22.462	13-08-2002	19.543	27-09-2003	18.745	08-08-2006	69.258
26-07-2001	40.062	14-08-2002	19.947	28-09-2003	34.523	09-08-2006	36.69
27-07-2001	52.359	17-08-2002	22.462	12-07-2004	22.895	10-08-2006	30.386
29-07-2001	25.581	19-08-2002	19.947	19-07-2004	40.062	11-08-2006	32.422
31-07-2001	17.581	22-08-2002	17.581	26-07-2004	28.415	12-08-2006	40.062
01-08-2001	20.356	09-07-2003	26.043	27-07-2004	19.947	13-08-2006	35.059
02-08-2001	28.415	11-07-2003	29.392	02-08-2004	18.745	14-08-2006	43.58
						16-08-2006	34.78

Table. 6.2. Discharge events more than 17.553 m^3/s after construction of Koga dam

Date	Discharge (m^3/s)	Date	Discharge (m^3/s)	Date	Discharge (m^3/s)	Date	Discharge (m^3/s)
20-07-2007	19.947	16-09-2007	18.353	19-07-2008	20.356	18-08-2008	21.186
21-07-2007	19.543	21-06-2008	27.932	21-07-2008	28.415	19-08-2008	18.353
24-07-2007	23.774	22-06-2008	28.415	22-07-2008	24.22	21-08-2008	20.356
28-07-2007	18.353	23-06-2008	28.415	23-07-2008	23.774	22-08-2008	23.774
06-08-2007	17.965	24-06-2008	29.392	24-07-2008	23.774	23-08-2008	21.186
08-08-2007	21.186	25-06-2008	44.786	25-07-2008	33.464	07-09-2008	19.543
09-08-2007	22.032	26-06-2008	28.415	26-07-2008	26.98	29-06-2009	57.101
10-08-2007	39.49	27-06-2008	28.415	27-07-2008	25.123	04-08-2009	28.322
11-08-2007	17.965	28-06-2008	26.043	28-07-2008	24.67	25-08-2009	35.908
16-08-2007	24.67	29-06-2008	24.67	29-07-2008	26.98	07-07-2010	60.752
17-08-2007	18.745	30-06-2007	29.392	30-07-2008	20.356	29-07-2010	28.913
21-08-2007	22.032	01-07-2008	23.774	01-08-2008	28.415	03-08-2010	30.117
22-08-2007	17.965	02-07-2008	21.186	02-08-2008	20.356	13-08-2010	40.841
23-08-2007	17.965	03-07-2008	19.543	06-08-2008	34.523	28-08-2010	18.447
24-08-2007	19.142	15-08-2010	19.369	07-08-2008	29.392	30-08-2010	17.997
28-08-2007	25.123	16-08-2010	35.908	08-08-2008	29.887	01-09-2010	22.296
29-08-2007	19.543	17-08-2010	19.839	09-08-2008	29.392	02-09-2010	22.809
30-08-2007	20.356	18-08-2010	21.293	10-08-2008	26.043	03-09-2010	18.905

01-09-2007	17.965	19-08-2010	19.839	11-08-2008	26.043	11-06-2012	30.731
03-09-2007	21.186	20-08-2010	27.738	12-08-2008	24.67	15-07-2012	39.393
06-09-2007	19.543	21-08-2010	18.447	13-08-2008	28.415	08-08-2012	21.791
07-09-2007	18.745	23-08-2010	19.369	14-08-2008	26.043	16-08-2012	44.601
09-09-2007	18.745	25-08-2010	18.905	15-08-2008	22.462		
14-09-2007	18.745	27-08-2010	22.809	16-08-2008	20.356		
15-09-2007	20.356	18-07-2008	18.353	17-08-2008	25.581		

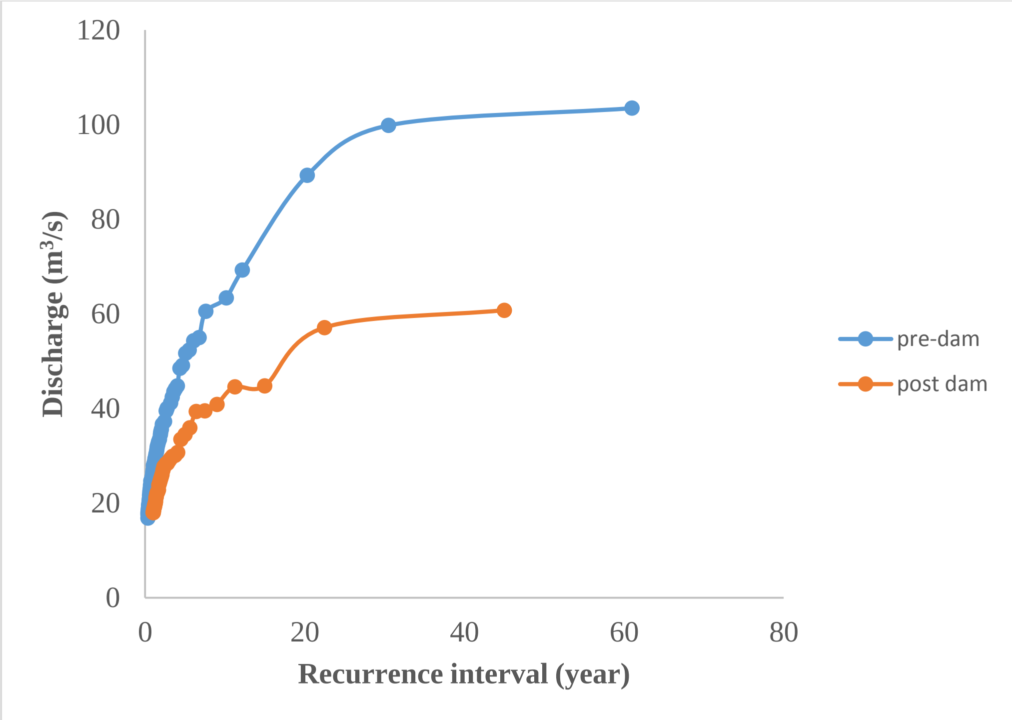

Figure 6.14. Magnitude of flood frequency values of pre and post dam construction of Koga River

6.3.3. RIVER SEDIMENT LOAD ANALYSIS

Effect of dam on sediment transport was evaluated using RUSLE and SDR as explained using the following section.

6.3.3.1. Rainfall erosivity factor (R)

Mean annual rainfall of Koga watershed before (2001-2006) and after (2007-2012) construction of dam at Merawi meteorological station is 1570 mm and 1572 mm, hence, the rainfall erosivity factor estimated according to equation (6.2) is also 874 and 875 respectively.

6.3.3.2. Soil erodibility factor (K)

According to Gelagay and Minale (2016), the K values of Koga watershed were composed of three different soil colour types, and five soil classes as explained in Methodology section. Thus, the K Value was assigned for each soil class with special reference to their colour as recommended by Hurni (1985). Hence, the K value for

Eutric Vertisols (Black), Eutric Regososl and Haplic Luvisols (Brown), and Haplic Nitosols and Alisols (Red) was assigned 0.15, 0.20, and 0.25 respectively. The soil erodibility factor value for water bodies was assigned zero (Erdogan et al., 2006). So that, the impounded water of Koga reservoir was assigned K value of zero (0). The estimated K values and area weighted k values are given in Table 6.3 and 6.4 respectively.

Table 6.3. Soil Erodibility factor (K) Values for some Soils in Koga watershed

Soil Series	Soil Color	Area (km^2)	Estimated K value [metric tons ha^{-1} MJ^{-1} mm^{-1}]
Vertisols	Black	220.41	0.15
Cambisols,	Brown	10.97	0.20
Luvisols	Brown	53.86	0.20
Nitosols	Red	9.97	0.25

Table 6.4. Watershed-wise area weighted K factor

Soil classes	Vertisols	Cambisols	Luvisols	Nitisols	Total area (km^2)	Average area weighted C factor
K	0.15	0.20	0.20	0.25		
Koga watershed area (km^2)	220.41	10.97	53.86	9.97	295.21	0.16

6.3.3.3. Slope Length and Steepness factor (LS)

The topographic component of RUSLE was computed using equation (6.3) suggested by Moore and Bruch 1985; Mitasova and Mitas 1999; and Simms et al., 2003). Slope length was substituted by upslope contributing area so as to take in to account the flow convergence and divergence in a three dimensional complex terrain condition. As a result, the LS factor of RUSLE extends from 0 in the lower part of the watershed to 201 in the steepest slope upper part of the watershed. This implies that, the influence of the combined slope length-steepness (LS) factor for soil loss is significant in the upper part of the watershed. On the other hand, the topographic (slope length steepness) factor contribute insignificantly for soil erosion in the lower part of the watershed.

6.3.3.4. Erosion management (support) practice factor (P)

As explained in detail in the methodology section, (Gelagay and Minale, 2016; Wischmeier and Smith, 1978) method of calculating the P value was used. Therefore, in this study water body, grazing land, shrub land, and forest lands were assigned as other land class and given the P value of 1.00 regardless of the slope class, whereas the cultivated land was classified in to six slope classes and given P values. Therefore, P Values were assigned considering local management practices along with values suggested in Wischmeier and Smith (1978).The estimated area weighted P values for 2001 and 2013 are given in Table 6.7 and 6.8 respectively.

Table 6.5. P Value (Gelagay and Minale, 2016; Wischmeier and Smith, 1978) for 2001

Land use type	Slope (%)	Area (km^2)	P-factor
Cultivated land	0-5	86.58	0.10
	5-10	63.77	0.12
	10-20	22.53	0.14
	20-30	15.19	0.19
	30-50	7.12	0.25
	50-100	6.49	0.33
Other land	-	102.90	1.00

Table 6.6. P Value (Gelagay and Minale, 2016; Wischmeier and Smith, 1978) for 2013.

Land use type	Slope (%)	Area (km^2)	P-factor
Cultivated land	0-5	60.44	0.10
	5-10	42.28	0.12
	10-20	14.39	0.14
	20-30	9.26	0.19
	30-50	2.99	0.25
	50-100	1.05	0.33
Other land	-	169.07	1.00

Table 6.7. Calculation of watershed-wise area weighted P value for 2001 year

LU/LC	Cultivated land (slope %)						Water body	Forest land	Shrub land	Grazing/ grass land	Total area (km^2)	Average area weighted P factor
	0-5	5-10	10-20	20-30	30-50	50-100						
P value	0.10	0.12	0.14	0.19	0.25	0.33	1	1	1	1		
Koga area (km^2)	86.58	63.77	12.35	22.53	7.12	6.49	0.87	7.70	34.70	62.37	304.48	0.43

Table 6.8. Calculation of watershed-wise area weighted P value for 2013 year

LU/LC	Cultivated land (slope %)						Water body	Forest land	Shrub land	Grazing / grass land	Total area (km^2)	Average area weighted P factor
	0-5	5-10	10-20	20-30	30-50	50-100						
P value	0.10	0.12	0.14	0.19	0.25	0.33	1	1	1	1		
Koga area (km^2)	60.44	42.28	14.39	11.26	2.99	1.05	17.81	43.57	66.59	46.10	304.48	0.57

6.3.3.5. Cover and Management Factor (C)

The major land use/land cover types of the watershed identified from satellite image by supervised classification were forest land, shrub land, grazing land, water body, and cultivated land. The corresponding land cover C value was obtained from different studies as shown in Table 6.9 and the estimated area weighted c values for 2001 and 2013 are given in Tables 6.10 and 6.12 respectively.

Table 6.9. C Values for the watershed taken from different Studies from 2001 year satellite image

Land use/Land cover	C factor	Area (km^2)	Reference
Water body	0.00	0.87	Erdogan *et al.*,(2006)
Cultivated land	0.10	201.58	Hurni (1985)
Forest land	0.01	7.70	Hurni (1985)
Shrub land	0.014	34.70	Wischmier &Smith (1978)
Grazing/ grass land	0.05	62.37	Hurni (1985),Yihenew &Yihenew (2013)

Table 6.10. Calculation of watershed-wise area weighted C value from 2001 year satellite image

LU/LC	Water body	Cultivated land	Forest land	Shrub land	Grazing/ grass land	Total area (km^2)	Average area weighted C factor
C	0.00	0.10	0.01	0.014	0.05		
Koga area (km^2)	87	201.58	7.70	34.70	62.37	304.48	0.08

Table 6.11. C Values for the watershed taken from different Studies from 2013 satellite image

Land use/Land cover	C factor	Area (km^2)	Reference
Water body	0.00	17.80	Erdogan *et al.*,(2006)
Cultivated land (Millet and Maize	0.10	130.41	Hurni (1985)
Forest land	0.01	43.57	Hurni (1985)
Shrub land	0.014	66.59	Wischmier &Smith (1978)
Grazing/ grass land	0.05	46.10	Hurni (1985),Yihenew &Yihenew (2013)

Table 6.12. Calculation of watershed-wise area weighted C value for 2013 year

LU/LC	Water body	Cultivated land	Forest land	Shrub land	Grazing/ grass land	Total area (km^2)	Average area weighted C factor
C	0.00	0.10	0.01	0.014	0.05		
Koga watershed area (km^2)	17.81	130.41	43.57	66.59	46.10	304.48	0.05

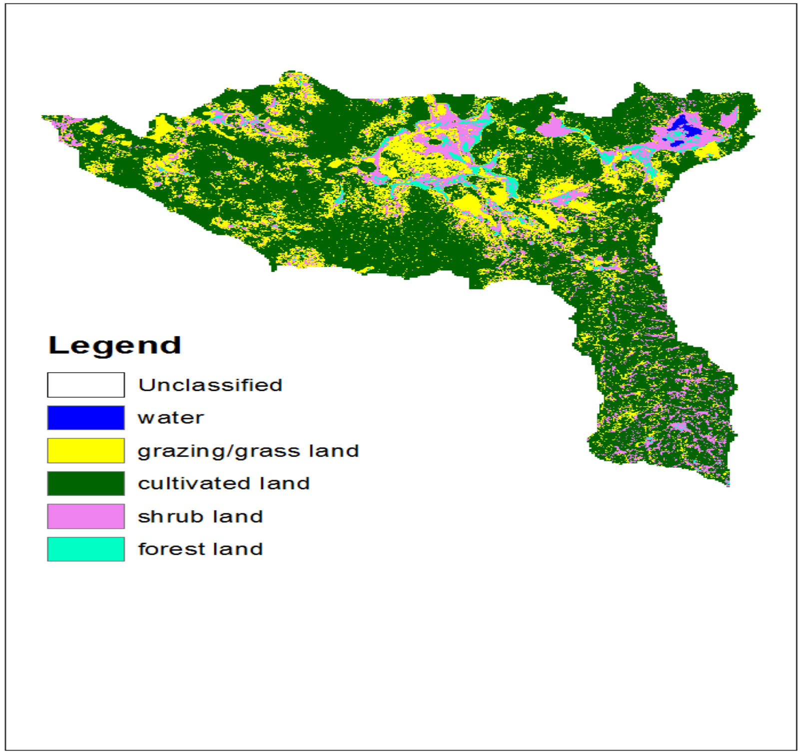

Figure. 6.15. LU/LC map of Koga watershed 2001 (Feberuary 12)

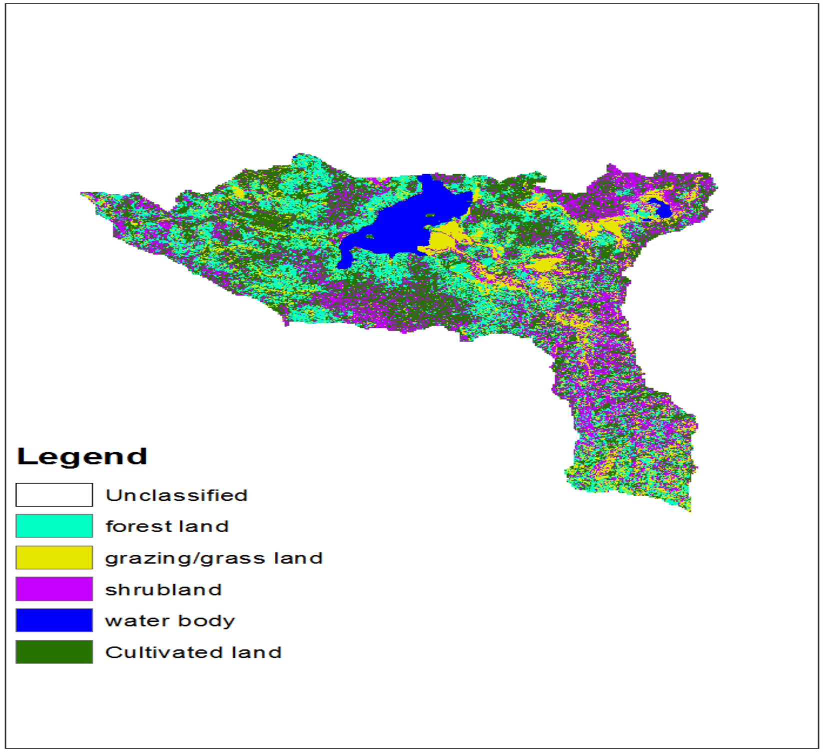

Figure. 6.16. LU/LC map of Koga watershed 2013 (March23)

6.3.4. Effect of dam on Suspended sediment yield

The impact of Koga dam at Gilgel Abay River on sediment flow was studied by comparing the total amount of sediment yield at the catchment outlet of Koa River before and after the construction of dam. This was carried out by comparing catchment sediment yield at Koga river outlet in 2001 with catchment sediment yield at Koga river outlet in 2013 year.

According to equation (6.5) suspended sediment yield at Koga river outlet before and after construction of dam is calculated and shown in Table 6.14.

Table 6.13. Calculation of soil loss (tons per hectare/year)

Year	R	K	LS	C	P	A (t/ha/year)
2001	874	0.16	5.3	0.08	0.43	25.5
2013	875	0.16	5.3	0.05	0.57	21.15
Difference						4.35

The amount of sediment yield at each hectare of land per year before (2001) construction of dam varied compared to the amount of sediment yield at each hectare of land per year after (2013) construction of dam that is 25.5 t/ha/year and 21.15 t/ha/year respectively, which is within the range of soil loss in Ethiopian situation. Hurni (1990, 1993) estimated soil loss due to erosion of cultivated fields in Ethiopia average amount about 42 t/ha/year. The difference in value due to construction of dam is 4.35 t/ha/year. This indicates that the construction of dam has an effect on catchment sediment yield.

6.3.5. Sediment yield estimation at the watershed outlet

The annual sediment yield at the watershed outlet, which is having mean slope of main river channel of 6.8% and SDR 1.36 is given in Table 6.13 according to equations (6.5) and (6.6).

Table 6.14. Calculation of sediment yield at watershed outlet (t/year)

Year	SY(t/year)
2001	1.36*25.5=34.68
2013	1.36*21.15=28.76
Difference	1.36*4.35=5.9

The amount of sediment yield at the catchment outlet before the construction of dam was 34.68 t/year but after the construction of Koga dam the amount of sediment yield at the catchment outlet became 28.76 t/year. This indicates that there is reduction of 5.9 tons per year of sediment yield at the outlet of Koga River which is flowing to Gilgel Abay, due to construction of Koga dam.

6.4. CLOSURE

Construction of Koga dam has an effect on watershed sediment yield at Koga outlet as well as suspended sediment transport to Gilgel Abay River. A GIS based RUSLE and SDR have been used for estimation of soil loss or amount of sediment yield at the catchment as well as the catchment outlet before and after construction of dam for identifying effect of dam on sediment transport. Based on the methods, there is reduction of 5.9 t/year of sediment yield at the catchment outlet of Koga river which drain to Gilgel Abay River and there is also a reduction of 4.35 t/ha/year of sediment yield at Koga catchment.

Construction of dam has an effect on river hydrology, it caused reduction in Peak mean annual discharge from 7.2 m^3/s to 5.1 m^3/s, peak daily discharge decreases from 103.5 m^3/s (pre-dam) to 63 m^3/s (post-dam) as well as the magnitude flood frequency analysis at downstream of dam also shows decreasing in frequency of high magnitude discharges.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1. GENERAL

The primary objectives of the present study are to develop hydrological PRMS model and simulate stream flow, evaluate effect of LU/LC and climate changes on stream flow, predict future flood and flood frequency as well as to identify effect of dam on river hydrology and sediment transport at Gilgel Abay river basin. These objectives are achieved by applying LU/LC and climate change studies, future flood and flood frequency change studies, the river hydrological studies and river sediment load analyses studies.

In identifying changes in LU/LC, vegetation type and vegetation density on stream flow, different LU/LC, vegetation type and vegetation density data from 1990-2000 and 2001-2010 were considered. For climate change studies, 10% change in the amount of daily precipitation and a 1.5^{o}c increase in the amount of daily temperature were chosen on basis of general circulation model output. For combined effect studies; LU/LC, vegetation type and vegetation density data_bin of period one (1990-2000) and period two (2001-2010) were given to GIS Weasel to generate parameters for PRMS model. These generated parameters for different periods within time series climate data (daily minimum and maximum temperature, daily precipitation) and daily stream flow data for different periods fed to PRMS model to simulate stream flow.

In addition, for prediction of future flood and flood frequency; air temperature was adjusted by temperature values of no change, 1.5^{0}c and 3^{0}c changes of historical temperatures. Precipitation was adjusted by two different precipitation values ranging from -10% to 10% of observed precipitation. In the river hydrological studies and river sediment load analyses, the results were compared before and after construction of dam of the same river. Various conventional (rainfall, temperature, soil and stream flow) and remote sensing (FAO soil map, LU/LC, Vegetation type and vegetation density map and DEM) data were used in this study for analysis.

7.2. SUMMARY OF RESULTS

A brief summary of the results obtained from LU/LC studies, climate change studies, combined LU/LC and climate change studies, future flood and flood frequency studies, the river hydrological studies and river sediment load analyses studies are explained briefly in the next sections.

7.2.1. Model Calibration and Validation

For the area of interest which has 26 numbers of Hydrological Response Units, there is a good agreement between daily simulated and measured stream flow during calibration and validation periods with average E values of 0.71 and 0.70 respectively. For monthly stream flow average E values for calibration and validation are 0.91 and 0.90 respectively. This indicated that the monthly observed and simulated stream flow showed better agreement between observed and simulated stream flow. Hence, model is more compatible for monthly stream flow simulation than daily stream flow simulation at Gilgel Abay River Basin. It is also clear that the model simulated stream flow well in daily mode of simulation.

7.2.2. LU/LC Change Studies

Analysis have been done by considering baseline period (1993-2000) and simulating stream flow for 2001-2008 periods using input parameters generated from LU/LC, vegetation type, vegetation density of 2001-2010 with the time series data of daily maximum and minimum temperature and daily precipitation using PRMS model. Finally simulated stream flow and ET for 2001-2008 periods compared with baseline period (1993-2000) and evaluated as follows. As LU/LC, vegetation type and vegetation density changed from 1993-2000 period to 2001-2010 period, stream flow increased from 7.8% (1,482 m^3/s) to 25.3% (5000 m^3/s) and ET decreased from 4.2% (40 mm) to 20% (279 mm) from baseline period. For the whole simulation periods (2001-2008) stream flow increased by 10.8% (463 m^3/s), but ET decreased 6.6% (16 mm) related to baseline period. Hence as LU/LC, vegetation type and vegetation density changed; there is an increase in stream flow by decreasing ET.

7.2.3. Climate Change Studies

The whole simulation period (1994-2005) indicated that as precipitation is increased by 10% there is an increase of stream flow and ET by 18.8% (1,748 m^3/s) and 2.3% (12 mm) respectively. Whenever there is 10% increase of precipitation on August 5 and September 8, 2003 simulation indicated under estimation of peak stream flow. On the other hand a decrease of 10% precipitation resulted in a decrease of 30.4% (2,835 m^3/s) average mean annual stream flow and 5.3% (27 mm) mean annual ET compared to baseline period. The range of decrease in mean annual stream flow and mean annual ET is 24% to 36% and 2.5% to 7.5% respectively. The highest decrease in mean annual stream flow occurred in 1997 (37% or 6,655 m^3/s) and lowest decrease occurred in 1995 (24% or 4,792 m^3/s) compared to baseline periods (18,090 m^3/s and 19,769 m^3/s) respectively. There is also a decrease of Mean annual evapotranspiration with the range of 2.5% to 7.5% compared to baseline periods. In addition, the highest decrease in mean annual stream flow occurred in 1995 (7.5% or 1,956 m^3/s) and lowest in 2003 (2.5% or 590 m^3/s) compared to baseline period (26,042 m^3/s and 24,225 m^3/s) respectively. For a decrease of 10% precipitation there is a decrease of 72,141 m^3/s and 713 mm of stream flow and ET respectively for whole simulation periods.

On the other hand a change in 1.5^{o}c temperature has an effect on stream flow and ET. As temperature is increased by 1.5^{o}c mean annual stream flow resulted in a decrease of average stream flow of 54% (9,016 m^3/s from total average 16,979 m^3/s) compared to baseline period. The highest change occurred in 1998 (62% or 16,458 m^3/s) and lowest change occurred in 1995 (44% or 10,880 m^3/s compared to baseline periods (26,701 m^3/s and 19,769 m^3/s respectively). But there is an increase of mean annual evapotranspiration with the range of 30% to 61% compared to baseline periods. The change in ET is highest in 2003 (61% or 91 mm) and lowest in 1997 (30% or 430 mm) compared to baseline periods (1029 mm and 1440 mm) respectively. In general, the whole simulation period (1994-2005) indicates that there is a decrease of 59.6% (5,555 m^3/s) of stream flow and an increase of 48% (246 mm) of ET as temperature increased by 1.5^{0}c. In general, an increase in 1.5^{o}c temperature indicated that there is a decrease of mean annual stream flow by increasing mean annual ET.

7.2.4. Combined LU/LC, Vegetation Type, Vegetation Density and Climate Change Studies

To evaluate combined effects of LU/LC, vegetation type, vegetation density and climate changes on stream flow, two periods of LU/LC, vegetation type, vegetation density and climate changes were identified and evaluated for their effects on stream flow. By considering period one (1990-2000) as baseline period and relating stream flow with period two (2001-2010), combined effects are evaluated and identified as follows. As climate and LU/LC, vegetation type and vegetation density changed from period one to period two stream flow increased with the range 3.4% (845 m^3/s) to 43.3% (6,377m^3/s), but ET decreased with the range of 2.7% (706 m^3/s) to 32% (10,058 m^3/s) related to baseline period. Generally, for combined effects (as climate, LU/LC, vegetation type and vegetation density changed) stream flow increased 13.5% (579 m^3/s) and ET decreased 18.2% (44 mm) compared to baseline period. Finally, when individual effects and combined effects are evaluated on stream flow and ET, combined effects are more on stream flow and ET than individual effects (effects of climate change alone or LU/LC, vegetation type and vegetation density alone).

7.2.5. River Hydrological Studies

The impact of Koga dam on River hydrology, hydrograph variation over 6 years, changes in peak stream flow, variation in discharge and magnitude of flood frequency analysis at Koga River Basin before and after the construction of Koga dam are identified and evaluated, hence due to the construction of Koga dam annual daily peak stream flow decreased from 103.5 m^3/s to 60 m^3/s and mean annual peak discharge decreased from 7.2 m^3/s to 5.1 m^3/s.

The detailed analysis of 6 years of monthly discharge data of the Koga river before (2006-2007) and after (2007-2012) the construction of dam was considered and variation in each year was plotted. Hence, the maximum monthly discharge was 28.3 m^3/s before (2006-2007) the construction of dam and was just nearer to 18.8 m^3/s after the construction of dam (2007-2012) maximum monthly discharge. This showed a decreasing trend of monthly discharge after the construction of dam.

Time series of daily discharge hydrograph of Koga River before (2001-2006) and after (2007-2012) the construction of Koga dam showed a decrease of maximum daily discharge from 103.5 m^3/s to 63 m^3/s. And a decrease of total discharges from 12,033.87 m^3/s to 8,569.40 m^3/s pre-dam and post-dam respectively. The trend line for time series of Koga discharge data before and after construction of dam indicated that there is a decreasing trend of discharge due to construction of dam but the trend was constant for before construction of dam.

The magnitude of flood frequency analysis was performed by considering stream flow before and after the construction of Koga dam. For this analysis a threshold value of 17.553 m^3/s was selected to get at least one peak stream flow per year for time series data. This analysis showed the number of peak stream flow before and after the construction of dam and this is useful for identifying effect of dam on frequency of peak stream flow. The analysis was done by considering 6 years discharge data before and after construction of Koga dam. It is identified that 145 discharge events with values greater than 17.553 m^3/s are available for 6 years of pre-dam period where as only 97 discharge events with values greater than 17.553 m^3/s are available for 6 years of post-dam period. This indicated that the reduction in peak stream flow during post period is due to obstruction of dam. According to Discharge verses recurrence interval graph, the magnitude frequency analysis at downstream of dam also shows decreasing values of high magnitude discharges.

7.2.6. River sediment load analyses

The impact of Koga dam at Gilgel Abay River on sediment flow was studied by comparing the total amount of sediment yield at the catchment outlet of Koa River before and after the construction of dam. This was carried out by comparing catchment sediment yield at Koga river outlet in 2001 with catchment sediment yield at Koga river outlet in 2013.

Suspended sediment yield at Koga river outlet is calculated before and after construction of dam. The amount of sediment yield at each hectare of land per year before (2001) construction of dam varied compared to the amount of sediment yield at each hectare of land per year after (2013) construction of dam that is 25.5 t/ha/year and 21.15 t/ha/year respectively, which is within the range of soil loss in Ethiopian Catchment scenario. Hurni (1990, 1993) estimated soil loss due to erosion of cultivated fields in Ethiopia amounts about 42 t/ha/year. The difference in values are due to construction of dam is 4.35 t/ha/year. This indicates that the construction of dam has an effect on catchment sediment yield.

The amount of sediment yield at the catchment outlet, which is having mean slope of main river channel of 6.8% and SDR 1.36, before construction of dam was 34.68 t/year but after construction of Koga dam the amount of sediment yield at the catchment outlet became 28.76 t/year. This indicated that there is reduction of 5.9 t/year of sediment yield at the outlet of Koga River which is flowing to Gilgel Abay, due to construction of Koga dam.

7.3. CONCLUSIONS

PRMS a modular-design, deterministic, physically based and distributed-parameter modelling system was used to simulate stream flow of Gilgel Abay river basin based on LU/LC and climate change. And also construction of Koga dam on this basin has an effect on river hydrology and sediment transport to Gilgel Abay river.

- GIS Weasel is compatable for Ethiopian catchments to generat standard parameters from grided data_bin of LU/LC, Vegetation type, Vegetation density and soil map for PRMS model, hence PRMS model is also compatable in Ethiopian catchments.
- The PRMS model performs better for simulating monthly stream flow than simulating daily stream flow, because it has higher E value (0.9) relating to daily mode (E=0.7) of stream flow simulation.

- A change in LU/LC from 1990-2000 to 2001-2010 increased stream flow by 463 m^3/s due to decrease of evapotranspiration by 16 mm which may be resulted from deforestation.
- A change in climate, LU/LC, vegetation type and vegetation density caused an increase in stream flow by 579 m^3/s due to decrease of evapotranspiration by 44 mm. This may be because of changes in vegetation cover is greater than changes in climate (which caused changes in evapotranspiration).
- For 1% and 50% AEPs, changes in annual daily peak stream flow will be 14.3% of historically modeled annul daily peak stream flow for 21st century, therefore this value should be considered during designing of hydraulic structures and flood control mitigations.
- Construction of dam has an effect on river hydrology hence, there is a reduction in peak mean annual discharge from 7.2 m3/s to 5.1 m^3/s, daily peak discharge decreased from 103.5 m^3/s (pre-dam) to 63 m^3/s (post-dam) as well as the magnitude of flood frequency analysis at downstream of dam also showed decreasing of high magnitude discharges.
- A GIS based RUSLE and SDR have been used for estimation of soil loss or amount of sediment yield at the catchment as well as the catchment outlet before and after the construction of dam for identifying effect of dam on sediment transport. Hence, there is reduction of 5.9 t/year of sediment yield at the catchment outlet of Koga river which drains to Gilgel Abay River and there is reduction of 4.35 t/ha/year of sediment yield at Koga catchment.

7.4. LIMITATIONS OF THE STUDY

1. Absence of measured sediment data before and after the construction of dam for direct identification of impact of dam on sediment transport.
2. Absence of high resolution vegetation map at specific study area for data_bin preparation.

7.5. THE SCOPE FOR FUTURE STUDIES

1. Future stream flow and flood frequency may be predicted using future land use/land cover change scenarios jointly with future climate change scenarios.
2. Effect of dam on sediment transport may be estimated either by using reservoir sedimentation or trap efficiency method.

CHAPTER 8

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1. Mulu, A and G.S. Dwarakish, (2016). Hydrological effects of land use /land cover changes on stream flow at Gilgel Abay River Basin, Upper Blue Nile, Ethiopia. International Journal of Earth Sciences and Engineering, India. Volume 9 No 5.
2. Mulu, A and G.S. Dwarakish, (2015). Different Approaches for using Trap Efficiency for Estimation of Reservoir Sedimentation. International Conference on Water Resources, Coastal and Ocean Engineering, India.
3. Mulu, A and G.S. Dwarakish, (2016). Estimation of Future Peak Stream Flow and Flood Frequency based up on changes in air temperature and precipitation at Gilgel Abay River basin, Upper Blue Nile, Ethiopia. Journal of Hydrologic Engineering ASCE (under review).
4. Mulu, A and G.S. Dwarakish, (2016). Simulation of the potential effects of Land use/ land cover and climate changes on Stream flow. A case study at Gilgel Abay River Basin, Upper Blue Nile, Ethiopia. Journal of Water Resources Management, Springer (under review).

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